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Preface

This volume contains the full papers presented at BIUST Research & Innovation Symposium 2017 (RDAIS 2017) held on June 12-14, 2017 at Botswana International University of Science and Technology in Palapye, Botswana.

There were a total of 137 submissions for three tracks of Poster, Paper and Innovation with an acceptance rate of 0.95. We received 469 reviews with each submission receiving three to four reviews on the average. We had 75 reviewers who were all BIUST academics. Of the accepted 130 submissions there were 46 Posters, 43 Oral Presentations, and 31 Innovations.

In terms of participation, there were six countries that participated outside of Botswana, with 46 authors outside of BIUST. Of these submissions, there were three international collaborations and ten local collaborations. Participation within BIUST had 48 academics and 100 undergraduate and postgraduate students.

I would take this opportunity to acknowledge the contribution of the postgraduate students who significantly helped in the data compilation of the review process and the production of this symposium proceedings, namely, Naledi Kefitile, Oratile Mogapaesi, and Tumelo Tabane. In addition, I would also like to acknowledge the help of Prof. Jens Andersen and Dr. Adewole Oladele who secured the ISSN and ISBN of this proceedings. And lastly, I would like to thank EasyChair with its free version that greatly helped us to automate the review process and the proceedings generation.

June 12, 2017
Palapye, Botswana

Dr. Rodrigo S. Jamisola, Jr.
Proceedings Editor and EasyChair In-charge

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Welcome Message

Fostering Innovation through Research in Science and Technology is part of BIUST's strategic plan to contribute to industry growth and development in Botswana. Our mission as BIUST is to lead in developing a dynamic innovation economy in Botswana through the advancement of science and technology research. The Innovation Week will create a platform to share ideas on cutting-edge research and innovation that can result in development of new industries and enhance the competitiveness of existing industries.

June 12, 2017
Palapye, Botswana

Professor Otlogetswe Totolo
BIUST Vice-Chancellor

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Welcome Message

BIUST is a research University with a vision to be on a par with the best in Southern Africa and beyond as well as with a mission to be a driving engine in lifting up the economy of Botswana to a knowledge based economy. Both the vision and mission rest to a large extent on the research agenda of BIUST. The BIUST Research and Innovation Symposium 2017 serves as a platform to showcase our efforts in working towards our vision and mission all the while maintaining the high standards we set for ourselves to achieve our mandate. I would like to thank all the participants for their contribution to make this symposium successful.

June 12, 2017
Palapye, Botswana

Distinguished Professor Dennis A. Siginer
BIUST Provost & Deputy Vice-Chancellor Academics

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Welcome Message

'Traditional' institutions of higher learning measure their impact mainly on the basis of the number of research articles published. However, there is growing demand on institutions of higher learning to demonstrate the value of science for society. Universities are increasingly expected to measure their impact on the basis of research that are converted into marketable or consumable products and services. BIUST has a mandate to produce world class research and innovation that can be transformed into tangible applications and products. The Innovation Week will provide an impetus to achieving this mandate.

June 12, 2017
Palapye, Botswana

Professor David Norris
BIUST Deputy Vice-Chancellor
Research, Development and Innovation

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Scientific methodology in Analytical Chemistry

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***Abstract*— Ever since the work of Robert Boyle, scientists have used the same methodology to obtain new information about mechanisms of nature. Together with other scientists at the time, Robert Boyle suggested that all scientific discussions could be settled by means of experiments. Without proper tools of statistics, it was difficult to arrive at any conclusive decisions in many cases. However, later discoveries of statistical tools have limited dissemination of flawed discoveries of nature but to a great number of scientists, these results have not been understood or recognized. This poses a major issue in science and it can be shown that some publications do not meet requirements of credibility and reliability, owing to scientific misconduct. Journals thrive on scientists who wish to publish results where data have been seriously manipulated. At present time, it seems like scientific methodology has been forgotten, which may explain the lack of ground breaking development in science? The quest for quality assurance in science is greater than ever, and initiatives of the European Commission constitute the first steps towards an environment that might bring back scientific methodology to science. Unfortunately, guidelines published by the European Commission do not underpin scientific methodology, and it has become evident that science and industry use two different concepts of scientific methodology that cannot both be true. Therefore, it is suggested to improve the guidelines of the European Commission to a level of simplicity and transparency that allows scientists to perform reliable method validations and obtain correspondence between experimental uncertainty and predicted uncertainty, which is so fundamental to scientific methodology. It is proposed that new methods of quality assurance should be embraced by not only analytical chemistry but also by other fields of science.**

Keywords*— *Quality assurance, method validation, scientific misconduct

Introduction

Imagine that scientist present only the best results they obtained during series of measurements aimed at solving a scientific issue. Clearly, all results obtained under such conditions relate to the statistical concept of precision whereas the real aim of science is to obtain information about trueness and accuracy [1,2]. If only the best results were shown in scientific publications, it would be a legitimate question to ask; what happened to all the other data? Such data may be denoted as dark data, and it would be interesting to know the magnitude of dark data that exist in the scientific production.

RESULTS AND DISCUSSION

Dark data

It is well known and almost an accepted fact that scientists are not able to reproduce results that are presented in coloured flyers with description of apparatuses, specifications and supreme performance. Under most circumstances, it is generally accepted that precision is slightly lower in the analytical laboratory as opposed to more controlled conditions that may be encountered only in manufacturer's laboratories. A slight decrease of precision is not really an issue and it rarely affects determination of figures of merits [3] that are obtained during the course of method validations [4]. The overall performance of most methods is acceptable, particularly with respect to qualitative analysis. Quantitative analytical chemistry is a completely different area of research where precision may reach unacceptably low levels [5]. However, there are instances where it becomes necessary to start thinking about how the technology and software are actually working together, and how it affects precision. Manufacturers of graphite-furnace atomic absorption spectrometry (GF-AAS) and electrothermal atomic absorption spectrometry (ET-AAS), prefer to allow for only certain data to be part of measurements Data that deviate by more than 5 % (default) must be excluded from the data set. Suppose that the inherent precision of that type of apparatus result in deviations of e.g. 60 % [6]; this would make the likelihood of re-calibration very high. Further, it would make it almost impossible to construct a calibration curve with many data points because the risk would be high of an outlier lowering the precision to below 95 % that would trigger the re-calibration. Accordingly, scientists use only a few data to construct calibration curves. Therefore are expected excessive amounts of dark data with such technologies.

Now, in the description of these technologies was not mentioned the sample but it is evident that the risk is high of large deviations from expected values. If a calibration curve were obtained by repeated re-calibrations, the correspondence between expected value and the value obtained by the calibration curve, would be entirely random. However, when such repetitions are performed in great numbers, a value obtained by one of the calibration curves would fit the expected value quite neatly, and it might be used for publication or decision making. All the data not shown may then be relegated to the pool of data generated on days when the apparatus was not working well or the operator was not concentrating enough on the work. Thus, either the apparatus or the operator may be blamed for generation of poor data. Unfortunately, it is not an

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easy task to decide if the apparatus or the operator was the cause of the problem and methods to distinguish between the two origins of bad data is currently investigated by science.

Nobody knows the genuine content of a sample with unknown content, and apparatuses of analytical chemistry can only be used to give a qualified estimate of the content that is based on calibrations. To the people not familiar with analytical chemistry, it is a complete mystery and impossible to understand how two accredited laboratories are able to obtain two completely different values, when they used for their measurements the same type of apparatus and the same sample. To the scientists, however, it is relatively easy to understand this deviation because they are familiar with the concept of uncertainty of measurement. Uncertainty of measurement is the key to understanding results of any type. It is also easy to explain to laymen the principle of uncertainty of measurement, except when it is large. To laymen, it may seem incredible that a very expensive apparatus does not always provide data of high precision. Nuclear magnetic resonance spectrometry and mass spectrometry are notable examples of very expensive types of apparatuses that are not particularly well suited for quantitation. More research is needed, in order to elucidate the mechanisms associated with stability of detector responses, which constitute the sensing part of the apparatus. Some reports indicate that detectors, and not operators, are the main culprits with respect to generation of uncertainty.

Consensus value

The operational calibration is supposed to eliminate day-to-day variations of the apparatuses' parameters and the influence on results. However, in reality something else happens; the calibration may present excellent results, as can be recognized by a very straight line and a low standard deviation of the sample. Many calibration data would result in narrow confidence lines and narrow confidence limits of the sample [7]. Frequently, the value obtained for the sample differs significantly from known value, which should not occur, owing to the operational calibration. The known value may be obtained from measurements of a certified reference material, so in the case of any deviation, there is reason to expect that something was wrong with the measurements. Interestingly, in the majority of scientific publications, authors find complete correspondence between measured and certified values where both were associated with very low standard deviations. This is quite disturbing because many authors failed to notice that the certified value was obtained after elimination of numerous outliers. Therefore, it should not be possible to reproduce the certified value, unless the same number and magnitude of outliers were deleted from the laboratory trials, which obviously is very unlikely or impossible.

Unfortunately, the correspondence is less pronounced between laboratories analyzing samples of unknown content. However, since nobody knows the exact content of a sample of truly unknown content, everybody is right. Therefore, the correct way forward is to average values combined of all laboratories , and resultant average value is denoted as the consensus value [7]. Most frequently, the uncertainty of the consensus value exceeds by far the uncertainty for an average value of a single laboratory. Contents of specific molecules of blood samples are truly unknown and the values of fundamental constants of nature are also not known but they may be estimated by various means of measurements.

International organisations

Issues of lack of correspondence between average values and uncertainties have been addressed by several international organizations, such as Bureau des Poids et Mesures (BIPM) [8], European Analytical Chemistry (Eurachem), Cooperation of International Traceability in Analytical Chemistry (CITAC), International Standardization Organization (ISO) and International Laboratory Accreditation Cooperation (ILAC). As stated on ISO website "Great things happen when the world agrees" but, paradoxically, ISO recommends rejection of outliers in the guide ISO 5725 [9], which is a route to disagreement (see above). During the past decades, the European Commission maintained a programme to deal with issues of analytical chemistry, and it delivered the organizations Eurachem and CITAC. The now 3rd edition of the Eurachem/CITAC guide [10] has obtained widespread recognition in the industry because it underpins traceability and it provides guidelines to calculation of uncertainty of measurement and uncertainty budgets. Although the Eurachem/CITAC guide is a step forward towards introducing to analytical chemistry the concept of uncertainty, it contains some serious flaws that, just like ISO 5725 [9], promote disagreement between results of different laboratories that analyze same samples. The main issue is concerned with the uncertainty budget where standard deviation of repetitions is included in the uncertainty budget. The uncertainty budget is designed to predict the uncertainty of the content of a sample. The sample is determined as an average value and a corresponding uncertainty that is supposed to match that of the uncertainty budget. Since the two are not separated in the Eurachem/CITAC guide, disagreement prevails again. Despite all the efforts and investments international guidelines do not promote scientific methodology. Scientific methodology is straightforward in the sense that it only requires that average values and standard deviations of measurements correspond to those of predictions and theory. In order to meet the requirements of scientific methodology, it is recommended that scientist use only certain sections of the guidelines and never reject any outliers whatsoever. It is always a good idea to produce an uncertainty budget for the method validation but the uncertainty of repeatability should not be included in the uncertainty budget because that is the parameter that is supposed to be predicted. However, with reference to guidelines of ISO, GUM and Eurachem/CITAC, scientists have the tools to treat data almost as they please, which continues to create confusion in analytical chemistry. Scientists of analytical chemistry may feel confused with statistical methods that are too complicated for everyday use, which excuses them from applying methods of QA to their investigations. Accordingly, further simplification is called for.

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Pooled calibrations and scientific methodology

The notion of consensus value is somewhat disturbing because it is never obtained during e.g. blood testing of patients and optimization of chemical syntheses. It is imperative to know the true level of uncertainty for optimization purposes. Blood testing is an important part of the general practitioners tools of diagnosis [11] and too much trust given to results of clinical analysis may jeopardize the validity of diagnosis. This entails risk of dosing medicine to somebody who is not sick or, even worse, not dosing medicine to somebody who is actually sick. Similarly, optimization cannot be performed with any degree of reliability if it were based upon underestimated standard deviations (short-term precision).

Usually, the uncertainty of repeated measurements of samples is larger than the uncertainty that was predicted upon the basis of calibration lines. This disagreement has been puzzling to scientist for a long time, and the guidelines of ISO and Eurachem/CITAC are published with the intent to better understand and quantify unexpected deviations. Recently, it was suggested to consider the worst-possible performance of a given apparatus, in order to model the lowest uncertainty of repeated measurements of the sample. The idea is to perform a series of completely independent measurements where the apparatus is shut down, turned on and calibrated between each series of measurements, and then calibration lines are pooled with the purpose of modelling the uncertainty [12]. Pooled calibrations are thus reserved for calculation of uncertainty of calibrations, u(cal). Results of individual determinations of the contents of samples are also pooled and the corresponding standard deviation of repetitions, u(rep) is calculated [13–15]. When u(cal) corresponds to u(rep), it is said that the system is in statistical control. For a number of different technologies, it seems possible to obtain this correspondence, at least within an order of magnitude. Although this procedure yields elevated uncertainties, it may be the correct uncertainty overall that also corresponds to the uncertainty of inter-laboratory testing and the uncertainty predicted by the Horwitz equation [16].

Certified reference materials

As a substitute for inter-laboratory testing, it has been generally accepted to validate analytical methods by using samples of certified reference materials, where the content of analytes was determined by many independent laboratories using different technologies. The average value of all measurements minus outliers is denoted as the certified value that can be used for comparison with results of other laboratories [12]. It seems that it becomes difficult to compare measured values to certified references, when the principle of pooled calibrations was applied to the measurements. This indicates that the issue of outliers needs to be considered in more detail. Occasionally, the uncertainty of determination of samples of unknown content is so large that it becomes easily comparable to certified references but this may be regarded as a token of poor method performance or relegated to influence of interferences.

CONCLUSION

In the research area of analytical chemistry, it has been recognized earlier that it is difficult to obtain correspondence between uncertainty of calibration and uncertainty of measured values. However, recent findings indicate that full correspondence between predicted and observed uncertainty is the key to understanding research results of analytical chemistry. By using the principle of pooled calibrations, it becomes possible to obtain statistical control in analytical chemistry but at the expense of relatively poor precision. In many instances, the uncertainty of measurement is underestimated, owing to rejection of outliers, which hampers comparison with contents of certified reference materials. Certified reference has become one of the prime requirements for method validations and for research to be published in scientific literature. Since comparison is hampered, it becomes difficult to maintain the good reputation of analytical chemistry. Issues with ISO, GUM and Eurachem/CITAC need to be resolved together with the practice of eliminating outliers related to CRMs before analytical chemistry can be gaining more in credibility.

REFERENCES

[1] J.C.F.G.I.M. JCGM, JCGM 200 : 2008 International vocabulary of metrology — Basic and general concepts and associated terms (VIM) Vocabulaire international de métrologie — Concepts fondamentaux et généraux et termes associés (VIM), Int. Organ. Stand. Geneva ISBN. 3 (2008) 104. doi:10.1016/0263-2241(85)90006-5.

[2] J.E.T. Andersen, S.-M. Glasdam, D.B. Larsen, N. Molenaar, New Concepts of Quality Assurance in Analytical Chemistry: Will They Influence the Way We Conduct Science in General?, Chem. Eng. Commun. 203 (2016). doi:10.1080/00986445.2016.1180290.

[3] J. Uhrovcik, Strategy for determination of LOD and LOQ values - Some basic aspects, Talanta. 119 (2014) 178–180. doi:10.1016/j.talanta.2013.10.061.

[4] E. Working Group, The Fitness for Purpose of Analytical Methods A Laboratory Guide to Method Validation and Related Topics, 1998.

[5] R. Chomchoei, E.H. Hansen, J. Shiowatana, Utilizing a sequential injection system furnished with an extraction microcolumn as a novel approach for executing sequential extractions of metal species in solid samples, Anal. Chim. Acta. 526 (2004) 177–184. doi:10.1016/j.aca.2004.09.043.

[6] J.E.T. Andersen, Determination of iron by Z-GFAAS and the influence of short-term precision and long-term precision, Cent. Eur. J. Chem. 12 (2014). doi:10.2478/s11532-013-0362-9.

[7] J.E.T. Andersen, Consensus science and the impact on analytical chemistry, Rev. Roum. Chim. 60 (2015) 397–402.

[8] JCGM, BIPM, IEC, IFCC, ILAC, ISO, et al., Evaluation of measurement data — Guide to the expression of

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ISBN: 978-99968-0-608-7

uncertainty in measurement, Int. Organ. Stand. Geneva ISO. 1 (2008) 1–120. doi:10.1373/clinchem.2003.030528.

[9] ISO 5725, Accuracy (trueness and precision) of measurement methods and results, 1994.

[10] CITAC, Eurachem, Quantifying Uncertainty in Analytical Measurement, BIPM. 3rd ed. (2012) 1–133. doi:0 948926 15 5.

[11] C. Lam, C. Law, K. Sze, K.K. To, Quantitative metabolomics of urine for rapid etiological diagnosis of urinary tract infection: Evaluation of a microbial–mammalian co-metabolite as a diagnostic biomarker, Clin. Chim. Acta. 438 (2014) 24–28. doi:10.1016/j.cca.2014.07.038.

[12] J.E.T. Andersen, On the development of quality assurance, TrAC - Trends Anal. Chem. 60 (2014). doi:10.1016/j.trac.2014.04.016.

[13] J. Cohen, Statistical Power Analysis for the Behavioral Sciences, 2nd ed., Hillsdale: Lawrence Erlbaum, 1988.

[14] O.I. Hedges L. V., Statistical methods for meta-analysis, Academic Press, San Diego, 1985.

[15] J. Cohen, How to Calculate the Pooled Standard Deviation, (n.d.). http://www.statisticshowto.com/pooled-standard-deviation/.

[16] W. Horwitz, Evaluation of analytical methods used for regulation of foods and drugs, Anal. Chem. 54 (1982) 67–76. doi:10.1021/ac00238a002.

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Surveillance of Antibiotic Resistance Determinants in Gaborone and Palapye Wastewater Treatment Facilities.

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Abstract

Antibiotic resistance genes (ARGs) and antibiotic resistant bacteria (ARB) are globally considered emerging environmental contaminants that pose a serious concern to human health and the ecosystem. The objective of the study was to detect the abundance of bacteria, characterize their antibiotic resistance phenotypic and genotypic characteristics in Palapye wastewater treatment facility (PWWTF), Gaborone wastewater treatment plant (GWWTP) and the downstream environments. The two chosen study areas are different in terms of population, wastewater treatment infrastructures and uses of final effluent. Culture dependent and independent approaches were used to determine occurrence, diversity and abundance of potentially pathogenic and antibiotic resistant bacteria and ARGs in wastewater influent, effluent and downstream environments samples. In PWWTF, 39% antibiotic resistant bacteria were detected in the influent, 25% in the effluent and 35% were detected in downstream environment. In GWWTP, the bacteria isolated with resistance to antibiotics were 36% in the influent, 39% in the effluent wastewater and the downstream environment had 25%. The ARB bacterial species detected were; *Staphylococcus species*, *E.coli*, presumptive *E.aerogenes*, *Pseudomonas species*, *Brucella species*, *Salmonella species*, *Listeria species* and *Campylobacter species*. The study also detected ARGs; *tet*A (tetracycline), *mph*A (macrolide), *str*B (streptomycin), *sul1* (sulphonamide), *dfr* (trimethoprim) and *int*1 (mobile ARG cassette) in all the sample sources including the downstream environments. The results reveal occurrence and diversity of clinically relevant ARB and ARGs that accumulate in wastewater treatment facilities and subsequently disseminated to the downstream environments, particularly water sources. This research is critical in the development of new water quality monitoring schemes and implementation of policies on the use of effluent water for irrigation purposes.

Keywords—Wastewater, antibiotic resistance, genes, bacteria, environment

I. INTRODUCTION

The misuse of antibiotics has recently been characterized as one of the major causes of antibiotic resistance. Initially antibiotics were developed for treatment of bacterial infections and improving human, animal and plant health but recently their use has widely increased particularly in agriculture as growth promoters in commercial livestock industry (Aminov, 2009).

Nearly all consumed antibiotics are excreted unchanged into the environment because the body partially metabolizes them. This together with disposal of unused antibiotics has led to the frequent detection of their residues in different environment such as wastewater treatment plants (Jelic *et al*., 2011). Wastewater treatment plants receives all sorts of discharges from hospitals, industries and domestic waste which make them an interface between different environments and, therefore, provide an opportunity for antibiotics in wastewater to select for resistant bacteria and promote the transfer of resistance genes in mobile genetic elements (e.g. plasmids, integrons) among the microbial communities (Szczepanowski *et al*., 2009). Antibiotic resistance genes can be disseminated among bacterial species through horizontal gene transfer mechanisms. (Luo *et al*., 2014).

Pathogens together with other non-pathogenic bacteria carrying resistance genes from the wastewater pose a threat to public health by migrating into groundwater or travelling off-site into surface water, soil and plants through the discharge of effluent wastewater and use in irrigation of crops. Different methods of waste treatment have been developed for public health safety, which aim at reducing pathogens, organic and inorganic components such as antibiotics in sewage prior to discharge. However, the effluent discharges still pose a major concern to the environment because many of these contaminants are not effectively removed.

The World Health Organization (WHO), the European Commission and the United States Centre for Disease Control and prevention (CDC) have acknowledged the importance of studying the emergence of resistance genes as well as the need for control strategies to minimise the development and spread of antibiotic resistance(Oteo *et al*., 2005).

This study was to focus primarily on determining the occurrence, abundance diversity and potential spread of pathogenic and antibiotic resistant bacteria, and antibiotic resistance genes in different wastewater treatment facilities and the environment receiving effluent waste water. The study also seek to understand the antibiotic resistance dynamics by considering Botswana's socio-economic and ecological factors.

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II. METHODOLOGY

A. Description of study area

The study areas were 1) Gaborone; Glen valley waste water treatment plant (GWWTP), downstream Notwane River receiving final effluent from GWWTP, 2) Palapye; Palapye wastewater treatment facility (PWWTF) and downstream man-made pond receiving the final effluent from PWWTF. Unless specified as influent, effluent or downstream, GWWTP and PWWTF acronyms will be used generally to differentiate the study areas Gaborone and Palapye respectively. The two chosen areas are different in terms of population (urban and rural), infrastructure (different treatment strategies) and different uses of the final effluent.

B. Sample collection

The sampling sources from Gaborone were influent wastewater (before treatment), effluent (after treatment), and Dws1 and Dws2; (downstream of GWWTP along the Notwane river). In Palapye, samples were also from influent, effluent and downstream of man-made pond. Samples were collected to cover all the four seasons; spring (September), summer (January), autumn (March) and winter (June) and were collected once per each month. Three samples per site were taken using grab sampling method, in the mornings between 8am and 10am. Samples were collected as previously described by Yuan *et al*. (2015). Briefly 750ml water samples each collected in a 250 ml portions from three different points of the sites in sterile polystyrene bottles were collected. Samples were placed in a cooler with ice-packs and transported to the laboratory and analyzed within 12 hrs.

C. Bacterial isolation and quantification

Fresh samples were analysed exactly as described by Yuan & colleagues (2015). Briefly a 0.1ml aliquot of water samples from each of the ten-fold serial dilutions were spread plated on different selective agar media targeting different bacterial species that are of public health concern; (Harlequin pseudomonas agar base(LabM laboratories), Harlequin salmonella™ ABC agar base(LabM laboratories), Lab 112 campylobacter selective media (LabM laboratories), Mannitol salt agar,(Biolab laboratories), Brucella agar(Conda laboratories), Chromo cult agar (Merk laboratories) and Listeria selective media (sigma-Aldrich)). The plates were incubated at 37^0C for 24hrs. Only plates with 30 to 300 colonies were considered quantifiable. Isolates growing in respective selective media were randomly picked and confirmed by gram stain procedure. An average of eight bacterial colonies in different media were then randomly picked and further sub-cultured to obtain a pure culture. The pure culture isolates were grown in nutrient broth and subsequently stored in nutrient broth containing 50% glycerol (ratio, 1:1) at -80^0C for further antibiotic resistance characterization. For statistical analysis, an average counts from triplicate plates were used to obtain the mean and standard deviation which were imported into Graph Pad Prism software (7^{th} edition) and the difference between treatments plants were determined by t-Test with P values less than 0.05 considered being significant

D. Antibiotic resistance characterization

Resistance analysis was done as previously described by Yuan *et al.*, (2015). Frozen isolates were thawed at room temperature and each bacterial isolate was aseptically sub-cultured into a number of nutrient agar plates containing different classes of clinically relevant antibiotics using a sterile tooth pick. Isolates were also sub-cultured on a nutrient agar without antibiotic as a control. The selected antibiotics and concentrations used were defined as the Minimum Inhibition Concentration (MIC) of bacteria listed in Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS, 2015). Antibiotics and concentrations used were; Penicillin(PEN)(16µg/ml),Ampicillin(AMP)(32µg/ml), ciprofloxacin(CIP)(4µg/ml),tetracycline(TET)(16µg/ml), streptomycin(STR)(64µg/ml),erythromycin(ERY)(8µg/ml), cephalosporin(CEP) (32µg/ml), meropenem(MEM) (4µg/ml), sulfamethoxazole(SMX)(512µg/ml) and trimethoprim(TMP) (64µg/ml). Cyclohexamide (75µg/ml) was also supplemented to the plates for fungal growth control. The plates were then incubated for 24 hrs at 37^0C and resistances of isolates were recorded on the basis of growth in the presence of antibiotic. Percentage values and graphs of isolated bacteria including resistant bacteria were calculated and designed using Microsoft Excel 2010 edition.

E. Molecular characterization of antibiotic resistance

DNA was first extracted from the chosen bacterial isolates (volume of 1ml) as previously described by Mirmohammadsadeghi *et al*., (2013), with few modifications. The yield of extracted DNA was measured using a nano drop spectrophotometer at an absorbance of 260nm. The DNA quality was checked by gel electrophoresis (0.8% agarose gel (3µl DNA plus 2µl loading dye)). Antibiotic resistance genes were identified using qualitative PCR with primers specific for each gene. The primers used are as follows; *mp*hA(Macrolides),*sul*1(Sulfamethoxazole),*int*1(Class1Integrase),*dfr*(Trimethoprim),*str*A(Streptomycin),strB(Streptomycin), *tet*A(Tetracycline),*tet*B(Tetracycline),*erm*A(Erythromycin),(*erm*B)(Erythromycin), (*erm*C)Erythromycin, (*qnr*)Quinolones, (catB3)Chloramphenicol and (*cat*A1)Chloramphenicol.

III. RESULTS

A. Bacterial quantification

Different bacterial species were detected at different quantities in different environments.

Detected *Salmonella species* from Gaborone were significantly higher in influent ($2.82x10^5$CFU/mL) followed by effluent ($9.53x10^2$CFU/mL), species significantly decreased further in the downstreams environments, environment 1 ($1.56x10^2$CFU/mL) and environment 2 ($1.57x10^2$CFU/mL). *Listeria species* were significantly higher in influent ($1.40x10^8$CFU/mL), significantly decreased in the effluent ($5.6x10^4$CFU/mL) and further significant increase in the downstreams, environment1 ($4.27x10^6$CFU/mL) and

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environment2 ($3.70x10^5$CFU/mL). *Staphylococcus species* were lower in the influent ($1.14x10^4$CFU/mL), then increased significantly in the effluent ($2.78x10^4$CFU/mL) and further significant increase in downstream1 ($2.78x10^6$CFU/mL) and downstream environment2 ($3.7x10^4$CFU/mL). In *Campylobacter species*, isolates were significantly higher in influent ($2.16x10^6$CFU/mL) followed effluent ($9.30x10^3$CFU/mL), then significant decrease in downstream environment1 ($1.85x10^3$CFU/mL) and environment2 ($3.7x10^2$CFU/mL). *Brucella species* were significantly higher in influent ($1.95x10^6$CFU/mL) than effluent ($2.04x10^4$CFU/mL).There was then a significant increase of the species in the downstream environment1 ($2.50x10^8$CFU/mL) and a decrease in environment2 ($4.69x10^7$CFU/mL). *E.coli* bacteria were significantly higher in influent ($8.80x10^6$CFU/mL) than effluent ($1.03x10^1$CFU/mL) and downstream environment1 ($1.00x10^1$CFU/mL). *E.coli* bacteria were non-quantifiable in downstream environment2. In *E.arogenes* bacteria, isolates were significantly higher in influent ($8.30x10^6$CFU/mL) followed by effluent ($4.1x10^4$CFU/mL), then evironment1 ($8.23x10^2$CFU/mL) and environment2 ($4.60x10^2$CFU/mL).There was no difference between effluent and downstream environments. *Pseudomonas species* were significantly higher in influent ($3.93x10^6$CFU/mL) than effluent ($1.01x10^3$CFU/mL).A significant increase of species in the downstream environment1 ($6.62x10^3$CFU/mL) & environment2 ($2.22x10^4$ CFU/mL) was then recorded **(Figure 1).**

In Palapye, *Salmonella species* were significantly higher in influent ($7.06x10^3$CFU/mL) than effluent ($2.67x10^3$CFU/mL).There was a further significant increase in the downstream environments ($2.08x10^4$CFU/mL). In *Listeria species*, isolates were significantly higher in influent ($1.75x10^5$CFU/mL), then a significant decrease in effluent ($4.2x10^3$CFU/mL).The species significantly increased further in the downstreams ($4.10x10^4$CFU/mL). *Staphylococcus species* were almost equal between influent ($5.53x10^2$CFU/mL), effluent ($2.13x10^2$CFU/mL) and the downstreams ($5.16x10^2$CFU/mL). *Campylobacter species* were significantly higher in influent ($7.16x10^4$CFU/mL) than effluent ($6.8x10^3$CFU/mL). There was then a further significant increase in downstreams ($3.73x10^5$CFU/mL). Detected *Brucella species* were lower in the influent ($1.17x10^5$CFU/mL), significantly increased in the effluent ($2.09x10^6$CFU/mL) and the downstream ($4.23x10^6$CFU/mL). *E.coli* bacteria were higher in influent ($7.53x10^5$CFU/mL), the bacteria was non-quantifiable in effluent. Quantifiable species were then recorded in the downstream ($1.03x10^4$CFU/mL).In *E.aerogenes*, isolates were significantly higher in influent ($2.83 x10^4$CFU/mL) than effluent ($3.53x10^3$CFU/mL) and downstream ($2.27 x 10^4$CFU/mL). In *Pseudomonas species*, isolates were significantly higher in influent ($2.82x10^{11}$CFU/mL) than effluent ($2.74x10^3$CFU/mL).There was then a significant further increase in downstream environments ($2.69x10^{11}$CFU/mL) (**Figure 1).**

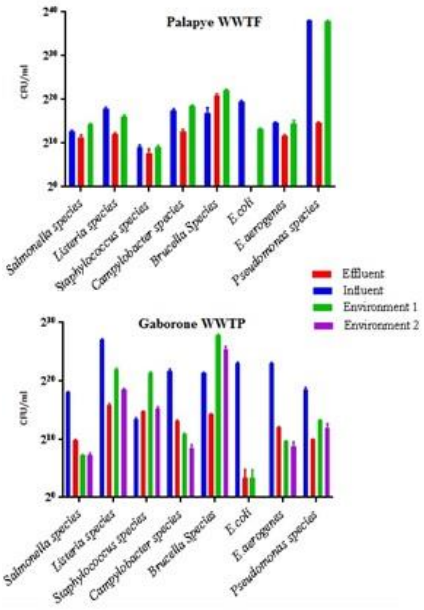

Figure 1: Quantification of bacterial isolates in the treatment facilities and downstream environments. Environment 1 and 2 are site Dsw1 and Dsw2 respectively

B. Antibiotic resistant bacteria

A total of 973 isolates from Gaborone wastewater treatment plant (GWWTP) 566 (58%), influent, effluent and downstream and Palapye wastewater treatment plant (PWWTF) 407 (42%) influent, effluent and downstream were analysed for antibiotic resistance. In PWWTF, 127 (39%) antibiotic resistant bacteria were detected in the influent, (82) 25% in the effluent and (113) 35% were detected in downstream environment. The bacteria isolated with resistance to antibiotics from GWWTP, were 191 (36%) in the influent, 204 (39%) in the effluent wastewater and the downstream environment had 131 (25%) **(Figure 2).**

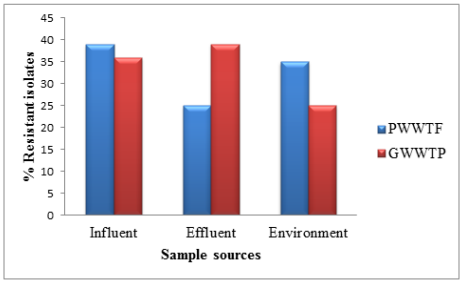

Figure 2: Antibiotic resistant bacteria isolated from different sources (influent, effluent and downstream environments) in GWWTP and PWWTF.

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In both wastewater treatment facilities, antibiotic resistant bacteria were frequently resistant against erythromycin, cephalosporin, trimethoprim, ampicillin, sulfamethoxazole, penicillin, tetracycline as well as ciprofloxacin. Streptomycin and meropenem were the least detected.

When analysing individual species isolates in GWWTP, *Staphylococcus species* were highly resistant against erythromycin, cephalosporin, trimethoprim, tetracycline, sulfamethoxazole and ampicillin while resistance against penicillin, streptomycin and meropenem were lower. Ciprofloxacin resistant *Staphylococcus* was not detected. In effluent, *Staphylococcus species* were highly resistant against cephalosporin, erythromycin, penicillin, tetracycline, sulfamethoxazole and ampicillin. The species resistance against trimethoprim, streptomycin, meropenem and ciprofloxacin was lower. In the downstreams, *Staphylococcus species* resistance against all the antibiotics was lower except ciprofloxacin resistant *Staphylococcus species* which were not detected.
Presumptive *Pseudomonas species* in influent and effluent, had a lower resistance against all the antibiotics used, meropenem resistant *Pseudomonas species* was not detected. In the downstreams, the species had a higher resistance against erythromycin, cephalosporin, trimethoprim, penicillin, and sulfamethoxazole. The species had a lower resistance against tetracycline, ciprofloxacin, streptomycin and meropenem.
Presumptive *Salmonella species'* resistance against all the antibiotics was lower except against streptomycin, meropenem and ciprofloxacin in influent which were not detected. In effluent and downstreams, presumptive *Salmonella species* resistance was lower against all antibiotics used, except meropenem resistant *Salmonella species* which were not detected in both and ciprofloxacin resistant *Salmonella species* in the downstreams.
Presumptive *Campylobacter species* resistance against all the antibiotics used were lower except meropenem and ciprofloxacin resistant *Campylobacter species* in influent which were not detected. In effluent, presumptive *Campylobacter species* were highly resistant against tetracycline, penicillin, sulfamethoxazole, ampicillin, trimethoprim and cephalosporin. The species showed a lower resistance against erythromycin, ciprofloxacin, streptomycin and meropenem. In the downstream the presumptive *Campylobacter species* resistance were lower against all antibiotics.
Presumptive *Listeria species* from influent and effluent had a lower resistance against all the antibiotics used except streptomycin, meropenem and ciprofloxacin resistant *Listeria species* which were not detected. In the downstream environments, the species had a lower resistance against all the antibiotics used except Ciprofloxacin resistant *Listeria species* which were not detected.
Presumptive *Brucella species* from influent, effluent and downstream environments had a lower resistance against all the antibiotics. Ciprofloxacin resistant *Brucella species* were not detected in effluent.
Presumptive *E.aerogenes* from influent and downstreams environment had a higher resistance against erythromycin and lower resistance against all other antibiotics. Meropenem resistant *E.aerogenes* bacteria were not detected. In effluent, the species had higher resistance against penicillin and lower resistance against all other antibiotics except meropenem resistance which was not detected.
E.coli bacteria from influent had higher resistance against erythromycin, penicillin and trimethoprim. It had lower resistance against all other antibiotics. In effluent, the bacteria had a higher resistance against penicillin, cephalosporin, sulfamethoxazole, tetracycline and lower resistance against ampicillin, erythromycin, trimethoprim, streptomycin and ciprofloxacin. Meropenem resistant *E.coli* bacteria were not detected. In the downstreams the bacteria had a lower resistance against all the antibiotics used except meropenem resistant *E.coli* bacteria which was not detected.

In PWWTF, *Staphylococcus species* from influent was highly resistant against erythromycin, cephalosporin, penicillin ampicillin, trimethoprim and sulfamethoxazole. Resistance against tetracycline, ciprofloxacin and streptomycin were lower. Meropenem resistant *Staphylococcus species* were not detected. In effluent, *Staphylococcus species* were highly resistant against erythromycin, cephalosporin, ampicillin, trimethoprim, sulfamethoxazole and tetracycline. The species' resistance was lower against penicillin, ciprofloxacin, streptomycin and meropenem. In the downstream environments, the *species* resistance against all the antibiotics was lower except tetracycline resistant *Staphylococcus species* which were not detected. Presumptive *Pseudomonas species* from influent, effluent and downstream environments had a higher resistance against all antibiotics except meropenem, streptomycin and ciprofloxacin resistance which was lower. Tetracycline resistant *Pseudomonas species* was not detected in the downstreams. The *species* from influent and effluent were higher against penicillin and lower against all other antibiotics in influent and not detected in effluent. In the downstreams, it was lower against all antibiotics except tetracycline, streptomycin, meropenem and ciprofloxacin resistant P*seudomonas species* were not detected.
Presumptive *Campylobacter species* from influent had a higher resistance against erythromycin, trimethoprim, sulfamethoxazole, tetracycline and penicillin. The species resistance were lower against cephalosporin, ampicillin, ciprofloxacin and streptomycin .Meropenem resistant *Campylobacter species* were not detected. In effluent, the *species* resistance was lower against all the antibiotics except streptomycin, meropenem and ciprofloxacin resistant *Campylobacter species* which were not detected. In the downstream, the *species r*esistance were lower against all the antibiotics except tetracycline, meropenem and ciprofloxacin resistance which were not detected.
Presumptive *Listeria species* from influent were highly resistant against; erythromycin, penicillin, trimethoprim, cephalosporin, ampicillin and sulfamethoxazole. The species had a lower resistance against tetracycline ciprofloxacin and

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streptomycin Meropenem resistant *Listeria species* were not detected. In effluent presumptive *Listeria species* had a higher resistance against erythromycin, penicillin, trimethoprim, cephalosporin, ampicillin and sulfamethoxazole. Lower resistance was detected against tetracycline, ciprofloxacin and streptomycin. Meropenem resistant *Listeria species* was not detected. In the downstreams the *species* had a higher resistance against erythromycin and penicillin. It showed lower resistance against all other antibiotics except streptomycin and ciprofloxacin resistant *Listeria species* which were not detected. Presumptive *Brucella species* from influent and effluent were highly resistant against erythromycin, cephalosporin, penicillin, trimethoprim and ampicillin. Lower resistance of the species were detected against tetracycline, ciprofloxacin; streptomycin, and meropenem. In the downstream environments, the species showed a lower resistance against all the antibiotics.

E.coli bacteria from influent had higher resistance against erythromycin, ampicillin, cephalosporin and streptomycin. Lower resistance occurred against penicillin, trimethoprim, sulfamethoxazole, ciprofloxacin and tetracycline. Meropenem resistant *E.coli* was not detected. In effluent; *E.coli* had a lower resistance against penicillin, trimethoprim, ampicillin and erythromycin. Cephalosporin, streptomycin, sulfamethoxazole, ciprofloxacin, tetracycline and meropenem resistant *E.coli* were not detected. The downstreams had a lower resistance against penicillin, erythromycin, cephalosporin, trimethoprim and sulfamethoxazole. Tetracycline, streptomycin, ciprofloxacin and meropenem resistant *E.coli* bacteria were not detected. Presumptive *E.aerogenes* bacteria from influent had a higher resistant against cephalosporin, ampicillin, erythromycin and penicillin. The bacteria had lower resistance against tetracycline, trimethoprim, sulfamethoxazole and ciprofloxacin. Streptomycin and meropenem resistant *E.aerogenes* were not detected. In effluent, the bacteria showed lower resistance penicillin only, all other were not detected. In the downstreams the bacteria had a lower resistance against all the antibiotics except streptomycin and meropenem resistant *E.arogenes* bacteria which were not detected.

C. *Antibiotic resistant genes*

The frequently detected genes in Gaborone WWTP influent were *tet*A, *mph*A, *dfr, sul1* and *int*1. *str*B and *tet*B genes were not detected. In effluent, the frequently detected genes were *tet*A, *mph*A, *sul*1, *dfr*, and *int*1. *str*B gene was detected in lower quantity while *tet*B was not detected. In the downstreams, frequently detected genes were *dfr*, *mph*A and *tet*A. *sul*1, *int*l and *str*B had lower quantities. *tet*B was not detected.

In Palapye influent, *tet*A, *sul*1 and *dfr* were detected in higher quantities. Genes that had a lower detection were *mph*A and *str*B. *tetB* and *int*1 gene were not detected. In effluent, genes that were frequently detected were *dfr*, *sul*1, *int*1 and *tet*A. *mph*A was detected in lower quantities while *tet*B and *tet*A genes were not detected. In the downstreams, frequently detected genes were *dfr*, *int*1, *tet*A, *mph*A and *str*B. *tet*B was detected in lower quantities while *sul*1 gene was not detected.

In antibiotic resistance genes per individual species, *Staphylococcus species* from Gaborone WWTP influent and effluent had *tet*A gene only. There was no gene detection in the downstreams. In *Pseudomonas species* the species from influent, effluent and downstreams environment had *tet*A and *sul*1.*dfr* was also detected in effluent. *Campylobacter species* from influent had *tet*A, *dfr* and *mph*A genes. *mph*A gene was further found in the effluent. There was no gene detection in the downstreams. *Listeria species* from influent had *tet*A, *dfr* and *mph*A genes. *Int1* and *mph*A were detected in effluent. In downstream environments, *dfr* and *mph*A were detected. *Brucella species* from influent had *int*1 and *mph*A. *tet*A was found in the effluent and the downstream had *int*1, *strB* and *mph*A. *E.coli* bacteria from influent had *tet*A, *int1, dfr, sul1* and *mph*A, effluent species had *tet*A, s*ul*1 and *mph*A. *tet*A and *mph*A were further found in the downstreams. In *E.aerogenes* bacteria from influent, *tet*A, *dfr* and *mph*A were detected. Species from effluent had *tet*A, *int*1, *str*B, *dfr* and *mph*A. In the downstreams, only *dfr* gene was detected.

Staphylococcus species from Palapye WWTF influent and effluent had *sul*1 gene only. The downstreams had *dfr* gene only. *Pseudomonas species* from influent had *tet*A and *str*B, effluent had *dfr* and *sul*1.In downstreams, *tet*A, *int*1, *dfr* and *mph*A were detected. *Salmonella species* from influent had *sul*1 while effluent had *int*1 and *dfr*. No gene was detected in the downstream. In *Campylobacter* from influent, only *dfr* gene was detected, effluent had *tet*A, *int*1, *dfr* and *sul*1.In downstreams *tet*A, *str*B and *mph*A were detected. In *Listeria species*, no gene detection in influent and downstreams. *tet*A, *dfr*, *mph*A, *int*1 were detected in effluent. *Brucella species* from influent had *tet*A, *dfr*, *sul*1 and *mph*A. *dfr* was further found in effluent. In the downstreams, *tet*B, *int*1 and *dfr* were detected. In *E.aerogenes*, no gene was detected in influent and effluent. *tet*A and *dfr* genes were detected in the downstreams.

IV. DISCUSSION

This study examined the occurrence, diversity and abundance of potentially pathogenic and antibiotic resistant bacteria and resistance genes from PWWTF, GWWTP and their downstream environments. All of the species were quantifiable (*Staphylococcus, E.coli, Brucella, Campylobacter, Listeria, Salmonella, Pseudomonas, and E.aerogenes*) in all the sample sources of the treatment facilities except for *E.coli* bacteria that were not quantifiable in the effluent samples of both treatment facilities. The abundance of the different bacterial species in effluent and the downstream environments indicates contamination by effluent wastewater from the treatment facilities. All of these species are of clinically importance and may pose a serious concern to the human and livestock, contributing to the spread of infectious diseases such as Brucellosis caused by *Brucella species* (Corbel, 2006),Campylobacteriosis caused by *Campylobacter species* and Listeriosis by *Listeria species* (Robert, 2004).

Both treatment facilities showed presence and diversity of antibiotic resistant bacteria in treated wastewater and the

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downstreams, with GWWTP having higher abundance of the resistant bacteria. The targeted antibiotic resistant species from both treatment facilities and downstream environments showed resistance against all targeted antibiotics with higher abundance against clinically important antibiotics; erythromycin, cephalosporin, trimethoprim, ampicillin, sulfamethoxazole, penicillin, and tetracycline. Even though some at lower frequencies, occurrence of resistance to the last resort antibiotics like meropenem is notable particularly in downstream environments and may have serious public health implications if the bacteria causes infection that could be otherwise untreatable.

The study further looked at the genotypic characteristics of some of the isolates. Different antibiotic resistance genes; *tet*A, *mph*A, *dfr*, *lnt1*, *sul*1, *str*B and *tet*B were detected in many of the isolates and the most dominant being *tet*A, *mph*A and *dfr* gene. The genes were mostly found in the influent water followed by the effluent then the downstream. Abundance of genes in the influent samples may be because this is untreated wastewater which is a reservoir of antibiotic resistance.

Contaminated water carrying the various ARGs can further pose a threat to public health when discharged to the environments because ARGs can further be transferred to other bacteria found in downstream. These results confirms the study expectations and also supports a suggestion by Hong *et al*., (2013), that most municipal wastewater treatment design are unable to remove antibiotic resistant bacteria and their associated resistance genes entirely. The presence of antibiotic resistant bacteria in effluent wastewater and the downstreams in the present study is supported also by other studies; (Thomas & Nielsen, 2005; Ferreira da Silva *et al*., 2006) while those of genes are supported by (Ziembińska-Buczyńska *et al*., (2015; Miller *et al*., 2016).The differences in efficiency of the treatment facilities may be because of different treatment processes used between the treatment plants. PWWTF treats its final effluent with bio-filters then disinfect with chlorine while GWWTP uses activated sludge and maturation ponds. Chlorination has been found as an ideal disinfectant for inactivating bacteria in WWTP, from a study by Iwane *et al*. (2001). On the other hand, resistant analysis showed high rates among isolated strains in four treatment which uses activated sludge for treatment. The treatment water plant does not chlorinate the final effluent (Munir *et al*., 2011).

V. CONCLUSION

Culture dependent method confirmed the occurrence of emerging contaminants like ARB and ARGs in the wastewater effluents and downstream environments. Molecular analysis revealed diversity of ARGs that were not eliminated by the treatment processes leading to the dissemination to the downstream environments. Improvement in infrastructure of the treatment facilities is necessary to mitigate the problem of antibiotic resistance dissemination and potential spread to clinical pathogens. More research on the environment dimension of antibiotic resistance is warranted as it links together clinical and non-clinical environments, with serious implications to human health. This research is also critical in the development of new water quality monitoring schemes and implementation of policies on the use of effluent wastewater for irrigation purposes.

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REFERENCES

1. Aminov, R.I., (2009). The role of antibiotics and antibiotic resistance in nature of Environmental Microbiology. 11, 2970–2988.
2. Corbel, M. J. (2006). Brucellosis in humans and animals. World Health Organization.
3. Ferreira da Silva, M., Tiago, I., Veríssimo, A., Boaventura, R.A.R., Nunes, O.C., Manaia, C.M., 2006. Antibiotic resistance of enterococci and related bacteria in an urban wastewater treatment plant. FEMS Microbiol E.coli 55:322–329
4. Iwane, T., Urase, T., & Yamamoto, K. (2001). Possible impact of treated wastewater discharge on incidence of antibiotic resistant bacteria in river water. Water Science and Technology, 43(2), 91-99
5. Jelic, A., Gros, M., Ginebreda, A., Cespedes-Sánchez, R., Ventura, F., Petrovic, M., & Barcelo, D. (2011). Occurrence, partition and removal of pharmaceuticals in sewage water and sludge during wastewater treatment. Water research, 45(3), 1165-1176.
6. Kummerer, K. (2009). Antibiotic in the aquatic environment—A review—Part II. Chemosphere, 75, 435–441.
7. Luo, Y., Yang, F., Mathieu, J., Mao, D., Wang, Q., & Alvarez, P. J. J. (2013). Proliferation of multidrug-resistant New Delhi metallo-β-lactamase genes in municipal wastewater treatment plants in northern China. Environmental Science & Technology Letters, 1(1), 26-30.
8. Mirmohammadsadeghi, H., Abedi, D., Mohmoudpour, H. R., & Akbari, V. (2013). Comparison of five methods for extraction of genomic DNA from a marine Archaea, Pyrococcus furiosus.
9. Munir, M., Wong, K., & Xagoraraki, I. (2011). Release of antibiotic resistant bacteria and genes in the effluent and biosolids of five wastewater utilities in Michigan. Water research, 45(2), 681-693.
10. Hong, P. Y., Al-Jassim, N., Ansari, M. I., & Mackie, R. I. (2013). Environmental and public health implications of water reuse: antibiotics, antibiotic resistant bacteria, and antibiotic resistance genes. Antibiotics, 2(3), 367-399
11. Oteo, J., Lázaro, E., de Abajo, F. J., Baquero, F., Campos, J., & Spanish EARSS Group. (2005). Antimicrobial-resistant invasive Escherichia coli, Spain. Emergence Infectious Diseases, 11(4), 546-53.
12. Roberts, M. T. (2004). Mandatory Recall Authority: A Sensible and Minimalist Approach to Improving Food Safety. *Food & Drug LJ*, *59*, 563.
13. Szczepanowski, R., Linke, B., Krahn, I., Gartemann, K. H., Gutzkow, T., Eichler, W., Puhler, A., Schluter A, 2009. Detection of 140 clinically relevant antibiotic-resistance genes in the plasmid metagenome of wastewater treatment plant bacteria showing reduced susceptibility to selected antibiotics Microbiol.155, 2306– 2319
14. Thomas, C. M., & Nielsen, K. M. (2005). Mechanisms of, and barriers to, horizontal gene transfer between bacteria. Nature reviews microbiology, 3(9), 711-721.
15. Yuan, Q. B., Guo, M. T., & Yang, J. (2015). Fate of antibiotic resistant bacteria and genes during wastewater chlorination: implication for antibiotic resistance control. PloS one, 10(3), e0119403.
16. Ziembińska-Buczyńska, A., Felis, E., Folkert, J., Meresta, A., Stawicka, D., Gnida, A., & Surmacz-Górska, J. (2015). Detection of antibiotic resistance genes in wastewater treatment plant–molecular and classical approach. Archives of Environmental Protection, 41(4), 23-32.

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Assessment of Airborne Bacterial Diversity and Antibiotic Resistance Patterns in Wastewater Treatment Plants, Hospitals and Public Transport

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***Abstract*—There is presently insufficient information on the atmospheric microbial level in Botswana, the occurrence and diversity of airborne microbes in Botswana is not well understood. In addition, there is also growing concern in the global spread of antimicrobial resistant bacterial pathogens that continue to emerge and pose a huge challenge to human health. This study, being the first of its kind in the country was aimed at understanding the occurrence, distribution and relative diversity of bacteria in the atmosphere surrounding wastewater treatment plants, in hospitals and public transport. The focus was also to further understand the effects of atmospheric conditions, temperature and humidity on the concentration of airborne bacteria. The highest level of culturable bacteria was detected in aerosols (up to 1.25 x10^3 CFU/m^3) wastewater treatment plant downwind. The atmospheric bacterial population is directly affected by temperature and relative humidity; the highest airborne microbial load was recorded during autumn followed by spring while the lowest was observed during winter season. *Pseudomonas species* was the most frequently detected (27.1%) bacterium followed by *Brucella* (15.3 %), *Listeria* (10.7 %) and *Staphylococcus* (8.9 %) species. Diversity of genes encoding resistance to various antibiotics was also detected in airborne bacteria captured in various environments. This study remains important to better understand and monitor the atmospheric basal microbial levels in Botswana.**

Keywords*— *airborne bacterial diversity, antibiotic resistance, wastewater treatment plant, hospital, public transport

I. Introduction

Although ambient air is not a suitable growth medium for microorganisms, it is considered as an inanimate transmitting vehicle by carrying biological agents from one host to another. In recent years, scientists are beginning to be aware of the diversity of environmental and health problems potentially caused by airborne microorganisms. These microorganisms (bacteria, fungi, bacterial and fungal spores, yeast, viruses, microbial toxins and other microbial fragments) exist as aerosols of biological origin (bioaerosols).

The major sources of bacteria maintained in suspension are among others the soil, water, human beings, animals, plants (Jeon *et al*., 2011; Soto, *et al*., 2009) whereas their survival and distribution highly depend on the microorganisms cell structure and the meteorological conditions (Lighthart, 1997). Wastewater treatment plants act as reservoirs of airborne bacteria. Burge and Rogers, (2000) and Kumar *et al*., (2011) indicated that the atmospheric microbial concentration depends on abundance of source and factors controlling the release of airborne bacteria and dispersal from the surface boundary layer. Bioaerosols are dispersed over considerable distances depending on the physicochemical and meteorological air conditions, landscape features, the time of the day, the season, and the type of treatment technology (Bauer *et al*., 2002; Karra and Katsivella, 2007). Variations in quantity and concentration of microorganisms in the atmosphere are temporal as well as spatial, meaning the concentration not only vary among areas but also over various time-scales, including seasons, months, days and hours (Chen *et al*., 2012; Jensen *et al*., 1994).

Pathogenic aerosol-associated microorganisms cause a wide range of diseases in human beings, animals and cause vegetation destruction (Chen *et al*., 2012; Lee *et al*., 2003). The atmospheric microbial contamination in hospital structures, mainly in operating theatre wards had continued to increase prevalence of nosocomial infections resulting in high mortality rates among hospitalized patients going through post operative surgery that is inseparable from Surgical Site Infection (SSI) (Hailemariam *et al*., 2016; Weigelt *et al*., 2010). Very few studies have highlighted the airborne microbial diversity and the ecology of bioaerosols in public transport, instead the bus stations and metro/subway stations have been more studied than the actual modes of transport. Zhou and Wang (2013) revealed that *Staphylococci* are the most common airborne strains isolated in metro stations likewise multiple-resistant *Staphylococcus aureus* reported on public transportation system in Portland (OR, USA). Therefore there are high chances that bacterial pathogens and antibiotic

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resistant strains can be spread through passenger flow in buses and trains.

The development of antibiotic resistant bacteria (ARB) and antibiotic resistant genes (ARGs) that lessen the therapeutic potential against bacterial pathogens (Rizzo, 2013; Zhang *et al*., 2009b) is related with the intensification of antibiotic use for medical and agricultural purposes. This can be considered a major anthropogenic environmental threat affecting the natural environment (Cabello, 2006; Hawkey, 2008; Segawa *et al*., 2013), where they are distributed into the surrounding environment by water and atmospheric circulation. The occurrence and diversity of airborne bacteria in Botswana is not well understood; therefore this study, being the first of its nature in the country is aimed at understanding the occurrence, distribution and relative diversity of bacteria in the atmosphere of selected areas; WWTPs (upwind and downwind air), hospitals (paediatric wards and operating wards) and public transport (bus and mini bus). The study is also aimed at identifying the antibiotic resistance patterns of the bacterial isolates by detecting antibiotic resistance phenotypes and genotypes in bacteria captured from the atmosphere. Furthermore, the study aims to find correlation between the different atmospheric conditions and the bacterial concentrations in the air.

II. Methodology

The distribution and relative diversity of airborne bacteria in WWTPs (upwind and downwind air), hospitals (paediatric wards and operating wards) and public transport (bus and mini bus), their correlation between atmospheric temperature and relative humidity were evaluated. The meteorological conditions; atmospheric temperature and relative humidity were recorded at each sampling site during the sampling periods. Antibiotic resistance patterns of the bacterial isolates were detected by identifying antibiotic resistance phenotypes and genotypes in bacteria captured from the atmosphere.

A. Experimental Setting/ Study Sites

Clinical Environment: Bacteria suspended in the indoor air of operating theatre wards and paediatric wards of Palapye Primary Hospital (PPH, Palapye), Nyangabwe Referral Hospital (NRH, Francistown) and Letsholathebe II Memorial Hospital (LMH, Maun) were assessed. An operating theater is one of the hospital's sterile facilities without windows and feature controlled temperature and humidity, where surgical operations are performed. The paediatric wards were assessed as one of the hospital units where the risk of infection in children have been reported to be the highest in most of the hospitals in the country due to the previously reported cases of *Salmonella*, *Escherichia coli* and other outbreaks. The operating theatre rooms were assessed because of high exposure of internal spaces of human body to possible infection during surgeries. The link between surgical site infection (SSI) or postoperative infection and operating theatre air quality in these environments warrants investigation.

Non-Clinical Environment: The airborne bacteria of public transport, shared passengers transport service available for commuting by the general public: bus (72 seater) and mini bus (26 seater) were assessed. Public transport bus services that were selected for this study are those confined to the country's main road (A1) circulating between Francistown and Palapye In addition, the wastewater treatments facilities (Palapye, Gaborone and Maun) as the main reservoirs for airborne bacteria were also assessed.

B. Meteorological data

Temperature and relative humidity (RH) and wind speed were recorded at each sampling site with a handheld Thermocron iButtons (Dallas Semiconductors, Model DS1920). Temperature and relative humidity were then reported as an average of 1 hour 30 minutes sampling period for each sampling.

C. Air sampling

The principle of air impaction was applied for the quantitative determination of airborne bacteria. Air was directed against the media plates using a portable Microbial Air Sampler MAS-100 NT® device (Merck, Germany), at a flow rate of 100 L/min. The air sampler was placed 1.5 m above ground level during the wastewater treatment plants and hospital wards sampling, whereas in public transport the air sampler was placed at heights that mimic the average height of seated passengers (about 0.91 m). Airborne bacteria were collected by impaction onto various selective and differential agar media; Mannitol Salt agar, Brucella agar, Pseudomonas Agar F, Campylobacter agar, Listeria agar, Salmonella agar, Chromocult agar and E. coli agar. Cycloheximide (1µg/µL, Sigma-Aldrich Co., St. Louis, MO, USA), previously shown not to affect bacterial counts (Dybwad et al., 2012) was added to each media to inhibit growth of fungi. All 8 media were used simultaneously to collect aerosolized bacteria due to the inherent biases caused by media selection, with each plate exposed to airborne bacteria collection for 10 minutes.

D. Quantification and isolation of total airborne bacteria

After each sampling session, the culture media plates were incubated for 24 hours at 37°C for enumeration of viable airborne bacteria. To estimate airborne concentrations, the number of colonies present were counted and related to the volume of the air sampled. Microbial concentrations were expressed as mean values of colony-forming units (CFU) per m^3, CFU/ m^3. Morphologically distinct colonies were randomly selected and sub-cultured in to fresh nutrient agar plates to obtain pure cultures. Morphological analysis of airborne bacteria was performed through macroscopic and microscopic analysis of all isolates All the isolates were stored at -80 ^oC in nutrient broth with 50% glycerol solution prior to antibiotic resistance typing and DNA extraction.

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E. *Antibiotic Susceptibility Test*

Antibiotic susceptibility was assessed qualitatively by designating isolates as being resistant or sensitive based on the growth or no growth of colony growth on nutrient agar plates supplemented with various antibiotics. All isolates were assayed for susceptibility against following antibiotics and concentrations; Trimethoprim (16 µg/ml), Ampicillin (32 µg/ml), Cephalosporin (32 µg/ml), Penicillin (16 µg/ml), Erythromycin (8 µg/ml), Sulfonamide (512 µg/ml), Meropenem (4 µg/ml), Tetracycline (16 µg/ml), Ciprofloxacin (4 µg/ml) and Streptomycin (30 µg/ml). The plates were incubated at 30°C for 48 hours.

F. *Detection of Antibiotic Resistance Genes*

A total of 30 antibiotic resistant strains were selected for detection of various antibiotic resistance genes. The strains were sub cultured to obtain pure culture prior to DNA isolation. Genomic DNA was extracted using the method described by Neela et al., (2015) with slight modification. The pure culture isolates were inoculated on nutrient broth and incubated for 24 hours at 37 ºC. The overnight cultured bacterial cells were harvested by centrifugation at 13000 rpm for 10 seconds, the pellet was resuspended in 600µl of Tris-HCl (50mM Tris hydrochloride - 10mM EDTA, pH8.0), the solution was then incubated for 5 minutes at 80 ºC then left to cool at room temperature. RNase solution (3 µl) was added, and then mixed by inverting the tube 25 times followed by incubation at 37 ºC for 30 minutes. The sample was cooled at room temperature and 200µl potassium acetate solution was added, followed by vortexing for 20s. The sample was then centrifuged at 13000 rpm for 3 minutes to pellet the protein, and the supernatant was transferred into a new tube and 600 µl of isopropanol added followed by centrifugation at 13000 rpm for 1 minute to obtain the pellet with the DNA. The extracted DNA was dissolved in TE (10 mM Tris-HCl, pH8.0, 1 mM EDTA) buffer.

The antibiotic resistance genes were detected by polymerase chain reaction (PCR). The bacterial isolates were detected using specific primers for the following resistance genes; Sulfonamide (*sul*1 and *sul*2), tetracycline (*tet*A and *tet*B), erythromycin (*erm*A, *erm*B and *erm*C), streptomycin (*str*A and *str*B), quinolone (*qnr*A), *dfr*1 resistant genes, integrons (*intI*1). The PCR amplification was performed with a PCR Thermal Cycler (Proflex PCR system, Applied Biosystems). The PCR mixture contained: 2 µl of template DNA, 12.5 µl premix (EmeraldAmp® PCR Master Mix, TAKARA BIO INC), 1.5 µl of each of the primers (forward and reverse) and 7.5 µl deoinised water. The following thermocycler parameters were used: initial denaturation at 95 °C for 5 min followed by 30 cycles of 1 minute at 98 °C, annealing for 40 seconds to 1 minute (the annealing temperature varied among the primers), this was followed by elongation at 72 °C for 1 minute with a final extension for 1 minute at 72 °C. The PCR products were then subjected to gel electrophoresis analysis. PCR products were analyzed on 1.0% (w/v) agarose gel stained with ethidium bromide. Electrophoresis of the DNA was carried out at a constant voltage of 60V for about 1 hour 30 minutes in a horizontal tank in 0.5X concentration of Tris-Borate-EDTA (TBE) buffer. After electrophoresis, the gels were visualized on UV transillumination. PCR products were sub-cloned and confirmed by DNA sequencing.

G. *Statistical analysis*

The variations in total bacterial in clinical and non-clinical environment were assessed using an analysis of variance (ANOVA) test. The one-way ANOVA was used to evaluate the difference between the bacterial concentrations in hospitals, WWTPs and pubic transport. Results with a p-value less than or equal to 0.05 ($p \leq 0.05$) were considered to be statistically significant whereas those with greater than 0.05 p-value were considered statistically not significant. The tests were performed with the software Graphpad Prism 7.0.

III. Results and Discussion

A. *Abundance and Diversity of Airborne Bacteria in Various Environments*

In all the sites studied in each of the three hospitals, all the paediatric wards showed the highest level of bacterial contamination, Letsholathebe Memorial Hospital (LMH) had the highest (6.74×10^2 CFU/m^3) bacterial load, followed by Palapye Primary Hospital (PPH) (4.62×10^2 CFU/m^3) lastly Nyangabwe Referral Hospital (NRH) (2.07×10^2 CFU/m^3). The operating theatre rooms had the lowest airborne bacteria concentrations; the highest bacterial load was isolated from LMH (3.46×10^2 CFU/m^3), followed by PPH (3.4×10^2 CFU/m^3) and the least at NRH (6 x10 CFU/m^3). Fig 1 reveals a significant difference ($p \leq 0.05$) between bacterial concentrations in operating theatre rooms and paediatric wards among all the bacterial isolates from hospitals.

The PPH operating theater room had high airborne bacterial concentration, it is the hospital's only major operating room thereby it experiences large volumes of activities daily. The hospital is old (more than 30 years old) therefore the design and ventilation system may have a significant impact on the cleaning of the unit consequently giving rise to the air bacterial contamination. The operating unit is poorly arranged, the entrance is located next to the washroom that is easily accessible to the building's pathways hence easy exchange with the outdoor air. Many studies have reported that the sink drains are frequently colonized by large numbers of bacteria therefore serve as potential reservoir for aerosolized pathogens or opportunistic microorganisms (McBain *et al*., 2003; Moore *et al*., 2002).

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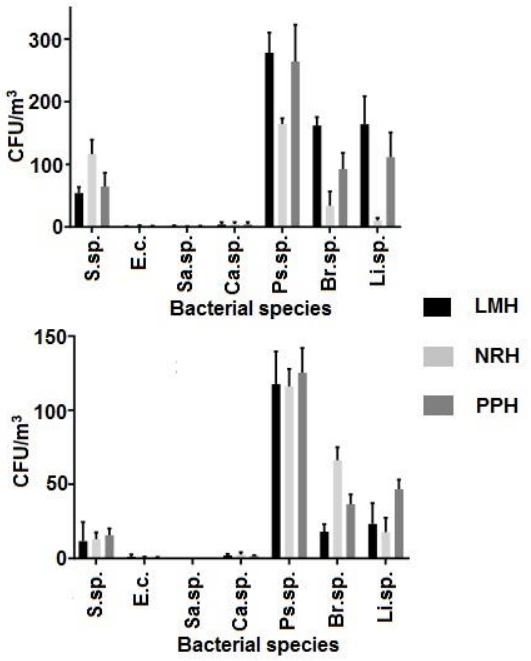

Fig. 1: Bacterial diversity of Isolates in Operating rooms versus in Paediatric wards.
S.sp. - *Staphylococcus* species, E.c - *Escherichia coli*, Sa.sp. -*Salmonella* species, Ca.sp-*Campylobacter* species, Ps.sp.-*Pseudomonas* species, Br.sp.-*Brucella* species, Li.sp. -*Listeria* species, LMH-Letsholathebe II Memorial Hospital, NRH-Nyangabwe Referral Hospital, PPH-Palapye Primary Hospital

Pseudomonas species were the most abundant bacterial isolates from all the operating rooms and the paediatric wards, *Brucella*, *Listeria* and *Staphylococcus species* were also present in high numbers. Similar studies that involved bacteria isolation from air samples in hospitals are in accordance with our results (Borrego *et al*., 2008; Gilbert *et al*., 2010; Qudiesat *et al*., 2009), their findings highlighted the high abundance of potentially pathogenic bacteria in the hospital air such as *Staphylococcus sp*., *Pseudomonas sp*., and *Streptococcus sp*. Other bacteria genera that were isolated in this study such as *Listeria* were also observed in similar studies conducted in hospitals such as Sarica *et al*., (2002), where airborne *Bacillus* and *Listeria* were reported to be predominant in various areas of a hospital under study.
Bacterial concentrations were higher in the downwind air, this could be due to constant flow of raw wastewater through the aerated grit chamber and the inflow on raw wastewater into the sedimentation tank, in which small droplets of bioaerosols were produced and dispersed to the air by wind. Downwind air also had the highest abundance and diversity of bacteria, with the most dominant microorganisms being *Pseudomonas*, *Brucella*, *Listeria* and *Staphylococcus* species. The data obtained from this study revealed the existence of a significant level of bacterial contamination in public transport in Botswana. Considering that the human's daily intake of air (more than 10.000 liters, Soto *et al*., 2009) and that a mean value of 7.2 x10^2 CFU/ m^3 was obtained, this study reveals that one public transport passenger may inhale a total estimate of no less than about 7.0 x 10^3 microorganisms from the air per hour on each trip made. The high bacterial percentages in buses and mini buses may be as a result of the build-up of airborne bacteria shed by the human body due to high numbers of passengers confined to a small space. Some pathogenic bacteria like *Staphylococcus aureus*, can survive for several months in dust particles (Qudiesat *et al*., 2009), thereby the lack of cleaning and poor ventilation (windows are usually closed throughout the trip) of the public transport may result in the accumulation of airborne bacteria. Passengers using public transport are therefore at high risk of infectious diseases. The airborne microbial data in public transport has been under-studied, not only in Botswana but the entire world.

B. Temporal Variation of Airborne Bacterial Communities

Botswana's climate is characterized by four seasons; hot and wet summers (November, December and January), wet autumns (February, March and April), cold dry winters (May, June and July) and arid windy springs (August, September and October). Fig. 2 below shows the total microbial load of the detected airborne bacteria (CFU/m^3) in PWWTP downwind air was highest in autumn (March) and at the beginning of winter season (May) compared to the end of the winter season (July). Whereas at GWWTP downwind air, the bacterial concentration in the atmosphere was the highest in spring (August) followed by autumn (March) and the lowest in winter (May), while at MWWTP microbial load was much higher in spring (August) and autumn (March) and the lowest in winter (May). The results of this study indicate that in all the three seasons, total bacterial concentration was highest during the autumn and spring.

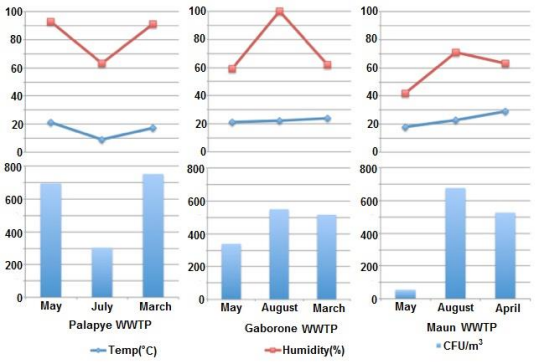

Fig. 2: Seasonal distribution of bacterial concentration isolated from WWTP (wastewater treatment plant) downwind versus temperature and humidity. During the study, temperature ranged between 9 and 29°C, RH ranged between 42 and 100%.

The analysis of the correlation of atmospheric temperature and humidity and total bacterial load revealed that levels of airborne bacterial pollution depend on climatic conditions, a

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greater number of bacteria were observed in the months of lower temperatures (autumn-spring), high temperatures have the potential to significantly reduce bacterial concentrations in the air. This study is consistent with the work by Michałkiewicz *et al*., (2011) in Kostrzyń WWTP premises, where large numbers of bacteria were recorded in autumn ($3{,}x10^3$ CFU/m^3), which made the air severely polluted at that time and lesser airborne bacteria concentrations in spring and winter. Gotkowska-Płachta *et al*., (2008) and Korzeniewska *et al*., (2008) indicated that the largest number of airborne bacteria was recorded at the WWTPs during early spring. The bacterial cells are found to absorb water from the atmosphere when the relative humidity ranges between 20% and 95% thus explaining the abundance of airborne bacteria within that range.

Similarly, in public transport bus services, the results found in this study revealed that the total bacterial concentration was highest during the autumn, followed by summer and was the lowest in winter. Although most of the airborne bacteria in public transport are emitted by indoor sources like humans, some may enter either by means of passive ventilation or by means of ventilation systems from the surrounding areas such as bus stations. However, the local public transports systems such as buses, mini buses and taxis lack ventilation systems such as air conditioners that could regulate the indoor air temperature and humidity disabling a sweeping out effect. Thereby growth conditions like excessive humidity content in transportation systems is encountered on a more frequent basis, which in most cases is the contributing factor for microbial growth. The results of this study are in accordance with Bowers *et al.*, (2012) study that demonstrated that bacterial abundances varied by season with the highest concentrations in autumn and spring.

C. Antibiotic Resistance Patterns

Of all the 1204 bacterial isolates, 79.4 % were resistant to at least one antibiotic while only 20.6 % were sensitive to all the ten antibiotics). The figure below, Fig. 3 indicate that most airborne bacteria are resistant to widely used clinical antibiotics, the mean percentage of antibiotic resistant bacterial isolates from the public transport: bus and mini bus was 83.5 % and the mean percentage of antibiotic sensitive bacterial isolates was 16.6 %. In hospitals, both operating theater wards and paediatric wards the mean percentage of antibiotic resistant and sensitive bacterial isolates were 86.4% and 13.6 % respectively. Lastly, the wastewater treatments plants had a mean percentage of antibiotic resistant and sensitive bacterial isolates of 73.4% and 26.6 % respectively.

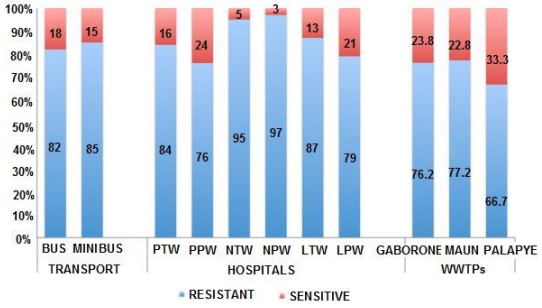

Fig. 3: The overall percentages of antibiotic resistant and sensitive bacterial isolates from public transport, hospitals and wastewater treatment plants.

Nyangabwe Referral Hospital had the highest antibiotic resistant bacterial population, both in paediatric wards (NRHPW) and operating theatre ward (NRHTW): 97.2 % and 95.3 % respectively. Similarly, other hospitals' wards had the high bacterial population with high antibiotic resistance, > 75%. The majority of hospitalized patients receive antibiotics for therapy or prophylaxis during their inpatient stay (Rehm *et al*., 2009; Woldu *et al*., 2013), and this is one of the factors driving antibiotic resistance in hospitals. Also, patients who enter hospitals for the treatment of resistant bacterial infections are a source of resistant bacteria and/or resistance-encoding genes. In Botswana, most of the broad-spectrum antibiotics are used indiscriminately and narrow-spectrum antibiotics are also used inappropriately. Woldu *et al*., (2013), compared the usage and prescription of one or more antibiotics in hospitals and reported the highest in Ethiopia than from a study in Botswana by Fisher *et al*., (2009), where the lowest percentage of antibiotic in prescriptions were recorded.

Public transportation has disturbing antibiotic resistant bacterial populations, and this could be due to the lower hygienic standard and higher number of commuters in confined space. Thereby antibiotic resistant bacterial strains released into the environment through the aerial route may contribute to antibiotic resistance development in wild-type strains of other bacterial strains. In wastewater treatment plants the antibiotic resistant bacterial load are mostly from the households, hospitals and other clinical settings (Baquero *et al*., 2008), these bacterial strains then enter into the atmosphere where they are carried over long distances to various environments and resistance genes introduced into natural bacterial ecosystems. The reported multiple antibiotic resistant bacterial concentrations in hospitals, public transport and the wastewater treatment plants are a great threat to the inpatients and health workers, commuters, workers and nearby inhabitants.

D. Detection of Antibiotic Resistance Genes

In the current study, the presence of Macrolide 2'-phosphotransferase A, *mph*(A) gene was identified in 9 of the 30 selected airborne bacterial isolates; *Pseudomonas sp*., *Listeria sp*., *Brucella sp*. and *Staphylococcus sp*. All the bacterial isolates screened for *mph* (A) gene were resistant to

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erythromycin, however the percentage of the airborne bacterial isolates harboring the *mph*(A) gene was 30%.
The *mph*(A) gene was identified in air samples isolated from the Palapye WWTP upwind, Maun WWTP upwind, Maun WWTP downwind, Gaborone WWTP downwind, Tsholofelo Extension, NRH paediatric ward, LMH operating theatre ward and the paediatric ward. Other macrolide resistance genes, *erm*A and *erm*B were not identified in any of the bacterial isolates whereas *erm*C was found in 10% of the airborne bacterial isolates. The bacterial strains with *erm*C were *Staphylococcus sp*. and two *Pseudomonas sp*. isolated from Palapye WWTP upwind, Gaborone WWTP downwind and LMH paediatric ward respectively. Only one bacterial strain harbored both the *mph*(A) and *erm*C resistance genes, and this was the *Pseudomonas sp*. from the Gaborone WWTP downwind. The *qnr* resistance gene was not detected in any of the bacterial isolates that were screened for the antibiotic resistance genes. Other authors (Pereira *et al*., 2007) described the low frequency of isolation of the *qnr* gene. Furthermore, Jacoby *et al*., (2003) evaluated 91 bacterial isolates and from all those, identified only one isolate harboring the *qnr* gene.

In the sulfonamide and trimethoprim resistance gene families, *sul*1 and *sul*2 resistance genes were absent from all the bacterial isolates that were screened whereas *dfr*1 was abundant in most of the bacterial isolates (40%). Trimethoprim dihydrofolate reductase (*dfr*) resistance genes were widespread amongst pathogenic bacteria; these were identified from *Staphylococcus sp*. (LMH operating theatre ward and the paediatric ward, public transport), *Escherichia coli* (Palapye WWTP downwind), *Brucella sp*. (NRH operating theatre ward, Tsholofelo Extension), *Listeria* (Maun WWTP downwind) and *Pseudomonas* (PPH operating theatre ward and paediatric ward, Gaborone WWTP downwind). Most of these genes are detected in isolates that are related to the hospital and wastewater treatment plants downwind atmospheric air. According to Jury *et al*., (2010), mostly are associated with integrons and use elaborate transfer mechanisms to laterally spread and proliferate within the bacterial community. They further explained the *dfr1* located on both Class1 and Class 2 integrons; particularly the Class 1 integrons (*int*1) that are predominant in gram-negative bacteria isolated from humans and animals hence the abundance of the gene in all the sampling areas involved in this study.

In the present study *tet*A and *tet*B resistance genes were not identified in any of the airborne bacterial isolates. Similarly, no *str*A resistance genes were detected in this study; *str*B resistance gene was however identified in only 1 bacterial isolate of the *Pseudomonas sp*. from the GWWTP downwind air. The results of this study are in accordance with those from a study by Zhang *et al*., (2009), that tetracycline, macrolide and multidrug resistance genes are the more represented whereas other resistances, such as resistance to aminoglycosides and sulfonamides and are less frequent. The results of this study clearly indicate that hospitals and wastewater treatment plants are hotspots for antibiotic resistance genes, which could be due to recurrent contamination with both antibiotic residues and resistant bacteria resulting in the further spread of multidrug resistant bacteria. In addition, public transport also has high abundances of antibiotic resistant bacteria, thereby the need to regularly monitor airborne biogenic material in hospitals, wastewater treatment plants, public transport and other areas where human population is high.

IV. CONCLUSION

Airborne bacteria are widely distributed in WWTPs (upwind and downwind air), hospitals (paediatric wards and operating wards) and public transport (bus and mini bus). High percentages of the airborne bacteria are resistant to clinically used antibiotics. Majority of the antibiotic resistant bacteria were found to harbor some antibiotic resistant genes, though in lower percentages, ≤30%. The results from this study revealed that most antibiotic resistant bacterial isolates were from the hospitals, followed by public transport and lastly the wastewater treatments plants. The results are not as expected, as it was hypothesized that the wastewater treatment plants would have the highest antibiotic resistant bacterial population followed by hospitals and lastly the public transportation.

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REFERENCES

[1] Burge, H. A., & Rogers, C. A. (2000). Outdoor allergens. Environmental Health Perspectives, 108(Suppl 4), 653.

[2] Bauer, H., Giebl, H., Hitzenberger, R., Kasper- Giebl, A., Reischl, G., Zibuschka, F., & Puxbaum, H. (2003). Airborne bacteria as cloud condensation nuclei. Journal of Geophysical Research: Atmospheres, 108(D21).

[3] Baquero, F., Martínez, J. L., & Cantón, R. (2008). Antibiotics and antibiotic resistance in water environments. Current opinion in biotechnology, 19(3), 260-265.

[4] Borrego, S., Guiamet, P., de Saravia, S. G., Batistini, P., Garcia, M., Lavin, P., & Perdomo, I. (2010). The quality of air at archives and the biodeterioration of photographs. International Biodeterioration & Biodegradation, 64(2), 139-145.

[5] Bowers, R. M., McLetchie, S., Knight, R., & Fierer, N. (2011). Spatial variability in airborne bacterial communities across land-use types and their relationship to the bacterial communities of potential source environments. The ISME journal, 5(4), 601-612.

[6] Chen, X., Ran, P., Ho, K., Wenju Lu, Bing Li, Zhongpeng Gu7, Chaojie Song, and Jian Wang (2012). Concentrations and Size Distributions of Airborne Microorganisms in Guangzhou during Summer. Aerosol and Air Quality Research, 12: 1336–1344

[7] Dybwad, M., Granum, P. E., Bruheim, P., & Blatny, J. M. (2012). Characterization of airborne bacteria at an underground subway station. Applied and environmental microbiology, 78(6), 1917-1929.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

[8] Jeon, E. M., Kim, H. J., Jung, K., Kim, J. H., Kim, M. Y., Kim, Y. P., & Ka, J. O. (2011). Impact of Asian dust events on airborne bacterial community assessed by molecular analyses. Atmospheric Environment, 45(25), 4313-4321.

[9] Jury, K.L., Vancov, T., Stuetz, R.M. and Khan, S.J. (2010) Antimicrobial resistance dissemination and sewage treat- ment plants. In: Méndez-Vilas, A.F., Ed., Current Re- search, Technology and Education Topics in Applied Mi- crobiology and Microbial Biotechnology, 509-519.

[10] Jensen, P. A., Lighthart, B., Mohr, A. J., & Shaffer, B. T. (1994). Instrumentation used with microbial bioaerosols. In Atmospheric Microbial Aerosols (pp. 226-284). Springer US.

[11] Jacoby, G. A., Chow, N., & Waites, K. B. (2003). Prevalence of plasmid-mediated quinolone resistance. Antimicrobial agents and chemotherapy, 47(2), 559-562.

[12] Jensen, P. A., Lighthart, B., Mohr, A. J., & Shaffer, B. T. (1994). Instrumentation used with microbial bioaerosols. In Atmospheric Microbial Aerosols (pp. 226-284). Springer US.

[13] Jacoby, G. A., Chow, N., & Waites, K. B. (2003). Prevalence of plasmid-mediated quinolone resistance. Antimicrobial agents and chemotherapy, 47(2), 559-562.

[14] Qudiesat, K., Abu-Elteen, K., Elkarmi, A., Hamad, M., & Abussaud, M. (2009). Assessment of airborne pathogens in healthcare settings. African Journal of Microbiology Research, 3(2), 66-76.

[15] Rizzo, L., Manaia, C., Merlin, C., Schwartz, T., Dagot, C., Ploy, M.C., Michael, I. and Fatta-Kassinos, D., 2013. Urban wastewater treatment plants as hotspots for antibiotic resistant bacteria and genes spread into the environment: a review. Science of the total environment, 447, pp.345-360.

[16] Soto, T., García Murcia, R.M., Franco, A., Vicente-Soler, J., Cansado, J. and Gacto M. (2009) Indoor airborne microbial load in a Spanish university (University of Murcia, Spain). Journal of Biology 31: 109-115

[17] Zhang, X. X., Zhang, T., & Fang, H. H. (2009). Antibiotic resistance genes in water environment. Applied microbiology and biotechnology, 82(3), 397-414.

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RENEWABLE ENERGY

DEVELOPMENT OF A SOLAR TRACKER SYSTEM FOR PV PLANTS

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Abstract—

Solar energy, amongst other renewable sources still stands out as one of the rosy sources of energy due to its inexhaustible capacity, its cost free and totally environmentally friendly. Conversion of solar energy is through the optimization of Photovoltaic panels (PV), which is not really a new concept. However, though solar possesses these desirable qualities, there still lays a challenge of getting the best out of the systems. Low efficiency of renewable sources serves as a limitation to advance their potential. One of the ways to improve the efficiency of solar energy is through the development and integration of solar tracker system. A solar tracker is a mechanism developed to follow and track the sun's trajectory by focusing the PV panel's perpendicular to the beam of sun rays.

Keywords—

Solar tracker, efficiency, Photovoltaic, single axis, DC motor

1. INTRODUCTION

Solar energy still stands as one of the promising renewable sources of energy of which its optimization can make a significant improvement in promoting a sustainable environment the global village is aiming to achieve. The production of electrical energy from non-renewable resources of energy, in the form of fossil fuels, has not only provided the human race with its needs but also has caused enormous environmental problems the world is facing today. Despite the efforts being made about the need and optimization of renewable energy technologies, there still lies a challenge of getting a relatively high efficiency from these promising sources of energy. Undoubtedly the financial capital needed to set up facilities for the conversion processes still sky rock and this serves as a limitation for the establishment and development of such promising sources of energy.

The conversion of PV systems in conversion of solar energy to electricity is not a very new concept. The challenge with them is the efficiency of the system which represents one of the promising and challenging energetic technologies to both the researchers and industries (1). Of the ways or technological methods in making significant improvement in these methods for better output is the ***solar tracking system.*** Though solar trackers are a good way of improving the efficiency of the systems, they however tend to be heavy and subjected to breakdowns.

Developing solar tracking systems is one of the promising technological developments, that has and proven to significantly have an improvement on the efficiency of the Photovoltaic systems. Solar tracking systems can be classified into two classes/categories; according to their moving-axis and their activity type (1), i.e. whether they are active or passively operated. In terms of moving-axis the systems can also be further classified with regards to their rotational axis whether the system is a single-axis or dual axis rotation. A single axis solar tracking system entail a tilted panel mount with a single electric motor to move the panel on a certain trajectory in relation to the sun's position.

Despite the fact that millions of money is channeled towards the development of such renewable technologies in promoting their benefits, as opposed to non- renewable ones, obtaining the optimum efficiency from the system still renders the system not highly effective in terms of getting the best out of the system. This is mostly the case in countries with slow economic growth. However integrating solar tracking mechanisms into fixed PV systems and in already existing systems and yet to be made designs could and will significantly improve on the efficiency of the systems by more than 30% (2). It becomes imperative to develop such methods not only to be innovative but also in the realization of the global efforts of phasing out fossil fuels which have over the past decades enormously given birth to some of the environmental, social and in some instances political problems the world is in the midst of. Advancing solar tracking technology will also assist in plans for attaining green environment but also play a vital role in sustainable development.

2. LITERARURE REVIEW

Renewable energy sources of energy are and still yet to be an important part of power generation that offers decreased negative effects to the environment. Besides their flexibility in

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terms of lowered greenhouse gas emissions, they also offer or add to the energy mix thereby helping in cutting the costs of dependency on fossil fuels (3). Solar energy provides a sustainable supply of energy which is inexhaustible and free throughout. The concepts of PV systems as aforementioned before is not a very new thing, however the challenge is in optimizing the efficiency of the system and one way to do just that is the solar tracking system. Tracking of the sun with the mandate of obtaining and absorbing its energy is best achieved when the tilt angle of the panel(s) is synchronized to the seasonal changes of the sun direction (3).

Figure 1: a dual axis solar taking mechanism. Source [10]

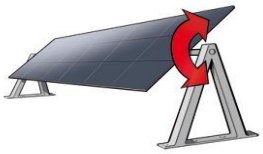

Figure 2: a single axis solar tracking. Source [10]

SOLAR TRACKERS

Solar tracking can be classified as actively or passively operated (1) [fig3 and 4]. Active solar trackers normally are much more electronically designed or integrated, including components such as microprocessor based, computer controlled based and time based, and also programmable logic control (3). Trackers which are microprocessor based would normally consist of a controller connected to the DC motors and also to sensors, i.e. photo sensors. What these sensors do is actually to measure the intensity of the solar irradiance, sends the signal to the microprocessor, and depending on the programming of the microprocessor, the DC motor rotates the panel to the direction of the sun, in which an incident ray or beam of light will be perpendicular to the panel.

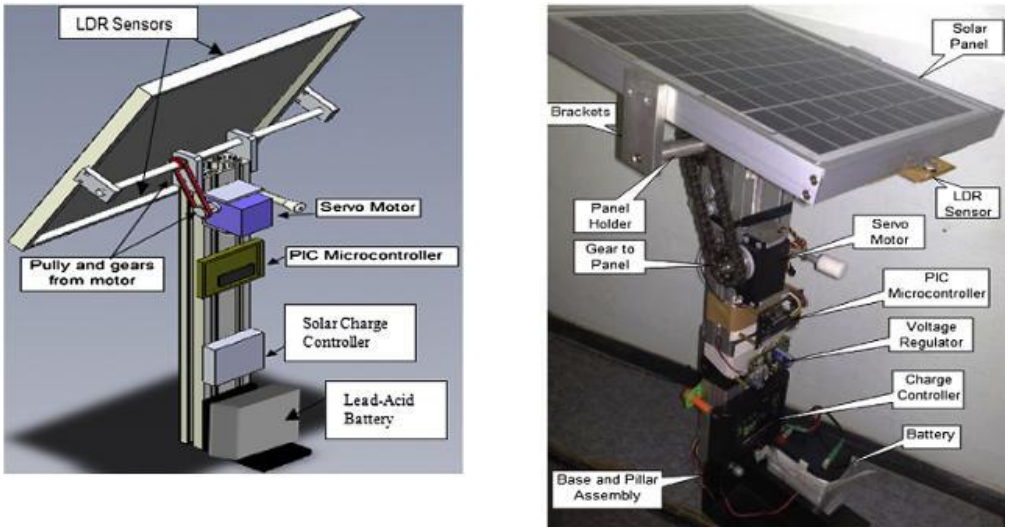

Figure 3: the images above depict a set of active solar tracking system with many electronic components (1)

Another solar tracker system would include a Bifacial Solar cell. Here the bifacial solar cell basically senses and drives the panel to the desired position. In this model, components such as batteries and driving electronics are eliminated (3). Using the Programmable Logic Control (PLC) would require one to calculate the required position and program it into the PLC in order to adjust the PV panel to the sun's trajectory and direction (3).

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According to (4) passive solar tracking devices do not really need to be facing directly at the sun to be effective. Continues to argue that if the degree of aim is off by 10 degrees the output is around 98%. (4) Highlights the use of one passive solar tracking system called the ZOMEWORK MODEL, which is a passive solar tracking product that is said to have installed around 17000 tracking systems since 1980 in different climates. Passive solar tracking systems can generate an output of 25% or more compared to the stationary model (4).

3. METHODOLOGY

Designing and building this single axis solar tracking system, firstly it would require a documentary study of various sources such as journals studied with the aim of acquiring a solid understanding of the operational principle of various

All the software's above will greatly assist in modeling the prototypes before it can be build, which is part of any engineering process in designing of artifacts or prototypes. The MATLAB software which is a high performance language for technical computing will be useful in any programmable job needed. MATLAB is more advantageous than other programming software's in such that in provides an environment that facilitates problems and solutions to be expressed in a more familiar mathematical notation. Its basic data is the matrix and allows graphical output to be optimized for operation. MATLAB will also facilitate the simulation of the design through SIMULINK, which is a block diagram environment for various simulation and model based design. Preference of SIMULINK to other software primarily include; its capability to provide a graphical editor and solve modeling and simulating dynamics system. PV syst is a wonderful trackers. Methods of investigation in data gathering would include giving out a set of questionnaires to solar contracting companies, personal interviews and incorporating design techniques that would assist in advancing the realization of the project. Questionnaires will be used to capture particular information of need from the aforementioned organization and other relevant stakeholders.

As part of the objective, the project entails modeling and simulation of the tracker system's mechanism. In order to achieve this, a set of software's will be utilized such as:

- MATLAB
- Simulink
- Solid works
- PV Syst

photovoltaic software tool that will allow for the calculation of solar angles such as tilt and azimuth angles

Basically the use of software's will be optimized during the design and modeling stage

The active solar tracker will exclude the utilization of electronics. However it will include the following components for the positioning mechanism:

Design and methodology helps accomplishing the objectives by defining the tools and processes which are to be utilized throughout the quest of accomplishing.

Table 1: Materials to be used:

Mechanical components	**Specifications**	**Control/Electrical components**	**Specifications**
Stainless steel rods	**100mm**	PV panel	745 x 350 x25mm polycrystalline panel
Stainless steel square rays	**1000mm**		
Stainlsess steel circular plate	**Diameter : 500mm**		
Worm gears			
Transmission shaft	**500mm**		
DC motor			
Bolts and nuts			

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Justification of materials to be used

- With regards to the materials to be used it was a selection of choice between stainless steel and aluminum. Aluminum is a good choice of material because of its metallurgical qualities such as being light than steel, and cheaper than steel as well. Steel on the other hand is strong, less likely to deform when subjected to weight, or heat, when compared to aluminum. Steel is also denser than aluminum and therefore will its qualities will assist in guarding the system against strong winds, thereby giving it a bit of stability.
- From the literature review, the motor drive system chosen for movement execution was : 24V, 3A, 3000rpm

The modeled concept

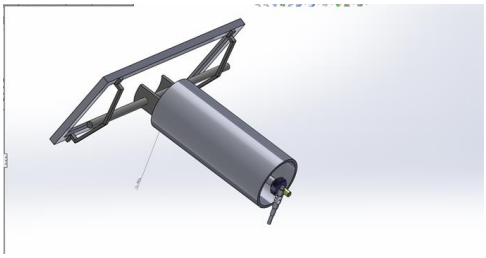

Figure 4: Proposed Concept

This concept uses the gear mechanism to drive the panel, actuated by a motor. It consists of mainly two elements which is the driving element (screw), driven element (helical gear). The driving element in this case is called or referred to as the worm and the driven element called the worm wheel. In this type of gear, power will be transferred from the worm (actuated by a motor) to worm wheel. The shaft will in turn rotate the panel from sunrise to sunset.

The above model was chosen looking at a number of reasons such as trends and the accuracy of which it is far better than the previous concepts. Also the stability of the system was also a factor keyed in.

Advantages

- ✓ Can be used to reduce speed
- ✓ Occupy less space
- ✓ Self- locking

Operates silently and smoothly

4. CONCLUSION

Solar energy, amongst other renewable sources still stands out as one of the rosy sources of energy due to its inexhaustible capacity, its cost free and totally environmentally friendly. Conversion of solar energy is through the optimization of Photovoltaic panels (PV), which is not really a new concept. However, though solar possesses these desirable qualities, there still lays a challenge of getting the best out of the systems. Low efficiency of renewable sources serves as a limitation to advance their potential. One of the ways to improve the efficiency of solar energy is through the development and integration of solar tracker system. A solar tracker is a mechanism developed to follow and track the sun's trajectory by focusing the PV panel's perpendicular to the beam of sun rays. Solar tracking can increase the energy yields by more than 25% compared to stationary solar panels

REFERENCES

(1). *DESIGN OF A SOLAR TRACKER SYSTEM FOR PV POWER PLANTS.* **TUDORRACHE, TIBERIU.** 2010.

(2). *Improving Solar PV System Efficiency Using One Axis 3-Positioning sun Tracking.* **Huang, Bin-Juine.** 2013.

(4). *Renewable enrgy* . **C.S Chin, A. Babu, W. Mobride.** 2011, Design, modelling and Testing of A Standalone Single Axis active Solar tracker Using MATLAB/simulink, pp. 3075-3079.

(5). *passive Solar Tracking System.* **Ass. Pro. Narendrasinh. J. Parmar, Ankit. N. Parmar, Vinod. S. Gautam.** 1, 2015, International Journal of Emerging Technology and Advanced Engineering, Vol. 5, pp. 138-139.

(6). *A Simple photo-voltaic tracking system.* **K.H.S. Karimax.** 2004, Solar Energy Materials & Solar Cells.

(7). *A Review of principles & Sun-tracking methods for Maximizing Solar Sytems Output.* **Hossein Mousazadeh, Alireza Keyhani, Arzhang Javadi, Hossein Mobli, Karen Abrinia, Ahmad Sharifi.** 2009, Renewable and Sustainable Energy Reviews.

(8). *Applied Energy.* **Al-Mohamad, Ali.** 2004, Effeciency Improvements of Photo-voltaic panles using a sun tracking system, pp. 342-352.

(9). **L. Abadi, A. Soeprijanto, A. Musyafa.** *DESING OF SINGLE AXIS SOLAR TRACKING SYSTEM AT PHOTOVOLTAIC PANEL USING A FUZZY LOGIC CONTROLLER.* 2017.

(10). ***solar choice*** **. [Online] [Cited: June 5, 2017.] https://www.solarchoice.net.au/blog/solar-trackers/.**

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A Review of Solar Tracking Mechanisms for Photovoltaic Systems

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Abstract: Solar tracking systems are devices used to optimize the harnessing of solar energy by the receiver. These systems use electro-mechanical devices which orientate the angle of solar receiver so that it is perpendicular to the sun. Therefore, developing tracking systems is vital as these systems could be used to track the bidirectional path of sun which constantly changes every day and seasonally. Dual axis tracking systems are often complex and consume a lot of energy when compare to single axis tracker but are usually more efficient. This paper provides a review of active solar tracking systems for PV modules. Future work will focus on the development of a dual axis

Key words: Dual axis tracking devices, Electro-mechanical, Photo-voltaic (PV) Module

1. INTRODUCTION

The uses of renewable energy resource in power generation have increased as they are environment friendly and are abundance. These resources also create an alternative source rather depending on the use of depleting fossil fuel. Among renewable resources solar is the most vital resource as it is widely and easily accessible. A significant body of research in renewable energy has been committed to photovoltaic system (PV). Photovoltaic system converts solar energy into electrical energy with the use of semiconductors. Though the use of PV is commonly associated with low conversion rates, years of testing and research have led to improvement of the conversion output of the PV system. Improved solar cells have been developed and the use of solar tracking system over the use of conventional fixed PV system has grown. In fixed photovoltaic system the solar receiver (PV module) is in a stationary position facing the true north.

Solar trackers are devices used to direct solar panels or modules toward the sun. These devices change their orientation from to time as they follow the sun's path to maximize energy capture resulting in minimized incidence angle between the incoming solar radiation and module surface. The system is made up of different components such as; receiver, solar irradiance sensors, automation/ control system and mechanical system.

2. LITERATURE REVIEW

2.1. Classification Of Solar Tracking Devices

Tracking devices are either that is passive or active solar trackers. Passive trackers are simple device which uses thermal expansions properties of a material (i.e. thermo-sensitive fluid or shape memory alloys). These types of tracker are commonly single axis as they only orientate the module along the east-west (azimuthal) direction. Low boiling point liquids are used to sense solar irradiance making use of their temperature increase and the resulting compression. (1) Passive trackers uses direct energy from the sun involuntarily to drive the whole tracking system without the use of generated electric energy. Though these

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trackers do not follow the sun precise they are used in the equatorial region which has an abundance of solar irradiance.

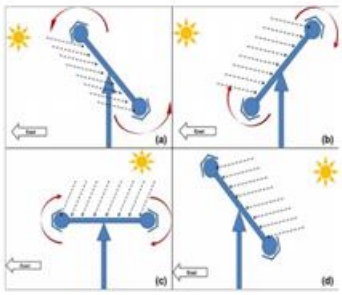

Figure 1: Fluid based passive solar tracker (1)

2.2. Active trackers

Electronic systems or mechanical systems are normally used to achieve more accurate sun tracking than that of the passive tracker. The active tracking can be further categorized into different classes according to the number of axial rotation, the type of actuator and the control system deployed on the tracking system. Solar trackers named according to the number axial of rotation are the single axis and the dual axis.

2.2.1. Single Axis Solar Tracking Devices

The single axis trackers have one degree of rotation which plays the role of the axis of rotation, which is aligned to the true north, therefore tracking the sun in only one direction of east-west, this tracking can either be open loop or closed loop controlled system for different types of actuator motorised or hydro/pneumatic system that drives the tracking devices. Varies types of single axis

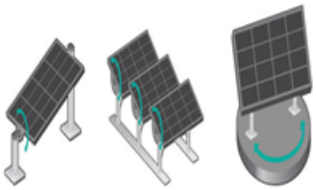

Figure 1: different types of single axis tracking device (from left to right; TSAT, HSAT and VSAT) (2)

tracker include; horizontal single axis tracker

(HSAT), vertical single axis tracker (VSAT) and tilted single axis tracker (TSAT) which are illustrated on *figure 2* below. Different studies shows that a single axis tracking system can yield an increase of about 20% above the conventional system of fixed system (2). Though common in application than the dual axis tracker for their simplicity but are limited since they only track the sun in single direction. A theoretical comparison of different solar tracking devices report scores, the single tracking devices 67% over the fixed system whereas the dual axis tracking system realised a 84.11% increased output over the fixed system (3).

2.2.2. Dual Solar Tracking Devices

Dual axis tracking system has two degree of freedom which are perpendicular to each other. These tracking devices are generally classified as tip-tilt and the azimuthal-altitude trackers.

2.3. Mechanical Trackers

These tracking devices entirely uses the mechanical systems to track the path of the sun with the help of predefined mathematical algorithms which are derived from sun path diagrams, the control of the devices is normally a real time mechanical clocks. Agarwal, Rohit (4) describe a tracking device that uses the mechanical potential energy to drive the whole system. Whereas train gears are deploy as control of the tracking speed as

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they reduce the speed of the system per the hourly and seasonally pre-calculated mathematical algorithms in order predict the sun position. In the study it was concluded that though the tracker could increase the output of the PV system tracks even when the weather conditions are unfavourable such as when there is cloud cover still tracks

(5)Presents a hydraulic tracking system which uses high pressure fluid to convert the potential energy in the mechanical structure that hold up the PV panel into kinetic energy. This kinetic energy is then used to move panel toward the sun. In this system the use of levers is important to manipulate the weight of the entire body which is the main source of energy and for control, hydraulic valves are used to regulate the flow of the fluid (i.e. direction, flow rate) before it reaches the actuator (hydraulic cylinder) which transmit the motion from the fluid to the mechanical positioning mechanism. This tracking device is based on the real timer control principle.

2.4. Automated Control Strategy

The control strategy of solar tracking system is categorized into two main types which are; the open loop (also referred to as passive control) and the closed loop control (active control). The open loop is a non-feedback system and commonly uses the solar algorithms to follow the path of the sun, whereas the closed loop is feedback systems that compensate the realised disturbance of the system. Combination these two methods; result in a hybrid control which in some instances can be used in tracking devices.

2.5. Open Loop Control

This type of control system uses an electronic logic device which uses of mathematical formulae to manipulate the positioning mechanism. Though sensors are not importance in this system they can be used in calibration of the device. This mode of solar tracking ensures that the receiver is positioned at the calculated solar angle for a specific time and date, through the use of solar astronomical algorithms or formulae which are developed based on the sun path chart (maps) that predict the sun`s position according azithumal and altitude angle of the sun at specified geographical location and time of certain point similar to the one depicted on *figure 3*.

A reference (6) reports a high performance rate for PV system with a tracking device. The study shows a 40% improvement of power generation due to the installation of tracking device rather the fixed panel. The research employed a real time clock tracking method. A DC motor is controlled by ARM processor which is programmed to a local solar time and compares the input value of the timer. At pre-set value the system is moved to the required position.

2.6. Closed Loop Control

The main characteristic of the control system is the uses of electro-optic sensors and microprocessor as main controller for the plant. Light dependent resistor (LDRs), photo-transistor and PV cell are commonly used as sensor to detect the coordinate of the sun through light intensity. (7; 8) Designed a optical sensor based dual axis tracking devices, both of the studies used LDRs arranged in criss-cross manner whereby a single LDR receive a higher light intensity than it another which is coupled to . This system uses 2 pairs of the LDRs one for the east-west direction and another for south-north, as the light strikes the sensor the microcontroller compares the input signal therefore executing the command through an H-bridge drive circuit which determines the direction of the motors. In these studies a gain of 25% and 28.31% were realized respectively.

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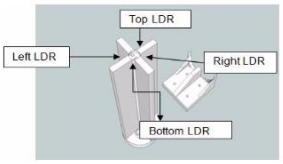

Figure 2: A crisis-cross arrangement of LDRs for dual tracking devices (8)

A PV cell based tracking is reported to have increased the energy gain by 16-20% which was attained by a system made up of four mini- solar module positioned on the North-south and east-west that detect the light intensity, this is system also use the Programmable Logic Controller (PLC) manipulate the two positioning mechanism through two DC motors (9)

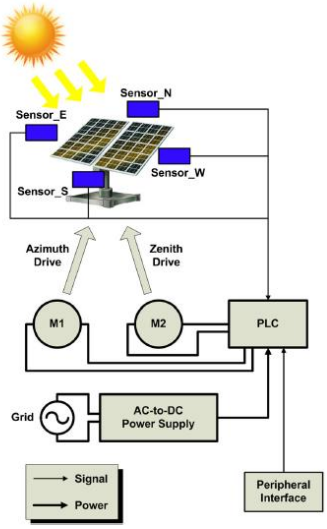

Figure 3: solar cell based dual tracking devices (9)

2.7. Hybrid Loop Control

Hybrid loop controllers combine the open and the closed loop systems. (10) Designed and implemented a hybrid control strategy, whereby a module tilt angle was varied by the means of a controller which is real time based as the altitude position of the sun according to seasons. This tracking system followed the sun in a chorological manner. As for azimuthal angle, the author implemented closed loop (photo-sensor based) tracking that followed the sun continuously. The authors concludes that the implemented tracking strategy was approximately equal with the continuous tracking in terms of energy gained when compared to the fixed conventional system, while it saved about 44.44% of power used for system operation.

2.8. Tracking Method (Motion Of Tracking)

Solar tracking device are proven to be vital in improving the efficiency of PV array. But factors as the installation and maintenance costs, reliability and high energy consumption of the tracking device reduce the performance of tracking devices. These factors led to different development of tracking methods in-terms of the motion of tracking this is divide into two main; chronological and continuous tracking.

Chronological trackers track the sun`s position in a predefined time intervals or in steps. The method of tracking is commonly applied for change of the altitude angle of the sun as change is gradual in this case, but in some researches chronological tracking is implemented for azimuthal direction as position correcting device that is the actuator is only engaged to orientate the PV system toward the sun after a certain period of time.

As for continuous is a method of tracking whereby the PV is moved along with the change solar vector it can be in a single or dual manner. but the literature shows that this tracking method is more practical for daily/ azimuthal direction rather than the altitude

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direction. This is due to increased energy consumption of the system while gain is relatively equal with the chronological tracking method.

2.9. Postioning Mechanism

A mechanical system of the solar tracking device is made up of the actuation devices, transmission system. The main function of this component is to convert any form of input energy into the require kinetic energy as it orientate the PV module towards the sun. Different actuator can be used in the solar tracking but the commonly used trackers are; hydraulic, pneumatic linear actuator and electric motor (that is either DC motor or servo-motor).

3. DISCUSSION

This study reviewed different solar tracking devices presented in various literature sources, and the various architectural designs of the solar tracking system. It was found that solar tracker can be classified according to whether is active or passive, the number of rotational axes, motion of tracking, control mechanism, and the type of positioning mechanism which can be referred to in the *appendix 1*. Also it was found that dual axis tracking mechanism can improved conversion rate of PV system by about 40% and an ideal system the conversion rate can reach approximately 85%.

4. CONCLUSION

It is therefore concluded that solar tracking devices are of great importance in photovoltaic system for improve efficiency of the system and reliability. However trackers still faces challenges such as loss of energy due to factors such as mechanical configuration, climatic condition, tracking efficiency, energy consumption of the tracking system and energy loss in the tracking system.

5. RECOMMENDATIONS

This study recommends:

- A design of electro-mechanical dual axis tracking with energy recycling and regeneration system to enhance the energy efficiency of tracking system.
- Improvement of tracking device to withstand unfavourable weather/ environmental conditions such as strong wind, dust etc.

REFERENCES

1. *Passive Solar Tracking System.* **Narendrasinh Parmar, Asst J, Parmar, Ankit N and Gautam, Vinod S.** 1, 2250, International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com ISO Certified Journal, Vol. 9001.

2. *Comparison of Solar Trackers and Application of a Sensor Less Dual Axis Solar Tracker.* **Aksoy Tirmikci, Ceyda and Yavuz, Cenk.** 2015, Journal of Energy and Power Engineering, Vol. 9, pp. 556-561. 10.17265/1934-8975/2015.06.006.

3. *Theoretical Gain in Solar Energy for Different Sun Tracking Systems in Delhi.* **Vij, Kanav and Kumar, Rajesh.** 7, 2007, International Advanced Research Journal in Science, Engineering and Technology ISO, Vol. 3297. 10.17148/IARJSET.2016.3745.

4. *Concept of Mechanical Solar Tracking System.* **Agarwal, Rohit.** IOSR Journal of Mechanical and Civil Engineering, Vol. 24.

5. *Tracking Of Solar Panel By Hydraulic System.* **K, Kusekar S, et al.** 28, 2015, International Journal of Informative & Futuristic Research ISSN (Online International Journal of Informative & Futuristic Research, pp. 2347-1697.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

6. *Design and Development of Real Time Clock based efficient Solar Tracking System.* **Anusha, K, Chandra, S and Reddy, Mohan.** 1, International Journal of Engineering Research and Applications, Vol. 3.

7. *Dual Axis Solar Tracking System for Solar Panel.* **Singh, Purnima, et al.** 4, 2016, Bulletin of Electrical Engineering and Informatics, Vol. 5, pp. 2302-9285. 10.11591/eei.v5i4.565.

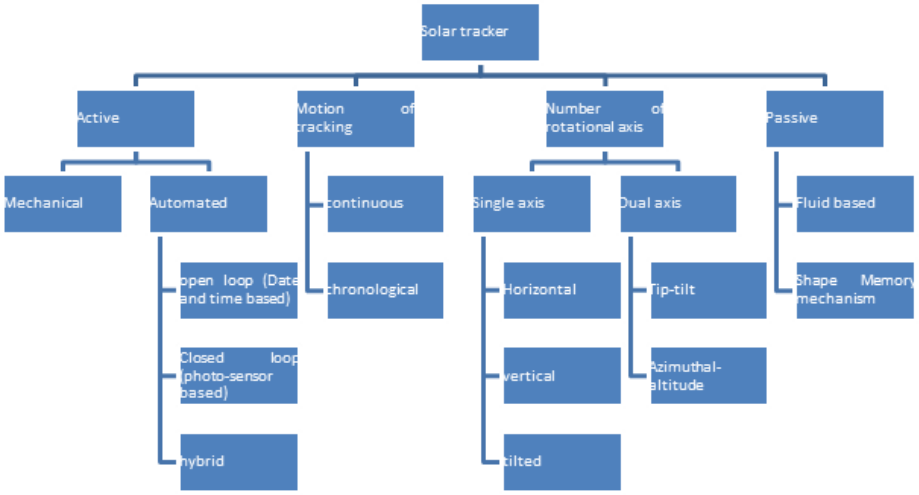
8. *Design and implementation of a sun tracker with a dual-axis single motor for an optical sensor-based photovoltaic system.* **Wang, Jing Min and Lu, Chia Liang.** 2013, Sensors (Switzerland). 10.3390/s130303157.

9. *A novel power benefit prediction approach for two-axis sun-tracking type photovoltaic systems based on semiconductor theory.* **Kuo, Kun Chang, et al.** 2014, Progress in Photovoltaics: Research and Applications. 10.1002/pip.2327.

10. *Energy Efficient Hybrid Dual Axis Solar Tracking System.* **Ferdaus, Rashid Ahammed, et al.** 2014. 10.1155/2014/629717.

APPENDIX

Appendix 1: solar classification tree



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Estimation of measurement uncertainty of routine pH measurement in selected chemical laboratories

Estimation of uncertainty of pH measurement

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A **procedure for estimation of measurement uncertainty of routine pH measurement using pH meter with pH range -2 to 16, three-point calibration, easy recall of calibration point and slope data, temperature compensation and combination glass electrode based on the ISO method is presented. The uncertainty of pH strongly depends on the pH meter itself. Buffers of different ions (NH_3/NH_4Cl, CH_3COOH/CH_3COO^-) at specified pH-values are prepared gravimetrically according to the Henderson Hasselbach equation. Both calibrations and measurements were performed at 25±1.0 °C on the same day. The pH-values of the buffer solutions were close to the expected values but notable uncertainties were also found. Basic statistical calculations and the law of propagation of uncertainty in a spreadsheet model will be used for analysis of uncertainty. The uncertainty of pH measurements will be compared to manufacturers' specifications. In essence, *interval* and *confidence level* are needed, in order to quantify uncertainty. This investigation was performed to provide adequate confidence that pH meters performed satisfactorily and corresponded with laboratory requirements. This approach is used to solve quality related problems in the industry as well ensuring product quality in the industry and to improve knowledge about quality assurance. The study is proposed to be used by assessing organizations, Quality Assurance specialists/ managers/ officers and analytical staff, both in industry and the academic world. It provides principles from which assessing organizations such as accreditation (the ISO/IEC standard 17025) or certification bodies could specify assessment criteria.**

Keywords: pH meter; Henderson Hasselbach equation; uncertainty; accuracy; corrective actions;

I. INTRODUCTION

Measurement of pH is a common and important analytical tool in the modern laboratory (Barron, Ashton, & Geary, n.d.), and it is considered an activity operation in the laboratory. Laboratory operations require the use of tools, equipments and procedures which ought to provide reliable and accurate data to make quality of the products certain (Williams Chairman et al., n.d.). The accuracy of these equipments depends on the uncertainty of the results measurements. Taking pH meter into attention, the uncertainty of its results is reliant on the pH meter itself as analytical measurements of the pH meter made from one chemical laboratory pH meter are not consistent with those made from another and this compromises quality of products and reliability on the equipment. Reliability is assured by consistent monitoring. Monitoring involves a full range of planned practices designed to ensure that quality control measures are being properly implemented which is referred to as Quality assurance. Control measures referring to practices that apply to analytical test like the use of blank samples, certified standard solutions, check samples from both within the lab and from outside, blind samples, quality manuals, replicate analyses, and control charts (Williams Chairman et al.).

The purpose of this research is to estimate uncertainty of the pH meters as one of the simple measurements in chemical and research laboratories; its value is an important quality control parameter and like in any test of physical properties, there is an obvious requirement for reliability of measurement results, which is associated with notable uncertainties. The experiments were conducted at the chemistry laboratories using the Department pH meter (Basic 20) and the pH meter (thermo scientific Orion star) of the Department of Biology and Biotechnology.

II. Experimental Procedure

A. Apparatus

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pH meters

Most measurements were performed by a Basic 20 pH meter. The meter has a large graphic display with resolution of 0.01 units in the pH measurement mode and 0.1 in temperature. It has a measuring uncertainty (±1digit), ≤0.01 in pH measurement and ≤0.2 in temperature. The meter is capable of measuring pH ranges from -2 to 16 by two measuring modes: by stability or in continuous mode. The calibration is programmable with validity between 0 h and 7 days and the meter gives an automatic recalibration warning. Calibration involves automatic recognition of technical buffers pH 2.00, 4.01, 7.00, 9.21, 10.90 values at 25ºC with 1, 2 or 3 buffers selectable inside the range. It has magnetic stirrer as the key to precise and repeatable measurements. This instrument has ambient conditions such; working temperature 5...40 °C, storage temperature -15...55 °C and Relative humidity < 80% (not condensed).

Another meter that was used is the thermo scientific Orion star. The meter has a large, informative screen; it has parameter specifications such as operating temperature 0-50℃, pH range -2 to 16, with resolution 0.1 or 0.01, relative accuracy being ±0.01 and up to three calibration points with easy recall of calibration point and slope of data.

B. *Materials*

Water bath at 25 degrees Celsius, pH meter (thermo scientific Orion star A111, basic 20), analytical balance, 250ml Erlenmeyer flask, 100ml beaker, weighing boat, spatula, top pan balance, thermometer.

C. Chemicals

- Ammonia solution (NH_4OH),Rochelle chemicals, Assay min.25%, 070515AM
- Ammonium chloride (NH_4Cl), Merck (Pty) Ltd, Assay 99%, Uni lab SAAR1122700EM
- Acetic acid (CH_3 COOH), Rochelle chemicals, Assay 99.5%, 090215AA
- sodium acetate ($CH_3COONa.3H_2O$), Merck (Pty) Ltd, Assay 99- 101.0 %
- Three standard buffer solutions (pH 4, 7 and 9)
- Electrode storage solution (3M KCl)

D. Preparing the buffer solutions

Pre lab calculations

In this experiment, mole ratio were assigned and expected pH values calculated with Henderson-Hasselbach equation, and having the number of moles, the required mass were calculated using equation (*moles* = $\frac{mass\,(g)}{molarmass\,(g)}$) and buffer solution was then prepared. There were two sets of acid-base pairs available in the lab. These are:

1. Acetic acid (CH_3CO_2H, K_a = 1.8 × 10^{-5}) and sodium acetate ($NaC_2H_3O_2$).
2. Ammonium chloride (NH_4Cl, K_a for NH_4^+ = 5.6 × 10^{-10}) and ammonia solution (NH_3).

E. Procedure

The buffers were prepared by calculating the mass ratio of acid to base that will produce the assigned pH, and then mixed the calculated amounts of the two compounds with enough deionised water to make 250 mL. Amount of the buffer component needed we measured accurately on an analytical balance (i.e. NH_4Cl) and top pan balance (under a fume hood for NH_3), and dissolved in a small quantity of water in the beaker, the solution was transferred quantitatively into a 250 ml volumetric flask and filled to the mark with distilled water. Then the solution was mixed homogenously by tilting the capped flask upside down a few times. The buffer solution was kept at temperature of 25.0 ±1.0 degree Celsius.

pH meters were set under fume hood, then standardized using three buffers (three-point calibration). The three standardization buffers used were pH 4.01 buffer, a pH 7.00 buffer, and a pH 9.00 buffer (at 25 °C) according to the manufacturer's instructions. About 25 ml of buffer solution was poured into a small beaker and measured the pH. At all

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times the electrode was rinsed off with demonized water when transferring it between different solutions. The pH-values of the solutions were close to the expected value but not exactly the same.

III. RESULTS

IV. Table 1: quantification of uncertainty using interval and confidence level at various calculated pH values of NH_3/ $NH_4Cl$and CH_3CO_2H/ $NaC_2H_3O_2$buffer measured with thermo scientific Orion star thermometer at 25±0.1 °C

a. Parameter of measured pH ↓ f.	b. Calculated pH values c. NH_3/ NH_4Clbuffer				d. Calculated pH values e. CH_3CO_2H/ $NaC_2H_3O_2$ buffer		
	g. 11.25	h. 10.25	i. 9.25	j. 6.75	k. 4.75	l. 3.75	m. 2.75
Mean	*11.071*	*10.21*	*8.907*	*6.464*	4.70	3.354	2.264
SD	*0.0304*	*0.022*	*0.26*	*0.085*	0.15	0.023	0.026
F	0.00019	0.124	0.37	0.015	0.0088	0.016	0.94
t	*2.26*	*2.26*	*2.26*	*2.26*	2.16	2.78	2.78
CI	*0.022*	*0.027*	*0.18*	*0.061*	0.089	0.029	0.032

NB;t<0.05= significance difference, (t>0.05) = no significance difference
; SD- standard deviation
F – F test
t- T Test/ student's t
CI- confidence Interval @ 95%

Table 2: quantification of uncertainty using interval and confidence level at various calculated pH values of NH_3/ $NH_4Cl$and CH_3CO_2H/ $NaC_2H_3O_2$buffer measured with Basic 20 thermometers25±0.1 °C

n. Parameter of measured pH ↓	o. Calculated pH values p. NH_3/ NH_4Clbuffer				q. Calculated pH values r. CH_3CO_2H/ $NaC_2H_3O_2$ buffer		
	11.25	10.25	9.25	6.75	4.75	3.75	2.75
Mean	*11.52*	*10.44*	*8.99*	*6.15*	*4.65*	*3.50*	*2.51*
SD	*0.13*	*0.037*	*0.19*	*0.014*	*0.071*	*0.097*	*0.025*
F	0.00019	0.12	0.37	0.015	0.0088	0.016	0.94
T	*2.26*	*2.26*	*2.26*	*2.26*	*2.16*	*2.78*	*2.78*
CI	*0.093*	*0.015*	*0.13*	*0.010*	*0.041*	*0.12*	*0.03*

NB;t<0.05= significance difference, (t>0.05) = no significance difference
; SD- standard deviation
F – F test
t- T Test/ student's t
CI- confidence Interval @ 95%

V. Statistical Analysis of Experimental Data

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We reasonably anticipate that the uncertainty is dependent on the pH meter itself, and (Leito, Strauss, Koort, & Pihl, 2002) states that the uncertainty of pH depends on the pH value itself. Uncertainty with two decimal places was used deliberately in order to detect small differences in uncertainty introduced by the pH meter as (Meinrath & Spitzer, 2000) made it obvious that a result is meaningless without statement of the associated measurement uncertainty.

The Henderson Hasselbach equation, even though it has limitations as stated by(Po & Senozan, 2001) it was used to calculate pH values. This equation can only be used to calculate pH values that are close to the pK_a of the acid. That gives the reason to use two different buffer solutions with different acids and ionic strength **(**NH_3/ NH_4Cl and CH_3CO_2H/ $NaC_2H_3O_2$). NH_3/ NH_4Cl buffer (pKa= 9.25) was used to attain higher pH value of 11.25 and CH_3CO_2H/ $NaC_2H_3O_2$buffer (pK_a= 4.) was used to attain lower pH 2.75.

Concurring with (Schmitz, 1994) in common practice we cannot expect to get differences between calculated and measured pH values, but the results show that most of the measured pH values were not equal to the calculated ones. When using acetate buffers, results of both pH meters were observed to be always lower than the calculated ones as reflected by mean values (table1 and table2). This is supported by (Schmitz, 1994) who made a kinetic study in acetate buffers and gave explanation to be caused by the relation between the pH meter reading and the activity of hydrogen ions. For ammonia buffer, pH values measured by thermo scientific Orion were observed to always be lower than the expected values, while for Basic 20, the values were at times lower or higher than expected ones.

Measurements of the pH buffer solutions with Thermo scientific meter were less accurate; for pH 11.25 buffer it gave a pH reading that was less: pH =11.071 0.030, the pH = 10.25 buffer it gave a reading of 10.21±0.22 (table 1) which falls within the 95% confidence interval, so there is a chance that when measurements are repeated tenth times the meter will give out the known answer for pH 10.25. Even though, it cannot be concluded that the Thermo scientific Orion star thermometer is accurate because almost all of the mean values are just outside the 95% confidence interval. Therefore, there is less than 5% chance that when measurements are repeated tenth times it will give out the known answer, as well as the Basic 20 pH meter. We used *t* test to compare mean values with another to decide whether there is a statistically difference between the two pH meters readings. The *null hypothesis* in statistics states that the mean values from two sets of measurements are not different; we reject the null hypothesis if there is less than a 5% chance that the observed difference arises from variations of the meters. Table 1 and 2, *t test* results shows that the mean values from the two meters are different, so we reject the null hypothesis.

Although most of the mean values are not close to the calculated pH values, from calculations of repeatability standard deviation (SD), it is understandable that the measured pH values are close to the mean of the data set, in average, for both the pH meters and thus resulting in precision that does not agree closely with calculated value. This is supported by (Andersen & Alfaloje, 2013) stating that high standard deviation results in low accuracy and vice versa.

VI. CONCLUSION

Both the pH meter readings generally did not agree closely with the calculated pH values, but gave similar readings to each other, so the pH meters appear to be too inaccurate in this research. It is clear that we have seen differences on the pH meter that people did not care much about.

All the calculations were performed using the Henderson Hasselbach equation which has limitations, so for future work we intend to formulate a new equation without limitation. As well it was discovered that the manufacturers claims that their pH meter can measure within the range -2 to 16, so in future

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we are going to use sodium hydrogen sulphate/ sulphuric acid buffer with hydrogen sulphate (HSO_4^-) pK_a equal to 2 to try reach lower pH, if possible down to pH = -1, then use acid with pK_a equal to 11 to reach higher ranges in the pH scale.

The measurements we repeated tenth times, but for future work we intend to repeat it several times.

VII. TABLES AND FIGURES

Table 3: The assigned moles ratios and the calculated expected pH values of NH_3/ NH_4Clbuffer components used

Trial	*Assigned mole ratios*		*Expected*	*Calculated masses (g)*	
	NH_3	*NH_4Cl*	*pH*	*NH_3*	*NH_4Cl*
1	*100/100*	*1/100*	*11.25*	*35.05*	*0.5349*
2	*1/100*	*100/100*	*7.25*	*0.3505*	*53.49*
3	*1/100*	*1/100*	*9.25*	*0.3505*	*0.5349*
4	*10/10*	*1/10*	*10.25*	*35.05*	*5.349*
5	*1/10*	*10/10*	*8.25*	*3.505*	*53.49*
6	*0.001*	*0.316*	*6.75*	*0.03505*	*16.9028*

Table 4: The assigned moles ratios and the calculated expected pH values of CH_3CO_2H /$NaC_2H_3O_2$ buffer components used

Trial	*Assigned mole ratios*		*Expected*	*Calculated masses(g)*	
	CH_3CO_2H	*$NaC_2H_3O_2$*	*pH*	*CH_3CO_2H*	*$NaC_2H_3O_2$*
1	*100/100*	*1/100*	*2.75*	*60.05*	*1.3608*
2	*1/100*	*100/100*	*3.75*	*60.05*	*13.608*
3	*1/100*	*1/100*	*4.75*	*0.6005*	*1.3608*

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Figure 1: Basic 20 pH meter

Figure 2: Thermo scientific Orion star pH meter

VIII. Acknowledgements

Would like to recognize and give thanks to my supervisors, Professor Jens Andersen for the supervision provided throughout my project. And Special thanks to the laboratory technicians from the Department of Biology and Biotechnology for always willing to lend me their departmental pH meter.

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IX. REFERENCES

1) Andersen, J. E. T., & Alfaloje, H. S. H. (2013). Pooled calibrations and retainment of outliers improved chemical analysis. In *Revue Roumaine de Chimie*.

2) Barron, J. J., Ashton, C., & Geary, L. (n.d.). Care, Maintenance and Fault Diagnosis for pH Electrodes.

3) Leito, I., Strauss, L., Koort, E., & Pihl, V. (2002). Estimation of uncertainty in routine pH measurement. *Accreditation and Quality Assurance*. https://doi.org/10.1007/s00769-002-0470-2

4) Meinrath, G., & Spitzer, P. (2000). Uncertainties in determination of pH. *Mikrochimica Acta*. https://doi.org/10.1007/s006040070005

5) Po, H. N., & Senozan, N. M. (2001). The Henderson-Hasselbalch Equation: Its History and Limitations. *Journal of Chemical Education*. https://doi.org/10.1021/ed078p1499

6) EURACHEM/ Citac QUALITY CONTROL GUIDE. (n.d.).

7) Schmitz, G. (1994). The Uncertainty of pH.

8) Williams Chairman, A., Berglund, M., Haesselbarth, W., Hedegaard, K., Kaarls, R., Månsson, M., … Galsworthy, D. (n.d.). EURACHEM/CITAC Guide Quantifying Uncertainty in Analytical Measurement Composition of the Working Group EURACHEM members Jung-Keun Lee EA Representative.

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A REVIEW OF SOLAR POWER INVERTERS FOR HOUSEHOLD APPLIANCES

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***Abstract*— Botswana citizens experience energy shortage especially at the rural areas where grid transmission is not accessible. Therefore, rural dwellers find it difficult to use their gadgets and sometimes they are compelled to travel to nearby places or towns in order to get electricity. Sun energy is available and is a cheaper alternative that could be used to address the problem of power accessibility especially in remote areas. Photovoltaic panels are normally used to harvest the solar energy however they generate a DC electrical signal but majority of modern appliances use AC voltage signal. A power inverter is used to convert DC voltage signal to AC signal, suitable for most house hold appliances. The conversion principle output rely on how efficient the converter is, in terms of losses. The aim of this paper is to compare three (3) different circuits modeled via PSIM software in terms of their efficiency, cost and complexity of circuit construction. The PSIM software uses inbuilt gate drivers that generate Pulse width Modulation to drive Mosfet. Simulation results indicate that the four (4) mosfet bridge inverter principle produces nearly pure sine wave waveform that has fewer harmonics and can be easily modified to sinewave form.**

Keywords*— *Solar Energy, Solar Inverter, Appliances, Conversion, Pulse width Modulation (PWM).

I. INTRODUCTION

An inverter is a power electronic device used to convert direct current (DC) voltage to alternating current (AC) voltage. The DC input signal may be directly from solar panel, battery, DC motor generator or a solar cell. [1]. Solar inverters are mainly categorized into either stand alone or utility interactive (grid connected) inverters. Stand-alone inverter output is connected to the battery bank of AC device for example solar motor pump whereas utility-interactive inverter output is connected to the grid. However, within these categories each inverter may output certain form of power depending on varying level of efficiency and distortion impacts to appliances [2]. The output forms of inverters may be square wave form, modified sine wave form or pure sine wave form [3].Henceforth, there is a need for inversion of solar power because most of electric appliances require AC power.

Solar is renewable, green and utilizing it will mitigate continuous demand in energy. The development of a country and its economy is mainly dependent on industry basements it possesses, for these industries to suffice or emerge the country has to be self-sufficient in energy production despite of rapid population growth. Therefore, energy stands to be a limiting factor for development in most countries especially third world countries. Solar electrification is led by developed countries like Japan and United States of America which means all these photovoltaic power system that are available on market are mainly meant for their climatic conditions, which differs a lot from African countries hence the need to design solar inverter suitable for local conditions.

This paper presents a comparison of three (3) different circuit models in terms of their efficiency, cost, and number of components or complexity of construction. Simulation results indicate that the four (4) mosfet bridge inverter principle produces nearly pure sine wave waveform that has fewer harmonics and can be easily modified to sinewave form. Results obtained from the comparison will be used to inform the development of a low cost solar power inverter suitable for Botswana's climatic conditions.

II. LITERATURE REVIEW

Solar power inversion was considered when coming to the realization that some electric equipment's like motors, electric shaving clippers and radios use AC power whereas solar panel itself produce DC voltage. The designing of inverters had begun since then, with the mentality of trying to improve the efficiency of solar conversion at a lower cost. For the design to be accomplished, some parameters are considered; These parameters are based on inverter type of application, that is, either common type, charger integration type, telecommunications dedicated inverter or military dedicated inverter and also based on the output wave form types like square wave form inverter, step wave (modified sine wave) inverter and sine wave inverter.

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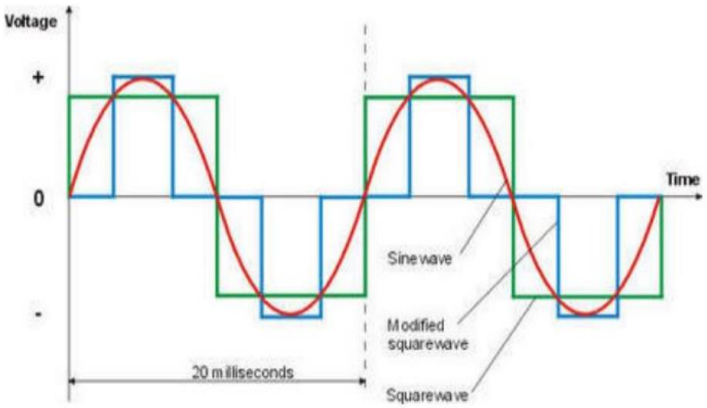

Figure 1; Classification of inverters basing on output waveform (source; Bernard, M. J. (2014). Microcontroller based power inverter)

The capacity of the inverter also plays an important role regardless of the conditions it is exposed to. The findings of Larsen, Gjini & Gray claims that a solar inverter comprises of a heat sink, DC module, an inverter module and AC module arranged in the chassis or printed circuit board in a way that the result is AC power when fed with DC power [8]. The inverter module composes capacitors connected with two switches either bipolar junction (BJT) or Metal oxide field Effect Transistor (MOSFET). These switches are mostly preferred among diodes and thyristors because they are controlled on both turn on and turn off. In some cases a solar inverter is connected dually such that it draws power from either solar panel or battery bank, this helps in case where sunlight is no longer available at night times.

Generally, the inverter comprises of three circuits which are the pulsating circuit, driving circuit and the transformer switching circuit. The pulsating circuit being the heart of the inverter where the DC voltage is subjected to process of switching on and off rapidly producing a square wave. The variation and control of switching times (delays) on and off produce the pulsating current of an inverter when controlled and semi-controlled switches are used. The other component that is used is the oscillator that convert unidirectional current flow from a DC source into an alternating waveform at a particular frequency. The oscillators used for pulsating circuit of inverters are regarded as constant-amplitude whereas other types exist which produce either increasing oscillations or decaying oscillations [9]. The other principle is through pulse-width modulation whereby a modulating and a carrier signal is used to produce the desired constant-amplitude waveform at a frequency.

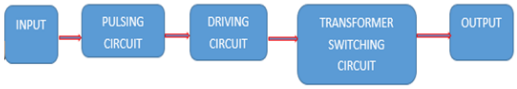

Figure 2: Showing process flow diagram of the inverter.

The diagram (figure 2) illustrate how the inversion system transcends when the input DC voltage is injected at the input pins. The driving circuit is normally the controller gate of the transistors used in processes of switching on and off. The driving circuit controls the frequency of switching, together with the duty cycle the inversion will require. Duty cycle describes the relationship between the operating time and the resting time of these switches. For efficiency purposes in inversion the duty cycle is set to half especially in H-bridge inverters. The transforming circuit collect the inverted power and vary its voltage and current at a constant frequency that suites the appliance connected to the inverter.

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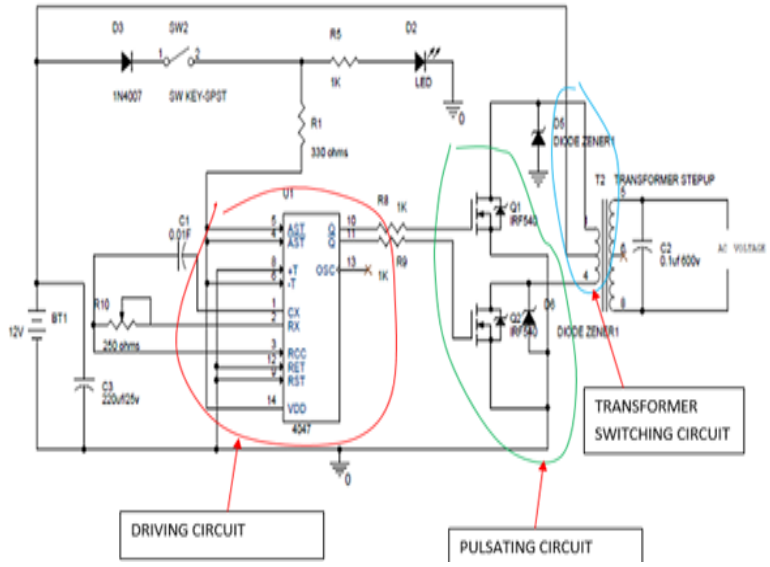

Figure 3: Inverter circuit diagram using PIC 16 micro controller.
(Source; ElectronicsHub.org)

The quantities that often give problems during solar inverter design is the filtration process, because to produce a square wave is simple but it is damaging to some electrical devices. At times a low pass filter or DC is used to modify square wave output that may suite other devices, but still some electrical components are more sensitive in that they would prefer pure sine wave. Henceforth, a multilevel principle of inverting is used to bring the output waveform asymptotic to the pure sine wave. This symbolizes that all energy cannot be converted from one form to another because of losses. According to Good and Johnson conclusions, the inverter loading ratio ought to be considered, 'to decrease the unit cost of electricity and increase the effective capacity factor relative to the inverter rating' [9].

Shafeeque & Subadhra conducted a conference paper titled "A novel single-phase single-stage inverter for solar applications" which emphasized that a single stage inverter working on buck-boost principle is more advantageous than conventional inverters [10]. Since it reduce the size of an inverter which normally depend on series of convention (converters) used. The output signal is closer to the sine wave whereas Ghalib, Abdalla, & Mostafa concluded that the conversant way to produce a pure sine wave output inversion is by implementation of Peripheral Interface Controller (PIC) microcontroller into the Sinusoidal Pulse Width Modulation method of controlling solar inverter [11]. The method is reputed to be superior to others and its results are verifiable by PSIM and Proteus software simulations. The PIC was embedded with a C language which was built in a suitable compiler to produce a HEX file to be burnt in it. The inverter was Full bridge single phase inverter and also tested with varying AC loads. The generation of signal for mosfet driver using the pulse width modulation proved to bear result more especially when using TL 084 (OP AMPS) and LM 339 (OP AMPS). The principle also produce less harmonic distortion, and the output was also tested using various ac appliances that proved compatibility with the voltage waveform produced.

The first step to program is to generate a C code and then translate it into an assembly language with the aid of particular instruction set of that peculiar chip desired to be used to perform embedded instructions of the device. The project targets Atmel / At mega microchip which means an Atmel instruction set is bound to be downloaded and then used for producing assembly language that would be easily understood by the chip to perform instructions. The chip act as the brain of the solar inverter that is by monitoring the following parameters;

1. Battery and input power conditions

The input power has to be of required value or within certain threshold for solar inverter efficiency supply. If the power is too low the chip coordinates the shutting down or disqualifies the input by allocating it with a zero value. The chip also monitors the delay times to prevent the surges from the source. In cases whereby both the battery and the panel inject voltage simultaneously, the chip has to act as a stress reduction snubber circuit.

2. Transistor heat sink

A heat-sink is designed to remove heat from a transistor and dissipate it into the surrounding air as efficiently as possible. Heat-sinks take many different forms, such as finned

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aluminum or copper sheets or blocks, often painted or anodized matt black to help dissipate heat more quickly. Good physical contact between the transistor and heat-sink is essential, and a heat transmitting grease (heat-sink compound) is smeared on the contact area before clamping the transistor to the heat-sink. The heat sink that is more than the required also lead to overcooling which also affect the efficiency of power transmission. Therefore, if the heat dissipated in the heat sink is more than it can handle the chip has to switch off the system to avoid the blowing of transistors or transistor thermal runway. The cooling media might be the air or spongy material (insulator).

1. Phase angle and Frequency

i) Basic Circuit model A

The phase angle and the frequency of the driver circuit that powers transistors need to be optimized by the controller in order to attain the required waveform of the inverter and the important aspect of the inverter is the duty cycle that need to be specified in the program entity.

III. RESULTS AND ANALYSIS

The different circuit models were modelled and simulated using the PSIM software producing different waveforms depending on the components used. The below diagram shows the test result produced by the software, also the analysis of physical components in terms of prices and number.

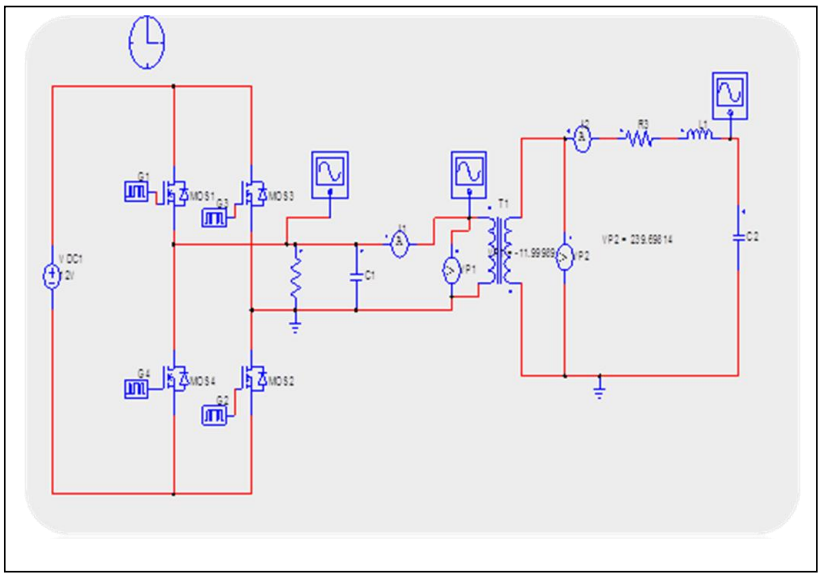

Figure 4: Circuit model A

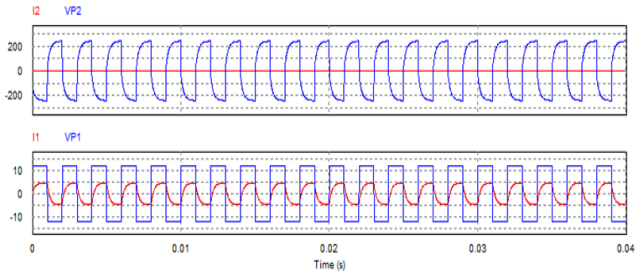

Figure 5: Waveforms

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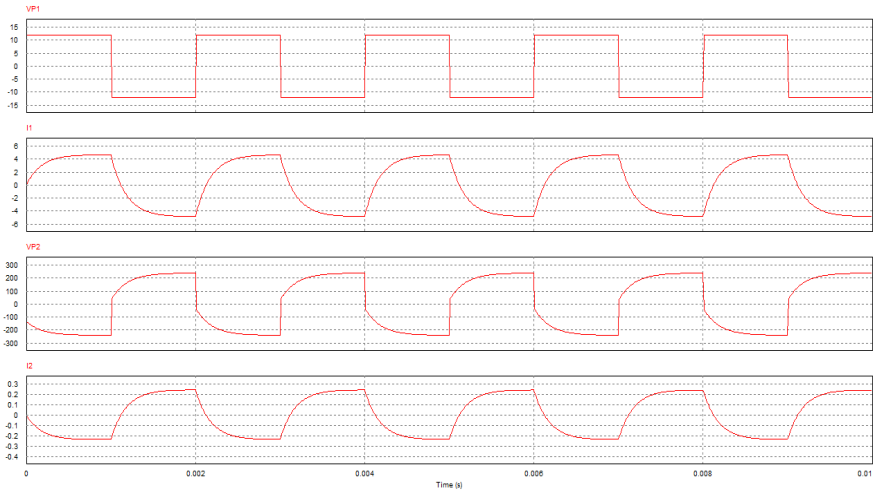

Figure 5: Waveforms

The waveform produced in model A is not a sine wave but it poses some curvature which means modifying it into sine wave would be cheaper provided that controller is cheap also. The components are also fewer but cost of switches and (1:20) transformer might be a little bit high, therefore, the need to reduce cost of this components may also bear the desirable results. It has less harmonic due to the RLC filter at the load but this harmonics could be eliminated by using pulse width modulation principle. The principle could be enhanced by the use of Atmel micro controller.

ii) Circuit model B

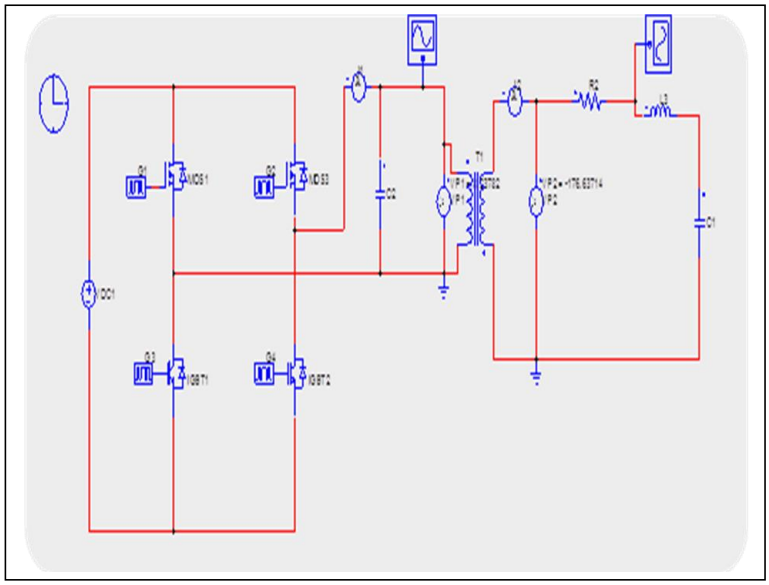

Figure 6: Circuit model B

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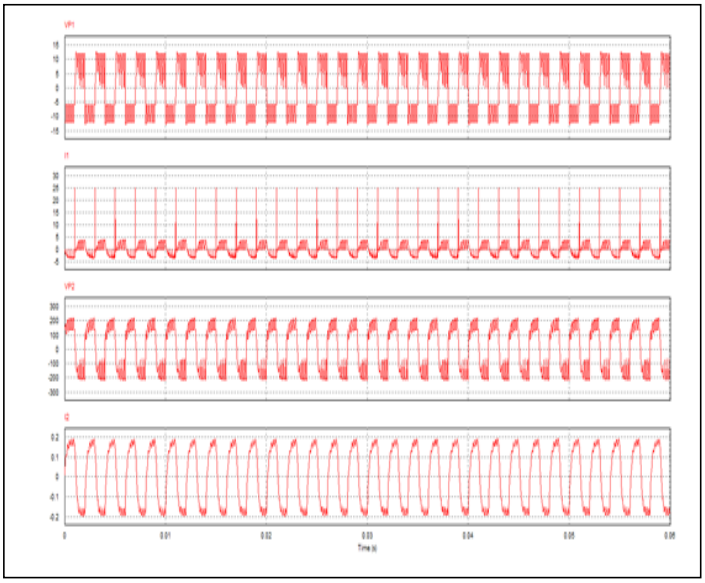

Figure 7: waveforms

The output wave form is not sine wave and also modifying it into sine wave could be intensive. It has more voltage and current ripples that is not filtered enough by rlc filter. The circuit also uses both mosfet and IGBT switches which means the cost will be higher than Circuit A and it will also require a series of filtering that would add to number of components in the inverter and also earn a loss of energy due to series of conversion.

iii) Circuit model C (Boosting & inverter)

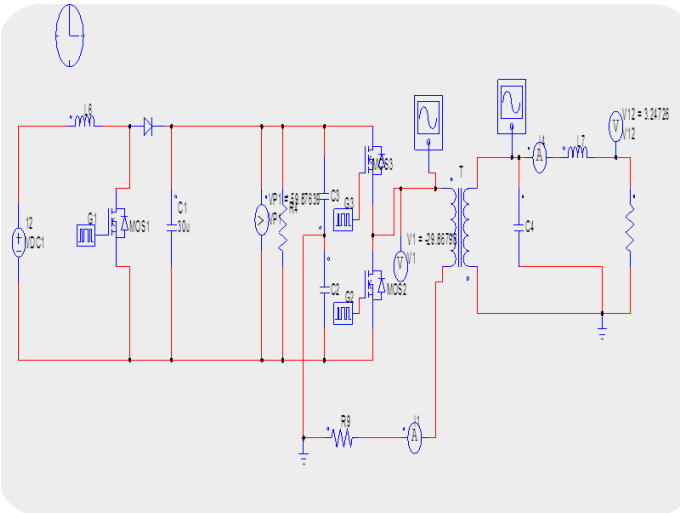

Figure 8: Circuit model C

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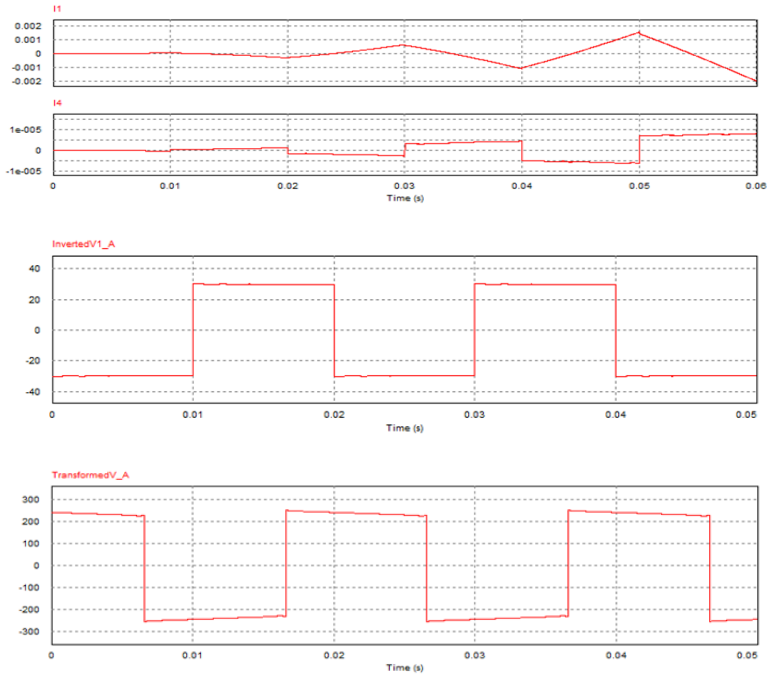

Figure 9: Waveforms

The circuit model produced a square waveform which also have high transient response time. Then, for it to qualify the research it needs transient response time reduction and also the filtration process to reduce harmonics in order to attain sine waveform. The ripples of voltage and current are both lower compared to circuit B. Circuit C also use 3 mosfet, 1 diode and a transformer with less turns ratio compared to other circuits. Henceforth, cost of switches and transformer is minimized. The pulse width modulation principle could be handy in for sine wave generation.

TABLE 1; Summary of Circuit Comparisons

CIRUIT TYPE	SWITCHES	INDUCTORs/Capacitors 100mH; 30 uF	Resistor(s) 1kOhm)	Transformer	Total Components	Cost (Estimated)
A	4 Mosfets	1 inductor,2 capacitors	1	1(1:20 winding)	9	P300.00
B	2 Mosfets 2 IGBT's	1 ,2	1	1(1:20)	9	P500
C	3 Mosfets 1 Diode	1 ,4	2	1(1:8)	12	P330

The circuit A is chosen and with the aid of Atmel micro controller is tested via the proteas software in order to achieve the sine wave waveform. The prototype would be designed and tested via the model also. The delays in order to compensate for transient response will also be viewed and assessed to see whether it bears results or not.

IV. CONCLUSION

The output produced by the proposed circuit was a square wave not the sine wave but through gate drivers, but it would further be introduced into the micro controller for pulse width modulation principle. The controller proposed is the Atmel and would be responsible for PWM signal waveform generation, output voltage regulation, low supply detection and overload protection for prototype testing.

V. REFERENCES

[1] Dokic', B. L., & Blanus'a, B. (2015). *Power Electronics-Convertors and Regulators.* London: Springer Cham Heidelberg.

[2] Thu, A. M., & Lwin, K. S. (2014). Design and Implementation of Solar inverter for Pure Sine Wave Inverter.

[3] Tsokolas, G. E., & Vokas, G. A. (2014, November). Functional characteristics of a typical grid photovoltaic system with various topologies and inverter types. In *Proc. 9th Med.*

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ISBN: 978-99968-0-608-7

Conf. Power Gen., Trans. Distr. Energy Convers. MEDPOWER, Athens, Greece.

[4] Akinsola, H. A. (2016). Effects of the AIDS epidemic and the community home-based care programme on the health of older Batswana. *Southern African Journal of Gerontology*, *9*(1), 4-9

[5] Essah, E. A., & Ofetotse, E. L. (2014). Energy supply, consumption and access dynamics in Botswana. *Sustainable Cities and Society*, *12*, 76-84.

[6] Ekhator, O., Ihenyen, J. O., & Okooboh, G. O. (2013). Desmids of Osse River, Edo State, Nigeria. *International Journal of Modern Botany*, *3*(2), 25-31.

[7] Abdulah, M. S., Matlokotsi, T., & Chowdhury, S. (2016, June). Techno-economic feasibility study of solar PV and biomass-based electricity generation for rural household and farm in Botswana. In *PowerAfrica, 2016 IEEE PES* (pp. 67-71). IEEE.

[8] Desai, P. C., Larsen, S. R., Gjini, O., & Gray, M. D. (2014). *U.S. Patent Application No. 14/568,233*.

[9] Jeremy Good, Jeremiah X. Johnson, Impact of inverter loading ratio on solar photovoltaic system performance, Applied Energy, Volume 177, 1 September 2016, Pages 475-486, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2016.05.134.

[10] Shafeeque, K. M., & Subadhra, P. R. (2013, August). A novel single-phase single-stage inverter for solar applications. In *Advances in Computing and Communications (ICACC), 2013 Third International Conference on* (pp. 343-346). IEEE.

[11] Ghalib, M. A., Abdalla, Y. S., & Mostafa, R. M. (2014). Design and Implementation of a Pure Sine Wave Single Phase Inverter for Photovoltaic Applications. *AMERRICAN SOCIETY FOR ENGINEERING EDUCATION, ASEE*, 1-8.

[12] Ibrahim, D. (2014). *PIC Microcontroller Projects in C: Basic to Advance*. Newnes.

[13]Thu, Aye Myat, and Kyaw Soe Lwin. "Design and Implementation of Solar inverter for Pure Sine Wave Inverter." (2014).

[14] Bernard, M. J. (2014). *Microcontroller based power inverter* (Doctoral dissertation, UNIVERSITY OF NAIROBI).

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Testing the Predictability of the Botswana Stock Exchange: Evidence from Supervised Machine Learning

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***Abstract*—Prediction of the stock market is a vital part of the economy especially for emerging markets in developing countries. There is significant literature on predicting the stock market particularly in developed countries like the US. However, there is need for more research in emerging markets such as developing countries like the Botswana Stock Exchange. This paper aims at evaluating the predictability of the Botswana Stock Exchange using supervised machine learning to specifically assess and test the null hypothesis of the Random Walk Theory. Machine learning is one of the upcoming trends of data mining; hence few machine learning algorithms have been used where their results have been compared using classification evaluation parameters such as Accuracy, Mean Average Error (MAE), Receiver Operating Characteristic Area (ROC), Kappa Statistic, Precision and Recall. Naïve Bayes have been considered the most effective model as it yielded the highest accuracy of 83.3% with the least error margin. The results reject the null hypothesis of the Random walk Theory for Botswana Stock Exchange for the period of January-December 2015, clearly indicating that the Botswana Stock market is predictable using machine learning techniques.**

Keywords*—*Emerging Markets, Machine learning, Random Forest, Naïve Bayes, Support vector machines

I. INTRODUCTION

Several studies have been conducted to predict the future stock price direction. Such studies would mainly use methods in financial analysis and data analysis. In recent years, machine learning has become a widely used method for stock prediction. The most used methods are Artificial Neural Networks and Support Vector Machine [1]. Even though a significant number of researches have been done on predicting the stock price index, most researches that have been done are on the developed markets. However, few researches exist on predicting the direction of stock price in emerging markets, especially in the Botswana Stock Market.

Accurately predicting the market is important because it helps in developing effective market strategies, which in turn, helps investors, mitigate risks and make profit [2]. Though it is very important, it is at the same time very difficult to predict the stock market because it is non-linear and is affected by a number of factors such as political, social and economic.

It is of great interest to study the prediction of the stock market using data from emerging markets such as that of Botswana. Since its establishment in 1989, solidified by the Botswana Stock Exchange Act of 1994, the Botswana Stock Exchange (BSE) has grown tremendously as an emerging market. The BSE is one of Africa's best performing stock exchange averaging 24% aggregate returns in the past decade. The BSE is the third largest stock exchange in terms of capitalization in Southern Africa. It has 35 marked listings and 3 stock indices; the Domestic Company Index, Foreign Company Index and the all Company Index [3]. The objective of this paper is to predict the direction of the BSE using machine learning techniques; Random Forest, Support Vector Machines and Naïve Bayes. The contribution of this paper is in demonstrating that the stock price is predictable using supervised machine learning techniques and in comparing the performance of these techniques on a given set of metrics.

II. RELATED WORK

This section gives a background and a synopsis of previous researches that have been carried out in the areas of stock market predictability, and machine learning techniques (Support vector machines, Random forest and Naïve Bayes). The purpose of the section is to ease the user into the subject matter through definition of important concepts and giving the necessary background discussion to motivate the problem under study.

A. Predictability of the Botswana Market

The random walk is a theory that states that stock prices are independent of each other though they have the same distribution [4]. This theory implies that past stock prices cannot be used to predict future stock prices. Even though a lot of research has been done in predicting the stock market, little research has been done on emerging markets like the Botswana market. The need for research in emerging markets is still not recognized. Radikoko [3] tested the effectiveness of the

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Botswana market. He was particularly interested in whether the random walk theory applies to the Botswana market. The author used different methods in order to validate his research.

The results presented by the authors showed that the random walk theory does not govern the Botswana stock market which meant that the market is weak-form inefficient. The results also meant that historical prices could be used to predict future stock prices. Similarly, Mollah in 2007 [2] tested the null hypothesis of the random walk theory by testing whether the Botswana Stock Exchange is predictable. The author used data from the Botswana stock exchange from 1989 to 2005. The author found that the Botswana market can be predicted using the Triangulation approach. Their results also nullified the null hypothesis of the random walk theory, suggesting that the market was predictable.

Chiwira and Muyambiri did some research in the same area in 2012 [5]. The research evaluated the efficiency of the Botswana Stock Exchange by assessing the random walk theory using a number of methods. Their research rejected the random walk hypothesis. The authors used BSE data from 2004 to 2008, which constituted monthly and weekly data. They showed that the market could be outperformed since stock prices are not independent of past price changes. The authors concluded that both fundamental and technical analysis can bring positive results. All these studies show that indeed the Botswana market is predictable. They therefore set a baseline for research in this field and also motivates for more research work to be done on predicting the Botswana stock market.

B. Stock Price Behaviour: Theories

The stock market is guided by a number of indicators namely; Technical analysis, Fundamental analysis, efficient market theory and the random walk theory. Technical analysis is a methodology for forecasting the direction of security prices through the study of past market data. Technical analysis examines statistics generated by the market using past prices and volumes in order to evaluate securities. Technical Analysis is the study of past prices in order to predict future prices, patterns and trends. Technical analysis studies the patterns on the market, the supply and the demand of stock shares [10]. There has been a lot of debate over whether technical analysis can actually predict the markets. Previous studies [6], [7], [8] examined the predictability of the stock market through the use of technical analysis. These studies failed to provide evidence of the usefulness of technical analysis since they had mixed conclusions [9].

Fundamental Analysis on the other hand, is the study of financial information like company earnings and value of assets. With fundamental analysis, everything is studied from financial conditions to the industrial conditions and even the management of the company [11]. Fundamental analysis evaluates a share through measuring its value by examining factors such as financial, economic, quantitative and qualitative. According to Suresh [12], fundamental analysis is actually the study of factors that affect the economy and companies. Much like technical analysis (when applied to stock markets), the goal of fundamental analysis is to predict the future stock price movement and thus making profit from it.

The random walk theory implies that the stock price fluctuates and its fluctuations are independent and may be described by a random process like tossing a coin, for example. It states that the current stock market price is independent and unrelated to previous market price patterns. The theory implies that stock price changes do not have memory, cannot be predicted basing on past history of the behaviour of the stock. However, the actual price of the stock may change in response to new information. The value of a stock is determined by fundamental analysis of the future earnings performance of the company. As new information becomes available investors may revise their estimates of expected future earnings and those revisions may affect the estimated value of the stock [13]. Furthermore, Poshakwale [14] states that, it refers to the fact that price changes are independent of each other. Tomorrow's price change and tomorrow's price cannot be predicted by looking at today's price change.

The Efficient Market Hypothesis (EMH) is a market theory that evolved from a 1960's Ph.D. dissertation by Eugene Fama [4]. The efficient market hypothesis states that, at any given time and in a liquid market, security prices fully reflect all available information. The EMH exists in various degrees: weak, semi-strong and strong, which addresses the inclusion of non-public information in market prices. This theory contends that since markets are efficient and current prices reflect all information, attempts to outperform the market are essentially a game of chance rather than one of skill. The weak form of EMH assumes that current stock prices fully reflect all currently available security market information. It contends that past price and volume data have no relationship with the future direction of security prices. It concludes that excess returns cannot be achieved using technical analysis.

The semi-strong form of EMH assumes that current stock prices adjust rapidly to the release of all new public information. It contends that security prices have factored in available market and non-market public information. It concludes that excess returns cannot be achieved using fundamental analysis. The strong form of EMH assumes that current stock prices fully reflect all public and private information. It contends that market, non-market and inside information is all factored into security prices and that no one has monopolistic access to relevant information. It assumes a perfect market and concludes that excess returns are impossible to achieve consistently [15].

C. Random Forests

Random forests are powerful learning algorithms that are used in classification tasks. Training a random forest generates a myriad of decision trees which are then classified based on the results obtained from those decision trees [16]. The mode of the targeted outputs from each decision tree is the output of the forest. Random Forest average out the multitude of the decision tree whereas other trees tend to overfit data because of low bias and high variance. They use random samples of the training data to generate decision trees. This reduces the variance in the overall model thus improving performance and also controlling overfitting. In classification, tree nodes

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represent features where important features are high up in the tree. Class labels are represented as leaves. The importance of a feature is determined by a Gini impurity where, the lesser the decrease in accuracy by randomly permuting the values of the feature, the less important the feature is [17].

Random Forest classifiers are more accurate and robust to noise and outliers than single classifiers. They run effectively on larger datasets and can handle thousands of input variables without variable deletion. They give an estimate of what variables are most important in the classification; it generates an internal unbiased estimate of the generalization error. Proximities between pairs of cases that can be used in locating outliers are computed using Random Forest. They contain a combination of classifiers where each classifier contributes with a vote for most frequent class to be assigned to the input vector [17]. Random Forest classifier is different to traditional classification trees since it is a combination of many classifiers and thus has special characteristics; it is an ensemble of classification algorithms, which use trees as their base classifiers. They can use some of the data more than once when training and the other data may not be used at all. This makes it achieve more stability, classification accuracy, and makes it more robust when facing variations in input data. Since they are based on bagging, they are not sensitive to noise and over training [18].

D. Naïve Bayes

The Naïve Bayes Classifiers are based on statistics. They are based on the Bayes theorem. The Naïve Bayes classifiers can predict class membership probabilities (i.e. the probability that a given sample belongs to a certain class). The classifier is based on an assumption called the class conditional independence, which assumes that the effect of an attribute value on a given class is independent of the values of an attribute [19]. Naïve Bayes classifiers are linear classifiers that are simple yet very efficient. The assumption is that, features in a dataset are mutually dependent thus the adjective, naïve. Though the independence assumption is normally violated, Naïve Bayes classifiers perform very well even under unrealistic assumptions. Naïve Bayes classifiers can even outperform the most powerful alternatives especially for small size samples. They can perform poorly when the independence assumptions are violated and when they are dealing with non-linear classification problems [20].

The naïve Bayes classifier is mainly used in machine learning models when it comes to the issue of document classification. The Naïve Bayes classifier is linear, meaning that a line on the vector model can separate all of its data samples. The word 'naive' means that all features within the dataset are independent of one another. This naive assumption states that the value of any particular feature is unrelated to and does not depend on the value or presence of any/all other features, given the label [21]. The success of Naive Bayes in the presence of feature dependencies can be explained by the fact that optimality in terms of the classification error is not in any way related to the quality of the fit to a probability distribution such as the appropriateness of the independence assumption. An optimal classifier is obtained when the actual and estimated distributions agree on the most probable class [22]. The probability model for a classifier is a conditional model

$$P(cj|d) = p(cj|x1, x2, x3, x4....xn)\, P(cj) \quad (1)$$

In equation 1, x1, x2, x3, x4…xn are features or words of a document. Cj is a set of classes used in classification, p (cj|d) is a conditional probability and P (cj) is the prior probability of class c. If a feature has large values or if the number of features is large then it is difficult to calculate the probability, the model will then have to be manipulated by changing parameters and filtering some features. According to Narayanan et al. [23], the Naive Bayes includes a simplifying conditional independence assumption. For example, if there is a given class (positive and negative), the two words are conditionally independent of one another. The accuracy of text classification is not affected by this assumption [23].

E. Support Vector Machines

Vapnik [24] originally proposed the Support Vector Machine (SVM) classifier in 1995. It finds a maximal margin separating hyperplanes between two classes of data. There are non-linear extensions of the SVM. The SVM classifier is used to classify both linear and non-linear data using a margin. It is a margin based classifier which works by selecting the maximum margin. It separates the classes with a surface that maximizes the margin. Support vectors are the data points near to the margin. The hyperplanes are the decision boundaries. In SVM, the data is trained using the known labeled classes and then a model is built. Elements of training data generated during SVM learning module are support vectors. The model and the vectors are used to classify the data [24].

Intuitively, a good separation is achieved by the learned hyperplane that has the largest distance to the nearest training data points of any class (so-called functional margin), since in general, the larger the margin the lower the generalization error of the classifier. Support Vector Machines provide an easy to use interface to the world of SVMs. The major drawback with SVM is that it scales badly with the size of the data due to the kernel transformation and the quadratic optimization. Therefore, choosing correct kernel parameters is important for obtaining good results. Support Vector Machines are binary classifiers though they can be used for multi-class classification by two methods being the: one vs. all and the one vs. one. For the one vs. one, for k classes, $k\,(k-1)/2$ binary classifiers are trained. Each classifier is trained with a pair of classes from the original training set and a hyperplane is learned between classes. A voting scheme is used to make predictions. In one vs. all, only a single classifier is trained in a class by labeling examples as positive and negative. This requires the base classifiers to produce a real score for its decision other than just a label. Predictions are then made using these scores [25].

III. EXPERIMENTATION

The proposed method in this paper uses general public mood as an input attribute to the prediction model. The output of the model is one of the four defined classes from the Google profile of Moods state; kind, vital, alert and happy. The model uses three machine learning algorithms and compares their

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results. The mood was normalised between [+1, 0, -1] because moods can have positive, neutral and negative values.

A. Scope

The data that was used in this paper spread over twelve months, from January, 2015 to December, 2015. The sentiments were collected from Facebook using Discover Text crawler. This was data from an official Facebook page of a company listed under the domestic index on Botswana Stock Exchange. The historical stock prices were collected from Botswana stock Exchange. It was opening and closing stock price of that particular day.

B. Attributes Used

1. Historical Stock Price Data

The first attribute used as an input for the model is the historical closing index of Botswana Stock Exchange. The historical data was not made part of the model directly.

2. Public Mood

The performance of the stock market can be influenced by the moods and sentiments of investors. The stock market performance is driven by collective sentiments. Through social media we can be able to achieve this. In this paper, Facebook is used as a source of public sentiment.

C. Experimentation

1. Data Collection

Data was collected and pre-processed so that it can be in a form that is acceptable as input to the model. The Facebook posts and comments for each day were gathered and categorized as kind, vital, alert or happy. About 3000 instances were collected for twelve months (from January to December 2015). Out of these instances, 60% was used in training and the remaining 40% were included in the test data set.

2. Implementing Machine Learning Algorithms

All three machine-learning algorithms were separately applied on the data sets and measures of their accuracy were obtained on two main aspects: 10 Cross Validation and 60% Data Split. For the SVM algorithm the SMO implementation in WEKA was used. Accuracy in this case considers the overall effectiveness of the classifier [26].

IV. RESULTS AND DISCUSSIONS

1. Results Presentation

Table 1 depicts the accuracy results of the classifiers. The SVM classifier gave 83.3% results when demonstrated on cross validation and 80.0% when demonstrated on data split. Applying Naïve Bayes algorithm on cross validation and Data split gave the same results as SVM. The algorithm produced 83.3% accuracy on cross validation but 80% on the data split. The Random forest algorithm did not perform well with 66.0% on cross validation and 20.0% accuracy on data split.

TABLE I. RESULTS FOR THE ACCURACY METRIC

Algorithm	**Accuracy**	
	10 Cross Validation	***60% Data Split***
Random Forest	66.0%	20.0%
Naïve Bayes	83.3%	80.0%
SVM	83.3%	80.0%

Table II on the other hand, depicts precision results. Precision is the measure of results relevancy. It is the agreement between the data labels and positive labels given by the classifier. Good precision means less false negatives [27] as defined in Formula 2.

$$P = \frac{Tp}{Tp+Fp} \quad (2)$$

Precision is the number of true positives over the number of true positives plus the number of false positives [27].

TABLE II. RESULTS FOR THE PRECISION METRIC

Algorithm	**Precision**	
	10 Cross Validation	***60% Data Split***
Random Forest	0.708	0.100
Naïve Bayes	0.900	0.867
SVM	0.900	0.867

From Table II, it is clear that the Naïve Bayes and SVM classifiers perform better than the Random Forest classifier in terms of precision in both test methods. The Naïve Bayes model gave 0.900 when demonstrated on cross validation and 0.867 when demonstrated on data split. The SVM algorithm produced 0.900 precision on cross validation but 0.867 on the data split. The Random forest algorithm produced 0.708 on cross validation and 0.100 precision on data split.

Recall is the measure of how many truly relevant results are returned. It is the effectiveness of the classifier to identify positive labels. Good recall means less false negatives [27].

$$R = \frac{Tp}{Tp+Fn} \quad (3)$$

Recall as depicted in Formula 3, is the number of true positives over the number of true positives plus the number of true negatives [27].

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TABLE III. RESULTS FOR THE RECALL METRIC

Algorithm	Recall	
	10 Cross Validation	*60% Data Split*
Random Forest	0.667	0.200
Naïve Bayes	0.833	0.800
SVM	0.833	0.800

From Table III, Naïve Bayes and SVM classifiers perform better than the Random Forest classifier in terms of recall in both test methods. The Naïve Bayes model gave 0.833 when demonstrated on cross validation and 0.800 when demonstrated on data split. The SVM algorithm produced 0.833 on cross validation but 0.800 on the data split. The Random forest algorithm produced 0.667 on cross validation and 0.200 recall on data split.

The ROC is a graphical plot for organising, visualising and selecting classifiers based on performance. It is created by plotting true positive rate against false positive rate. According to literature an optimal classifier would be more than 0.5 and not more than 1.00 [26]

TABLE IV. RESULTS FOR THE ROC METRIC

Algorithm	ROC	
	10 Cross Validation	*60% Data Split*
Random Forest	0.907	0.867
Naïve Bayes	1.00	0.867
SVM	0.935	0.867

From Table IV, the Naïve Bayes model gave 1.00 when demonstrated on cross validation and 0.867 when demonstrated on data split. The SVM algorithm produced 0.935 ROC metric on cross validation but 0.867 on the data split. The Random forest algorithm produced 0.907 on cross validation and 0.867 on data split. What is more interesting about this results is that for 60% data split all the three algorithms had the same results. Kappa compares observed accuracy with expected accuracy. Kappa of 1 indicates a perfect agreement and of 0 indicates agreement by chance [27]. The formula for calculating Kappa statistic is depicted in Formula 4.

$$K=\frac{P(A)-P(E)}{1-P(E)} \quad (4)$$

TABLE V. RESULTS FOR THE KAPPA METRIC

Algorithm	Kappa	
	10 Cross Validation	*60% Data Split*
Random Forest	0.556	0.1304
Naïve Bayes	0.788	0.6875
SVM	0.788	0.6875

From Table V, the Naïve Bayes model gave 0.778 when demonstrated on cross validation and 0.6875 when demonstrated on data split. The SVM algorithm produced 0.788 kappa on cross validation but 0.6875 on the data split. The Random forest algorithm produced 0.556 on cross validation and 0.1304 accuracy on data split.

Mean Absolute Error (MAE) is how close predictions are to the eventual outcomes as depicted in Formula 5 [27].

Average of absolute errors $|e_1| = |f_1 - y_1|$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|f_1 - y_1| = \frac{1}{n}\sum_{i=1}^{n}|e_i| \quad (5)$$

TABLE VI. RESULTS FOR THE MAE METRIC

Algorithm	Mean Absolute Error	
	10 Cross Validation	*60% Data Split*
Random Forest	0.2267	0.294
Naïve Bayes	0.0813	0.1501
SVM	0.2639	0.2667

From Table VI, the Naïve Bayes model gave 0.0813 when demonstrated on cross validation and 0.1501 when demonstrated on data split. The SVM algorithm produced 0.2639 on cross validation but 0.2667 on the data split. The Random forest algorithm produced 0.2267 on cross validation and 0.294 accuracy on data split.

2. *Performance Comparison of the Algorithms*

The results of all three algorithms over cross validation and data split are compared on Table VII. It is evident from the comparison table that the SVM and Naïve Bayes performed best on cross validation while the Random Forest algorithm did not do well on both cross validation and data split. Conventionally, the verification of the model was done using the Mean Absolute Error (MAE). Therefore, Naïve Bayes seems to be more efficient in predicting the market performance because it had less error margins. While verifying the model's variants, Naïve Bayes outperforms the remaining two algorithms.

TABLE VII. COMPARISON OF MACHINE LEARNING ALGORITHMS

Algorithm	Accuracy	
	10 Cross-Validation	*60% Data Split*
Random Forest	66.0%	20.0%
Naïve Bayes	83.3%	80.0%
SVM	83.3%	80.0%

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V. CONCLUSION

In this paper, we apply three different algorithms of machine learning to forecast movement direction of Botswana Stock Index from Botswana stock market. In this paper we presented a machine learning methodology for stock price prediction. Two algorithms, being the SVM and the Naïve Bayes produce good prediction with hit rate more than 80%. The SVM and Naïve Bayes outperformed the Random Forest algorithm. Overall, the results of this study confirm that machine-learning techniques are capable of predicting the stock market performance. Botswana Stock Market does follow a behaviour that can be predicted using machine learning techniques. The Naïve Bayes algorithm of machine learning predicted 83.3% correct market performance. Even with the lack of resources and unavailability of data for the market, the model was able to predict the performance of the model to a good extent showing that BSE can be predicted using machine learning techniques. Therefore, SVM and Naïve Bayes are recommended for forecasters of stock index movement and the better model, SVM, is more preferred since it had less error margins. We have presented a machine learning approach toward predicting a company's financial performance using Facebook posts and comments that are related to them from Facebook. Three different classification algorithms (Random forest, Naive Bays and SVM) are used to find the best model for prediction. Our experiment shows that with an accuracy of 83.3% Naïve Bayes can predict whether a company will over-perform or under perform.

VI. RECOMMENDATION

This research can be extended by including more companies to check if the same prediction accuracy will still apply. Twitter can also be used for the same analysis where companies are more active in Twitter than Facebook. Other media forums other than Twitter and Facebook can be used to check the optimal accuracy since those forums may reflect the companies much better. It has been shown in this paper the ability of the SVM, Random Forest and the Naïve Bayes to predict the closing stock price of a selected company. As a result some recommendations can be made that there is need to evaluate the performance of these algorithms over a larger set of data; the need of identifying other variables apart from social media data which also might be used in determining the stock prices.

REFERENCES

[1] V. Shahpazov, B. V. Velev, and A. L. Doukovska, "Design and application of ANN for predicting the values of indexes on the Bulgarian stock market," Signal processing symposium, 2013.

[2] S.A. Mollah, "Testing the Weak Form market Efficiency in Emerging Markets: Evidence from Botswana Stock Exchange," International Journal Of Theoretical and Applied Finance, vol. 10, no. 6, pp. 1077-1094, 2007.

[3] I. Radikoko, "Testing the Random Walk behaviour of Botswana's Equity Returns," Journal Of Business Theory and Practice, p. 84, 2014.

[4] E. F. Fama and M. E. Blume, "Filter rules and stock market trading," Journal of Business, vol. 39, no. 1, pp. 226-241, 1966.

[5] O. Chiwira and B. Muyambira, "A Test of Weak Form Efficiency for Botswana Stock Exchange," British Journal of Economics, Management and Trade, vol. 2, no. 2, pp. 83-91, 2012.

[6] W. Brock, J. Lakonishok, and B. Lebaron, "Simple Technical Trading rules and the Stochastic Properties of Stock returns," Journal of Finance, vol. 47, no. 5, pp. 1731-1764, 1992.

[7] M. C. Jensen and G. A. Benington, "Random walks and technical theories: some additional evidence," Journal of Finance, vol. 2, no. 25, pp. 469-482, 1970.

[8] J. Fang, Y. Qin, and B. Jacobsen, "Technical market indicators: An overview," Journal of Behavioural and Experimental Science, vol. 4, pp. 25-56, 2014.

[9] H. Achelis, Technical Analysis from A-Z.: Vision Books, 2000.

[10] B. G. Malkiel, "The Efficient Market Hypothesis and its Critics, "Journal of Economic perspectives, vol. 17, no. 1, pp. 59-82, 2003.

[11] J. Van Horne and G. G. Parker, "The Random Walk Theory: Empirical Test," Financial Analysis Journal, 1967.

[12] A S Suresh, "A study on fundamental and technical analysis," International Journal of marketing, financial services and management research, vol. 2, no. 5, May 2013.

[13] J Grossman S and E Stiglitz J, "On the impossibilities of informationally efficient markets," The American economic review, vol. 10, no. 3, pp. 393-408, 1980.

[14] S. Poshakwale, "Evidence on Weak Form Efficiency and Day of the Week Effect in the Indiana Stock Market," Finance India, no. 3, pp. 605-616, 1996.

[15] A. Liaw and M. Wiener, "classification and regression by random forest," vol. 2, no. 3, December 2002.

[16] V. Svetnik et al., "Random Forest: A Classification and Regression Tool for Compound Classification and QSAR Modelling," Journal of Chemical Information and Computer Sciences, vol. 43, no. 6, pp. 1947-1958, November 2003.

[17] V. F. Rondiguez-Galiano, B. Ghimere, J. Rogan, M. Chica-Olmo, and J. P. Rigol-Sanchez, "An Assessment of the effectiveness of a random forest classification for land classification," Journal of photogrammetry and remote sensing, pp. 93-104, 2012.

[18] K. M. Leung, "Naive Bayes Classifier," Polytechnic University, Department of Computer Science, 2007.

[19] S. Raschka, Naive Bayes and Text Classification: Introduction and Theory, 2014.

[20] S.C. Gangireddy, "Supervised Learning for Multi-Domain Text Class," San Jose State University, San Jose, 2016.

[21] I. Rish, An Empirical Study of the Naive Bayes Classifier, Unpublished

[22] V. Narayanan, L. Arora, and A. Bhatia, "Fast and Accurate Sentiment Classification using an Enhanced Naive Bayes Model," India Institute of Technology, Varanasi, India.

[23] N.Christianini and J. Shawe-Taylor, "AN Introduction to Support Vector Machines and other Kernel Based Learning Methods," Cambridge University Press, United Kingdom, 1st Edition 2010.

[24] S.Bhatti, "Multi Class Sentiment Analysis on Movie Reviews," University of Illinois, Unpublished

[25] T. Fawcett, "An Introduction to ROC Analysis," Pattern recognition Letters, vol. 27, pp. 861-874, 006.

[26] C. M. Bishop, "Pattern Recognition and machine learning," Information Science and Statistics.

[27] M. Sokolova and G. Lapalme, "A systematic analysis of performance measures for classification tasks," Information processing and Management, vol. 45, no. 4, pp. 427-437, July 2009

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An Exploration of Navigation Technologies for Visually Challenged Students at a University

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***Abstract*— Education is an important aspect of individual life and key to the region's development. Education of disabled people has long been regarded as an area of concern. Visually disabled people struggle with a myriad of challenges for education. These challenges can be attributed to the absence of an enabling environment. The environment should provide them with proper facilities to get the education and also tools to navigate without any discomfort. Navigation in an unfamiliar environment is the common problem faced by visually impaired people.**

Earlier navigation in an outdoor environment was a challenge for visually disabled. With introduction of technologies like GPS (Global positioning system) it is no longer a challenging task. A GPS voice enabled smart phone will be able to do turn-by-turn navigation. A small application, Google Maps[2] with GPS Tracker on your mobile uploads your GPS position periodically over either General Packet Radio Service (GPRS) or 3G, which updates your position on a moving Google Map. GPS locates and identifies major landmarks encountered by the users and typically do not work indoors. There should be a technology to overcome this problem of indoor navigation for visually impaired. This paper studies the different technologies available for outdoor navigation, the pros and cons of each technology and proposes an ideal/best fit solution for indoor navigation in an environment like a University.

Keywords*— *Global positioning system (GPS), General Packet Radio Service (GPRS), wireless fidelity (Wi-Fi)

I. INTRODUCTION (*HEADING 1*)

Education is an important aspect of individual life and key to the region's development. Educating disabled people has long been regarded as an area of concern. According to world health organization (WHO) it is estimated that 19 million children are visually impaired. Among them 12 million children are visually impaired due to refractive errors, a condition that could be easily diagnosed and corrected and 1.4 million are irreversibly blind for the rest of their lives and need visual rehabilitation interventions for a full psychological and personal development. [1]

Securing the future of the visually disabled is a critical challenge for the society. Providing higher education can serve as an important gateway to secure the future of disabled as it creates valuable employment opportunities. In spite of hundreds of universities, thousands of colleges the number of low vision students getting education has not been on par growth. The lack of enrollment can be attributed to many factors like lack of access technology, lack of encouragement and the major inhibition can be the inability to navigate the physical campus. Navigation in an unfamiliar environment is the common problem faced by visually impaired people. Existing systems do not provide active guidance or are bulky, expensive and hence are not socially apt.

Earlier navigation on roads for blind without human assistance was a challenge, but with introduction of technologies like GPS it's no longer a challenging task. A GPS voice enabled smart phone will be able to do turn-by-turn navigation. Google Maps with GPS Tracker shows your physical position in real-time on a moving Google Map. A small application on your mobile uploads your GPS position periodically over either GPRS or 3G, which updates your position on a moving Google Map. GPS is a global positioning system [2]. Using a GPS it is easy to navigate the outdoor environments but the short coming is it locates and identifies major landmarks encountered by the users and typically they do not work indoors. GPS is suitable for outdoor navigation only, due to the need for line of sight access to satellites. There should be technology to overcome this problem of indoor navigation for visually impaired. The present paper focuses on the challenges of indoor navigation and proposes a solution.

Objectives of the paper are

- To study the existing literature on outdoor and indoor navigation technologies for blind.
- Identify how the outdoor navigation is different from indoor navigation.
- Propose a solution for indoor navigation which is similar to outdoor navigation.

II. LITERATURE SURVEY

There are many existing assistive tools available which supports a visually disabled person to navigate the physical campus like, Long cane, which is a walking tool used to support independent travel or to identify for others that the person is visually challenged. Another tool is the digital talking compass which is a directional device that announces the directions through an audio output. [3] But these technologies don't suffice the requirement. A more advanced technology and tools should be provided to assist the blind.

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The proposed model for Indoor navigation for university campus has come from the extensive study carried out on existing literature on outdoor/outdoor navigation technologies. Several studies were carried out on outdoor navigation for visually disabled. Development of a navigation tool for blind can be divided into two sub problems, location detection and object detection. Different studies and experiments were conducted using different technologies to find a solution for these problems. Some of them are outlined in Table 1 and Table 2.

A. Outdoor Navigation

For outdoor navigation Google developed a mobile application called Google Maps Navigation which works on Android/IOS OS and integrates Google Maps. The application provides turn-by-turn voice based instructions to reach the destination provided the mobile has an internet connection. The mobile application uploads your GPS position periodically over either GPRS or 3G, which updates your position on a moving Google Map. [2] GPS is a global positioning system. Figure1 explains the working of GPS. [4]

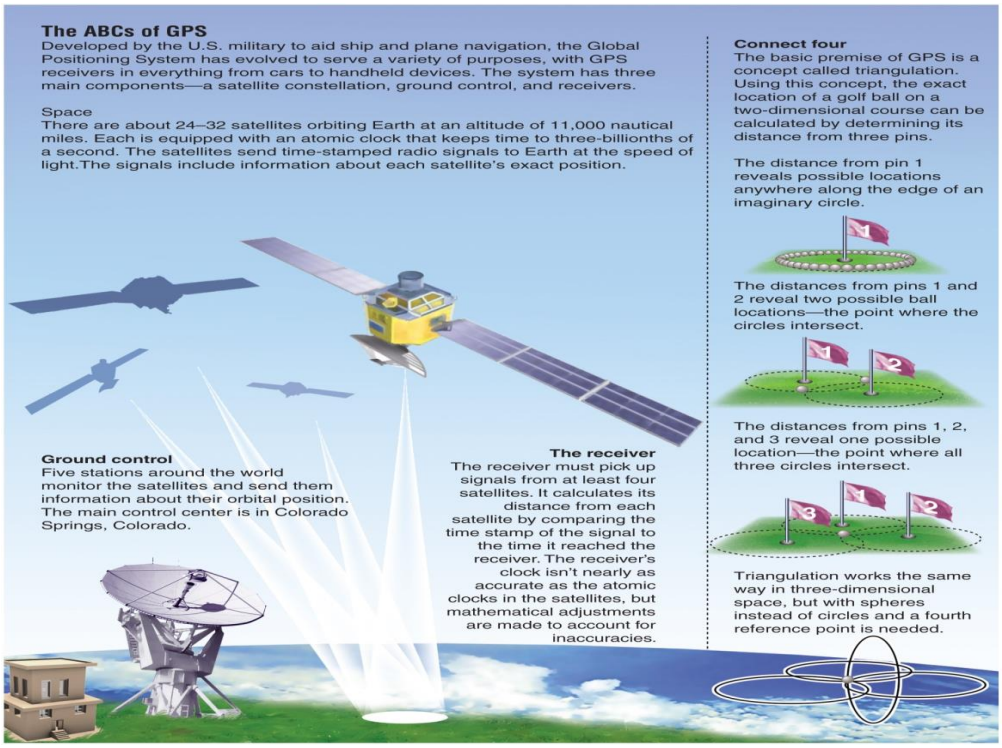

Fig 1: How GPS works
Adapted from: [4]

III. METHODOLOGY

Developing an Indoor Navigation System involves three steps,

- First step is to develop a web application like Google maps which works on an android phone for Indoor environment. It should read and analyze the maps of the Indoor locations like building and malls.
- Second step is developing and linking location recognition system like GPS to this Android application
- Third step is to develop an object sensing/detection system which should be attached to the user.

Integration of these three will aid the blind to navigate in an indoor environment. The system should be able to do the landmark identification with path based guidance in the indoor environments like Universities, Malls, and Hospitals.

The proposed system is a more advanced system which can be used to navigate within the university. For location detection and path navigation, the proposed system uses two main components, Hand Unit (Android Mobile which has the voice based user module installed. It acts as the interface) and Wall Units, WIFI Access points for getting the location coordinates..

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For obstacle identification, A walking cane with ultrasonic sensors will be used.

The University campus will span acres of land and consists of many buildings as shown in fig 2. The difference between outdoor and indoor navigation is that in indoor navigation there will be static obstacles like gates, walls, dustbins and stairs. The visually disabled should keep in mind all these obstacles and navigate. The system should facilitate with proper information about the obstacles and also the landmarks in each building. Tactile Feedback (Buzzer or vibrator also audio output) is ideal solution to alert about obstacles. The system uses the floor maps for navigation of building

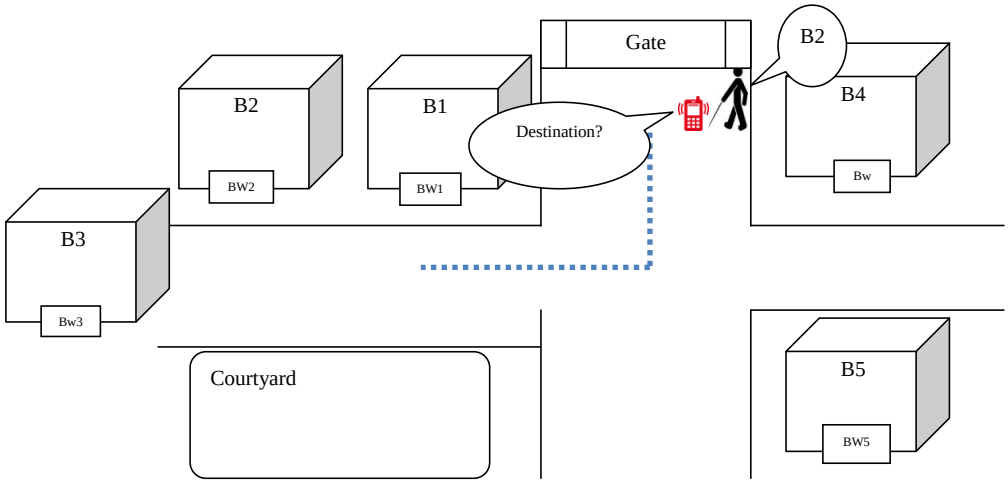

Fig 2: Campus View of the University

The user crosses the Entrance gate and the application in the handheld device will load blue print of the whole campus. The maps of the campus are stored as AutoCAD files in a spatial database. The DB should be integrated with the mobile application. This integration helps to find the way to the destination with turn-by-turn spoken directions as you move along the map also disclosing encountered landmarks information.

Wall unit (Wi-Fi access points) is fixed to all the main locations of the campus. Calculation of location is done using the received signal strength from Wi-Fi access points (a minimum of 3) to wireless access device. Each building will have wall units fixed. The units are placed such that there is no interference between the signals sent by two units. A wall unit is the WIFI access point which will locate the position of the handheld receiver by using a triangulation method similar to GPS.

Generally, people observe, follow and keep track of the landmarks while travelling an unknown place. When people navigate through the same place for the second time, they will keep track of the landmarks and ensure that the route is correct. If landmarks are not seen, then it can be understood that the chosen path is wrong. For a blind person it is not feasible to see observe and follow the landmarks while travelling so a voice based application should prompt the landmarks to ensure he is on right path.

The person navigates the campus with the assistance of the hand unit which will prompt voice based messages about the landmarks that are being crossed. After entering the destination building, the hand unit will be loaded with the blue print of the plan of each floor. That floor map is opened along with the landmarks of that floor. Whenever the person crosses that landmark the mobile will give a voice based prompt that he is crossing that land mark.

Person's location coordinates are calculated by the received signal strength from WIFI access point using triangulation method similar to GPS [5]. After receiving the location information from the access point the application should be able to find the nearest land mark and would be able to identify the distance from present location to the nearest landmark and should give the audio output of that information.

The application in the hand unit will guide the students in situations where they have queries in reaching the destination building. All the FAQ or scenarios will be saved in the DB. The application will mine the answers for the queries from the DB. Sample Voice based questions asked by the Application:

Scenario:

Q: Where is the student library?

S: In Building 1

Q: How to go building 1

S: Where are you?

Q: I m near main gate

S: Go straight 10 steps, then turn to your right you will be getting a signal from Building 1 Wall unit.

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The System starts by establishing the connection with Main Entrance Unit. The voice will be enabled and there is a possibility if series of voice based communicatons between the user and mobile application. once the user decides his destination tha application will periodically get the user to confirm the presence of landmarks, the buildings he will cross until, he reaches the destination building. After he reaches his destination building, the particular building wall unit will help in reaching the final destination (the particular room or department he wants to go in that particular building. If you are in one building and want to know about something in another department then application will give audio commands and assist you in knowing where it is and how to go back to the landmark points. These are considered as FAQ and saved in a DB. The FAQ DB will be updated with new queries periodically. Once the person reaches the destination building the wall units will navigate the person to the destination place. For obstacle identification, ultrasonic sensors are attached to the walking stick of the blind person. Ultrasonic technology detects obstacles and other objects that are located in front of the user's path produces tones which can be heard by the person.

IV. Limitations and Future Scope:

Proposed system will work with university whose layout is saved in DB. It will work with a different university. Future system can be made as a dynamic system, which can take a blueprint of any building with landmarks marked and give the voice based directions to the person. The person speed is fixed in the present system. An average walking speed of the blind person is taken as fixed in the present system. New technologies implemented in the mobiles are able to capture the acceleration of the person which will be introduced into the application in later versions. The scope of the system can be increased and can be made as an ideal system which will take the blue print of buildings and gives voice based instructions to navigate that building to the user.

The proposed system is restricted to only one route from one source to one destination. There is nothing like shortest route or longest route. There will be only one possible route between the source and destination. The average step length and average speed of blind person is considered be a constant number and work on it.

TABLE I. Outdoor Navigation Applications

Application Description	Location Detection Technology	Obstacle Detection Technology	Special Features	citation
Capstone research project is a prototype using technologies like SONAR, GPS, Cloud communication, light sensing and pulse sensing.	Skylab GPS module and WIFI	SONAR sensors (buzzer)	Cost effective, Interoperable	[6]
A navigation system that uses GPS, image database like Google street view image processing and shape recognition algortihms	GPS and Image processing	Shape recognition algorithm: RBRC (Retrieval Based on Rotation-invariant Classification).	Texture and Colour analysis of scene	[7]
Tyflos system uses a pair of glasses, a vision cameras mounted on the glasses, a laser range scanner, a microphone, a portable computer, ear speaker, and the communication system	GPS	Tyflos system carries two vision cameras and captures images from the surrounding 3-D environment, then it converts these images into verbal descriptions for each image into a verbal communication with the user	Laser Range scanner attached to vision cameras to take 3D images.	[8]
A Navigation assistant using RFID technology and ultrasonic sensors	The RFID reader matches with the information specified to that ID and a voice signal is generated. Wireless RF links is placed in the Bluetooth device/ headphone for voice guidance	ultrasonic Sensor Unit interfaced with microcontroller which is inter-linked to a vibrator that would be activated when nearing obstacles.	Reliable system for indoor and outdoor way finding and proximity sensing for visually impaired	[9]
Drishti, An Integrated Indoor/Outdoor Navigation System uses a precise position measurement system, a wireless connection, a wearable computer, and a vocal communication interface.	DGPS differential global positioning systems (outdoor).	The user can get vocal prompts to avoid possible obstacles and step-by-step walking guidance to move about in an indoor environment.	It can be used for both indoors and outdoors with in-door location measurements accuracy of 22 cm.	[10]
A wearable portable electronic travel aid, Bluetooth headset to receive audio inputs, five HC-SR04 ultrasonic sensors, Raspberry Pi 2 computer that controls the ultrasonic sensors and translates the data from their output into commands heard by the user through Bluetooth headset.	GPS	HC-SR04 ultrasonic sensor. ultrasonic sensors to survey the scene, the trigger and echo pins are responsible giving distance measurements that are read by the sensor.	low-powered, easily portable, low-cost, and still effective	[11]
Walking Assistant System with Vibrotactile Indication and Voice Prompts	GPS and speech recognition modules are used for navigation. wireless headset to	Kinect cameras and ultrasonic sensors, vibrating stimulus actuated by vibration belt		[12]

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	receive the audio			
Silicon eyes: GPS: GSM based navigation assistant GSM module for sending SMS of location coordinates to another phone for help in emergency.	GPS	SONAR	System allows blind people to enter notes and control device operation via Braille capacitive touch keypad provides Object color information using 24-bit color sensor.	[13]

TABLE II. INDOOR NAVIGATION APPLICATIONS

Application Description	Location Detection Technology	Obstacle Detection Technology	Special Features	Citation
RoboCart for navigation in grocery stores	Laser range finding and RFID tags, RFID reader, Camera	Laptop with a path planner stores the Declarative knowledge of the environment which gives instructions to avoid obstacles	Audio guided, Macro navigation in a store	[14]
Indoor self positioning systems which uses RFID, Bluetooth , FLC (flourescent light communication), a photosensor on users shoulder and PDA personal digital assistant.	A photo sensor put on the user's shoulder catches the signals from the fluorescent lights and the PDA will transmit the information to the blind person. RFID instruments are used to augment the FLC model for more precise location data	NA	Audio guided, Knowing precise details of their destination by visually impaired and also general population.	[15]
RFID based navigation assistant	RFID reader module with an integrated ZigBee transceiver for transmitting the tag's information.	NA	Feasible and reliable	[16]
Drishti: An Integrated Indoor/Outdoor Navigation System uses a precise position measurement system, a wireless connection, a wearable computer, and a vocal communication interface.	An OEM ultrasound positioning system is used to provide precise indoor location measurements (indoors).	The user can get vocal prompts to avoid possible obstacles and step-by-step walking guidance to move about in an indoor environment.	Audio guided , It can be used for both indoors and outdoors with in-door location measurements accuracy of 22 cm.	[10]
A compact portable navigation system (mobile push cart) for navigation in home that integrates wireless communication technologies, path planning, sensors and other technologies.	wireless mesh network, ZigBee based localization engine technique that continuously updates the server with the user location	proximity sensors enable detaction of obstacles	A digital compass located in the push mobile cart enables the system to identify the user orientation.	[17]
A pair of glasses with RGB camera, ultrasonic sensors, radio frequency signal receivers, accelerometer, gyroscope, magnetometer, voice recognition device, microphone, and bone conduction headset to naviagate in indoors	Mapping of Radio frequency markers and visual markers using pattern recognition algorithms	ultrasonic perception of barriers	Audio guided, low cost, wearable device which chooses optimal route while navigating	[18]

References

[1] http://www.who.int/mediacentre/factsheets/fs282/en/
[2] https://en.wikipedia.org/wiki/Google_Maps_Navigation.
[3] Assessing Students' Needs for Assistive Technology (ASNAT), 5th ed., Milton, June 2009.
[4] Brian K. Williams, Stacey Sawyer, "Communications, Networks, & Cyberthreats", in Using Information Technology: A Practical Introduction to Computers and Communications, 5th ed., McGraw-Hill Global Education Holdings, LLC, USA.
[5] Commercial software EPE 2.1 available from Ekahau, 2006 (http://www.ekahau.com/).
[6] Sherin Gilson, Sagar Gohil, Faisal Khan, Vishal Nagaonkar, A Wireless Navigation System For the Visually Impaired., 2015.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

[7] A. DiLillo, A. Daptardar, G. Motta, K. Thomas, J. Storer "Applications of compression to content based image retrieval and object recognition", in *proc. International Conference on Data Compression, Communication, and Processing*, CPP–11, 2011, pp. 179–189
[8] N. G. Bourbakis, D. Kavraki, "Tyflos—An intelligent assistant for navigation of visually impaired people", *Proc. IEEE Symp*. BIBE-01, 2001, pp. 230-235.
[9] M. R. B. Kumar and C. M. Sibu, "Design for visually impaired to work at industry using rfid technol", in *Proc. International conference on Electr. Design, Computer Networks Automated Verification* (EDCAV) Int. Conf. , Jan 2015, pp. 29–33.
[10] Lisa Ran, Sumi Helal, Steve Moore, "Drishti: an integrated indoor/outdoor blind navigation system and service", in Proc. *2nd IEEE Annual Conference on Pervasive Computing and Communications*, PerCom, *2004*, pp. 23-30
[11] Kevin Laubhan, Michael Trent, Blain Root "A Wearable Portable Electronic Travel Aid for Blind", *Proc. of International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, March 2016.
[12] Ni D, Wang L, Ding Y, Zhang J, Song A, Wu J , "The design and implementation of a walking assistant system with vibrotactile indication and voice prompt for the visually impaired". *In: IEEE conference on robotics and biomimetics (ROBIO)*, pp. 2721–2726, 2013.
[13] B. R. Prudhvi, R. Bagani, "Silicon eyes: GPS-GSM based navigation assistant for visually impaired using capacitive touch braille keypad and smart SMS facility", *Proc. World Congr. Comput. Inform. Technol*., pp. 1-3, Jun. 22–24, 2013.
[14] Kulyukin, V., Gharpure, C., and Nicholson, J. "RoboCart: Toward robot-assisted navigation of grocery stores by the visually impaired" *in Proc. of the IEEE/RSJ International Conference on Intelligent Systems and Robots (IROS-2005)*, Edmonton, Alberta, Canada 2005.
[15] V. Kulyukin, C. Gharpure, C. Pentico, "Robots as interfaces to haptic and locomotor spaces", *in Proc. ACM/IEEE Int. Conf. Hum.–Robot Interact.*, pp. 325-331, 2007.
[16]Murad, M., Rehman, A., Shah, A.A., Ullah, S., Fahad, M., Yahya, K.M., "RFAIDE—an RFID based navigation and object recognition assistant for visually impaired people",. *In: 7th International Conference on Emerging Technologies (ICET)*, Islamabad, Pakistan, pp. 1–4 (2011)
[17] Shamsi, M. A.; Al-Qutayri, M.; Jeedella, J.. "Blind assistant navigation system", *in 1st Middle East Conference on Biomedical Engineering (MECBME)*. (2011).
[18] W. C. S.S. Simões, V. F. de Lucena "Hybrid Indoor Navigation As sistant for Visually Impaired People Based on Fusion of Proximity Method and Pattern Recognition Algorithm", *In Proc. oF IEEE 6th International Conference on Consumer Electronics (ICCE-Berlin)*, Berlin, 2016

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Influence of the thermal radiation on the bioconvection of gyrotactic microorganism contains nanofluid

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Abstract— **Microorganisms play a vital role to understand the ecological system and so it is very important to understand the behavior of microorganism due to different parameters. In the present paper, we implement a mathematical model to understand the influence of the thermal radiation on the gyrotactic microorganism imbedded in water based nanofluid flow over a wedge. The Brownian motion and thermoforetic effects take place due to nanofluid. The governing equations based on the conservation of mass, momentum, energy, nanoparticle concentration and concentration of gyrotactic micro-organism are simplified to a set of coupled, non-linear ordinary differential equations using the similarity transformations. The transformed equations are then solved comfortably using a numerical method namely fourth order Runge-Kutta method. The numerical results accomplished in thepresent investigation are validated and are in good agreement with the prevously published results of some noteworthy researchers found in literature. The important outcomes of the present study is that the skin friction and local Nusselt number are enhanced during the suction while the local Sherwood number and local density of motile microorganism decrease due to suction. Thermal radiation reduces the heat transfer rate near the surface, while it increases the skin friction, concentration of the nanoparticle and concentration of the gyrotactic microorganism near the surface.**

Keywords— Bioconvection; Gyrotactic microorganism; thermal radiation; nanofluid; wedge.

Introduction

Microorganisms are denser than the cell fluid and so they easily move or able to move without any external propulsion. An overturning instability caused by the microorganisms swimming to the upper surface of a fluid which has a lower density to that of the microorganisms and it forms bioconvection. The first detailed observations of bioconvection were discussed by Wager [1] but it was taken up seriously after the work of Platt [2], who invented the term `bioconvection'. Pedley et al. [3] have developed a mathematical model on the swimming microorganisms which are contained in suspension of infinite depth. The work extended by Hill et al. [4] for a suspension of the finite depth.

A combination of a nanofluid and bioconvection is attractive due to its application on microfluidic devices and bio-chips. A mathematical model on bioconvection in suspension in a water based nanofluid has been developed by Kuznetsov and Avramenko [5]. Shaw et al. [6] have discussed the nature of bioconvection in a non-Darcy porous medium saturated with nanofluid in the presence of gyrotactic microorganism. Later, Shaw et al. [7] extended their work by considering the influence of magnetic field, Soret effect on bioconvection.
Radiation is quite significant for the microorganisms since at elevated levels, radiation can have a range of harmful effects on microorganisms. Radiation on microorganisms has been used in municipal wastewater sludge treatment mainly by UV and gamma ray [8], consider the effects on ecosystem [9]. In many laboratory and experiments, radiation is used to detect microorganisms [10]. El-Registan et al. [11] studied the effect and functions of microorganism cultures oxidative stress caused by irradiation. They showed that biological systems are substantially different in their sensitivity to radiation that caused a substantial but not completely lethal effect. Microorganism activation by UV and ionizing radiation has been shown by [12]. Relative resistance of microorganisms to different kinds of radiation has been discussed by several researchers [13, 14].

Bhattyacharya et al. [15] have studied the boundary layer flow of nanofluid over a stretching sheet. In the present study, we have developed a mathematical model on the stagnation point flow past a stretching / shrinking wedge saturated in a suspension nanofluid containing gyrotactic microorganisms and water as base fluid. The influence of the suction / injection, magnetic field and angle of the wedge on the bioconvection have been presented and discussed through graphs and tables.

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Mathematical Formulations

We considered the Cartesian coordinate system (*x*, *y*) to define the axis of the wedge surface. x and y –axis are defined along the wedge surface and normal to the wedge surface, respectively. The stretching / shrinking velocity of the surface is linear and defined as $u_w(x) = U_w x$, where U_w is a constant, for stretching surface U_w is non-zero positive while for shrinking sheet it is non-zero negative. It is static when $U_w = 0$. Similarly, we have considered the ambient fluid moves linearly following the relation $u_e(x) = U_\infty x$, where U_∞ is a constant. Utilizing the Oberbeck-Boussinesq approximation, the continuity and momentum equation of the boundary layer flow can be written as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{2.1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = u_e\frac{du_e}{dx} + \nu\frac{\partial^2 u}{\partial y^2} + g\beta_0(T - T_\infty)\sin\frac{\Omega}{2}, \tag{2.2}$$

where the velocity components of the nanofluid defined by *u* and *v* along the *x*-axis and *y*-axis, respectively, viscosity of the fluid by μ, acceleration due to gravity by *g* , temperature by *T* , volumetric thermal expansion coefficient of the base fluid, the ambient temperature and the wedge angle defined by β_0 , T_∞ and Ω , respectively.

The thermal energy equation is written as

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha_m\frac{\partial^2 T}{\partial y^2} + \tau D_B\frac{\partial T}{\partial \bar{y}}\frac{\partial C}{\partial \bar{y}} + \frac{\tau D_T}{T_\infty}\left(\frac{\partial \bar{T}}{\partial \bar{y}}\right)^2 + \frac{16\sigma T_\infty^3\sigma}{3k}\frac{\partial^2 T}{\partial y^2}, \tag{2.3}$$

where, the Brownian and thermophoretic diffusion coefficient are defined as D_B and D_T , respectively, α_m is the effective thermal diffusivity of the porous medium and $\tau = (\rho c)_p / (\rho c)_f$, where $(\rho c)_p$ and $(\rho c)_f$ are the volumetric heat capacities for nanoparticle material and fluid, respectively.

The solute concentration equation is written as

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}, \tag{2.4}$$

While, the equation for the concentration of gyrotactic microorganism is defined as

$$u\frac{\partial n}{\partial x} + v\frac{\partial n}{\partial y} + \frac{\partial}{\partial y}\left(n\frac{bW_c}{\Delta C}\frac{\partial C}{\partial y}\right) = D_n\frac{\partial^2 n}{\partial y^2}, \tag{2.5}$$

where $\Delta C = C_w - C_\infty$ represents the characteristic nanoparticle volume fraction respectively, and C_w and C_∞ are related to the nanoparticle concentration at the wall and the ambient concentration of nanoparticle. Other parameters *b* and W_c are the chemotaxis constant and the maximum cell swimming speed, respectively. The product bW_c is assumed to be constant.

The corresponding boundary conditions are

$$\begin{aligned} &v = v_0, u = u_w(x) = U_w x, T = T_w, C = C_w, \\ &\qquad n = n_w \text{ at } y = 0, \\ &u = u_e(x) = U_\infty x, T = T_\infty, C = C_\infty, \\ &\qquad n = n_\infty \text{ as } y \to y_\infty \end{aligned} \tag{2.6}$$

where n_w is the density of motile microorganism at the plate surface. The ambient values of the density of motile microorganism are denoted by n_∞. We introducing the stream function ψ such that $u = \partial\psi/\partial y$ and $v = -\partial\psi/\partial x$ and applying the following similarity transformations

$$\begin{aligned} &\psi = \sqrt{U_\infty \nu}\, x f(\eta), \eta = \sqrt{\frac{U_\infty}{\nu}}\, y, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \\ &\phi(\eta) = \frac{C - C_\infty}{\Delta C}, \chi(\eta) = \frac{n - n_\infty}{\Delta n}, \end{aligned} \tag{2.7}$$

where $\Delta n = n_w - n_\infty$ .Governing equations after using the above mentioned similarity transformation is written as

$$f''' + ff'' + 1 - f'^2 + M\theta\sin\left(\frac{\Omega}{2}\right) = 0, \tag{2.8}$$

$$(1+\gamma)\theta'' + Pr\left(f\theta' + Nb\theta'\phi' + Nt\,\theta'^2\right) = 0, \tag{2.9}$$

$$\phi'' + Lef\phi' + \frac{Nt}{Nb}\theta'' = 0, \tag{2.10}$$

$$\chi'' + Scf\chi' - Pe(\phi'\chi' + \chi\phi'') - Pe_0\phi'' = 0, \tag{2.11}$$

subject to the boundary conditions

$$\begin{aligned} &f = f_w, f' = \lambda, \theta = 1, \phi = 1, \chi = 1 \text{ at } \eta \to 0, \\ &f' \to 1, \theta \to 0, \phi \to 0, \chi \to 0 \text{ as } \eta \to \infty, \end{aligned} \tag{2.12}$$

where the prime denotes differentiation with respect to η, $M = \frac{Gr_x}{Re_x^2}$ is the convection parameter, $Gr_x = \frac{g\beta_0(T_w - T_\infty)x}{\nu^2}$ is the Grassof number, $Re_x = \frac{U_\infty x}{\nu}$ is the Reynolds number, $\gamma = \frac{16T_\infty^3\sigma}{3k\nu}$ is the radiation parameter, $Pr = \frac{\nu}{\alpha_m}$ is the Prandtl number, $Nb = \frac{\tau D_B \Delta C}{\alpha_m}$ is the Brownian motion parameter, $Nt = \frac{\tau D_t \Delta T}{\alpha_m T_\infty}$ is the thermophoresis parameter, $Le = \frac{\nu}{D_B}$ is the Lewis number, $Sc = \frac{\nu}{D_n}$ is the Schimdt number, $Pe = \frac{bW_c}{D_n}$ is the bioconvection Peclet number, $Pe_0 = \sigma Pe$ with a dimensional constant $\sigma = \frac{n_\infty}{\Delta n}$, $f_w = -v_0/\sqrt{U_\infty \nu}$ is the suction ($f_w > 0$) or injection ($f_w < 0$) parameter and $\lambda = U_w/U_\infty$ is the stretching $\lambda > 0$) and shrinking ($\lambda < 0$) parameter.

The skin friction (C_f), local Nusselt number (Nu_x) the local Sherwood number (Sh_x) and the local density number of motile microorganisms (Nn_x) are defined as

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$$C_f = \frac{x\tau_w}{\rho u_e^2},\ Nu_x = \frac{xq_w}{k\triangle T},$$
$$Sh_x = \frac{xq_m}{D_B\triangle C},\ Nn_x = \frac{xq_n}{D_n\triangle n}, \quad (2.13)$$

where

$$\tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0},\ q_w = -k\left(\frac{\partial T}{\partial y}\right)_{y=0},\ q_m = -D_B\left(\frac{\partial C}{\partial y}\right)_{y=0},$$
$$q_n = -D_n\left(\frac{\partial n}{\partial y}\right)_{y=0}.$$

Using the above non-dimensional and similarity transformation we get,

$$Ra_x^{1/2}C_f = f''(0),\ Re_x^{-1/2}Nu_x = -\theta'(0),$$
$$Re_x^{-1/2}Sh_x = -\phi'(0),\ Re_x^{-1/2}Nn_x = -\chi'(0), \quad (2.14)$$

where $Re_x = u_e(x)x/\nu$ is the local Reynolds number.

Results and Discussion

The system of governing equations (2.8)-(2.11) subject to the boundary conditions (2.12) was solved using the fourth order Range-Kutta and shooting method. In the present problem, we have calculated a unique solution only in the range $\lambda > \lambda_c$, where λ_c is a critical value of λ which depends on other parameters. There is no solution for $\lambda < \lambda_c$. In some case, we have expected a dual solution appears for both stretching and shrinking wedges which earlier observed by Merkin [16]. In general, the first solution is stable and physically realizable, while the second solution is unstable and it came due the mathematical establishment. Although the second solution seems to be deprived of physical significance, it is more interesting to study the stability in nonlinear differential equation theory since a familiar equation may reappear in some other situations where the corresponding solution could have a more realistic meaning. To reduce the maximum error, we have considered the value Nb and Nt each taking values in the range [0, 0.5] (as recommended by Nield and Kuznetsov [17]) and the range for Pe is [0, 5] (Kuznetsov [18]).

The numerical results have been compared with earlier works of those reported by Wang [19] and Bachok et al. [20] and displayed in Table 3.1. The comparison of results gave a very good agreement there by lending confidence as to the accuracy of the present method.

The velocity and temperature profiles due to different wedge angles are shown in Fig. 3.1. The wedge angle highly influences the velocity profiles rather that temperature profiles. The momentum boundary layer thickness enhances with increase in wedge angle. The thermal boundary layer thickness reduces with an increase in wedge angle. We get an opposite phenomena for the second solution.

The radiation parameter appears directly in the energy equation and so it is obvious that the temperature profiles would be susceptible to any changes in the radiation parameter. This clearly is the case as shown in Fig. 3.2. The thermal boundary layer thickness increases with introduction of thermal radiation in the system and continuously increases with increase of the thermal radiation parameter. The motile microorganisms are living creatures and cannot withstand heating above a certain temperature. So it becomes necessary to control radiation for the microorganisms to survive.

The skin friction, local Nusselt number, local Sherwood number and local density of the motile microorganism for different suction parameter values are shown in Fig. 3.3. Dual solutions are obtained for all value of λ. The first solution is shown in solid line and second solution in a dashed line. The solutions coincide at some critical point (λ_c), which depends on the suction parameter. For suction parameter values 3, 3.5 and 4, the values of λ_c are -4.4, -5.309 and -6.299. A loop appears in the first and second solutions for all the cases. The upper part of the loop defines the first solution while the lower part defines the second solution. A similar phenomena was observed (by Bhattacharyya [15]) in the absence of bio-convection.

Suction aids the function of bringing large quantities of ambient fluid near to the immediate neighbourhood of the wedge which enhanced the shear stress at the surface. Physical significance of the negative sign is that the surface employs a drag force on the fluid. It is evident that the skin friction coefficient is zero when λ=1 irrespective of the value of the other governing parameters. It is clear from the boundary condition that for λ=1, the fluid and surface of the wedge move with the same velocity and hence it not producing any shear stresses at the surface. As a consequence, the presence of fluid at near-ambient temperature close to the sheet and enhanced heat transfer rate. It is also obvious that the Sherwood number enhanced in the presence of the nanoparticles because of the contributions of the Brownian motion, thermophoresis and the buoyant motion prompted by the difference in the densities of the nanoparticles in the base fluid. But with an increase in the suction parameter, the nanoparticle Sherwood number decreases as shown in Fig. 3.4(a). This is because an increase in suction reduces the nanoparticle flux in the convective flow field. The density of the motile microorganism near the surface reduces when there is an increment in the suction parameter (see Fig. 3.4(b)).

The effect of convection and radiation parameters on the skin friction, heat transfer rate, mass transfer rate and local density of the motile microorganism are displayed through Table 3.2 by considering different values of the wedge angle. The second solutions are given in brackets. It is evident that the skin friction, local Nusselt number, local Sherwood number and local density of the motile microorganism increase as the wedge angle increases for both the first and the second solutions. A similar result is appearing for the convection parameter. This is because with an increase in the convection parameter, both the convective heat and mass transfer rates increase. This influences and enhances the skin friction, heat transfer rate and mass transfer rate at the surface. The skin friction increases since radiation increases the velocity of the fluid and the shear stress at the wall. Similarly, the local Sherwood number and density of the motile microorganisms

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increase with radiation. However the Nusselt number decreases as the temperature of the fluid increases due to the radiation parameter.

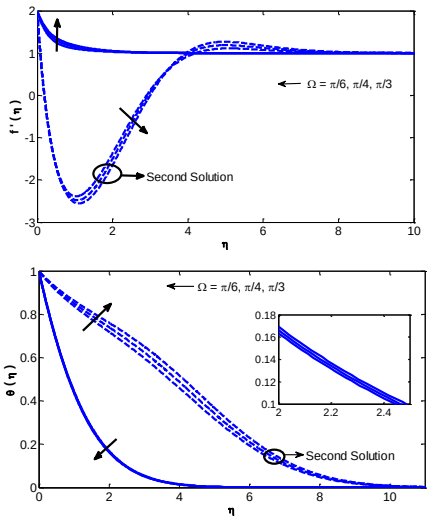

Fig 3.1: Effect of wedge angle on (a) velocity and (b) temperature with $M = 5$, $\gamma = 1$, $Pr = 6.2$, $Nb = Nt = 0.1$, $Le = 2$, $Sc = 1$, $Pe = 1$, $\sigma = 1$, $fw = 3$, $\lambda = 2$.

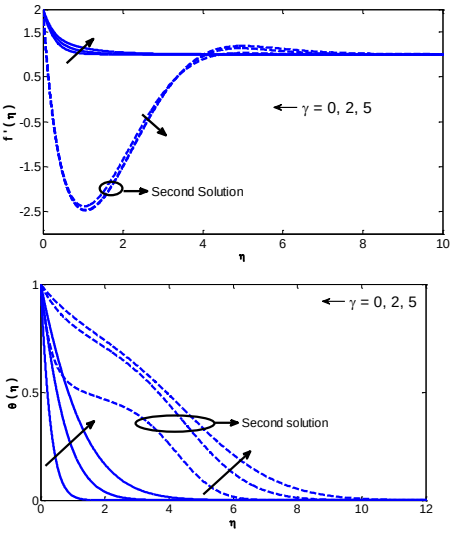

Fig 3.2: Effect of radiation parameter on (a) velocity and (b) temperature with $M = 5$, $\Omega = \pi/4$, $Pr = 6.2$, $Nb = Nt = 0.1$, $Le = 2$, $Sc = 1$, $Pe = 1$, $\sigma = 1$, $fw = 3$, $\lambda = 2$.

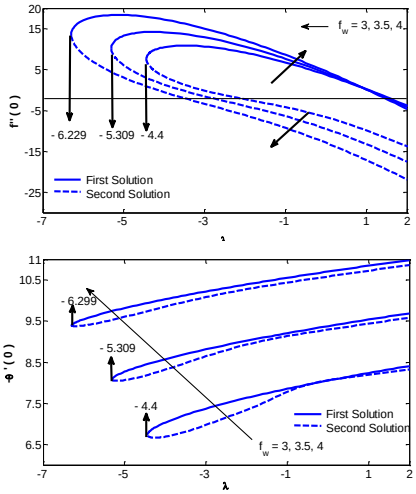

Fig 3.3: Effect of the suction / injection parameter on (a) skin friction coefficient (b) local Nusselt number .vs. λ with $M = 5$, $\Omega = \pi/4$, $\gamma = 1$, $Pr = 6.2$, $Nb = Nt = 0.1$, $Le = 2$, $Sc = 1$, $Pe = 1$, $\sigma = 1$.

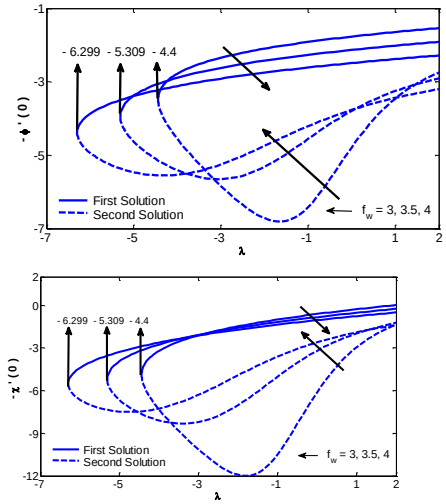

Fig 3.4: Effect of the suction / injection parameter on (a) local Sherwood number and (b) local density of the motile microorganism .vs. λ with $M = 5$, $\Omega = \pi/4$, $\gamma = 1$, $Pr = 6.2$, $Nb = Nt = 0.1$, $Le = 2$, $Sc = 1$, $Pe = 1$, $\sigma = 1$.

Conclusions

We have studied the stagnation point flow over a stretching / shrinking wedge with a nanofluid containing motile micro-organisms with water as base fluid. The influence of the suction parameter, wedge angle, convection parameter, radiation and stretching / shrinking parameter are discussed. The present results are compared with those of well-established

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publications available in the literature with some limiting values. Dual solutions were observed for both stretching and shrinking wedges. It was observed that the velocity and density of the motile microorganisms increase with suction for the case of a stretching wedge while they decrease in the case of a shrinking wedge. Temperature and nanoparticle concentration decrease with increase in suction parameter for both stretching and shrinking sheets. Radiation enhances both the velocity and temperature of the microorganism-rich nanofluid. A loop like graph observed due to the existence of the dual solution for all the physical parameters e.g., skin friction, local Nusselt number, local Sherwood number and local density of the motile microorganisms. An increase in the suction parameter, increases the skin friction and the local Nusselt number while the local Sherwood number and local density of the motile microorganism decreases

Table 3.1: Comparison of the present results with existing literature for different stretching parameter

λ	Wang [19]		Bachok et al. [20]		Present	
					$M = \lambda = f_w = Nb = Nt = 0$	
	$f_1''(0)$	$f_2''(0)$	$f_1''(0)$	$f_2''(0)$	$f_1''(0)$	$f_2''(0)$
-0.25	1.40224		1.4022408		1.40267084	
-0.5	1.49567		1.4956698		1.49566977	
-0.75	1.48930		1.4892983		1.48929824	
-1	1.32882		1.3288170	0	1.32881688	0
-1.1			1.1866805	0.0492290	1.18668029	0.04922896
-1.15	1.08223	0.116702	1.0822315	0.1167022	1.08223117	0.11670214
-1.2			0.9324739	0.2336497	0.93247336	0.23364973
-1.2465	0.55430		0.5842956	0.5542825	0.58428167	0.55429619
-1.24657			0.5639733		0.57452578	0.56401249

Table 3.2: Values of $f''(0)$, $-\theta'(0)$, $-\phi'(0)$, $\chi'(0)$ for different value of Ω, M, γ when Pr = 6.2, Nb = Nt = 0.1, Le = 1, Sc = 1(Second solution in next row)

Ω	M	γ	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$	$-\chi'(0)$
$\pi/6$	5	1	−3.83595048	8.19597689	−2.69497850	-2.27970326
			−13.87873953	8.15350761	−3.82719202	-3.49750774
$\pi/4$			−3.77353449	8.19643314	−2.69433385	-2.27821274
			−13.80858003	8.15376909	−3.82316528	-3.48897130
$\pi/3$			−3.71444108	8.19686489	−2.69372413	-2.27680289
			−13.74218910	8.15401639	−3.81936286	-3.48091952
$\pi/4$	0	1	−3.96645204	8.19502220	−2.69632850	-2.28282433
			−14.02555090	8.15295989	−3.83564564	-3.51546132
	2		−3.88925621	8.19558705	−2.69552959	-2.28097736
			−13.93868770	8.15328406	−3.83063947	-3.50482406
	5		−3.77353449	8.19643314	−2.69433385	-2.27821274
			−13.80858003	8.15376909	−3.82316528	-3.48897130
$\pi/4$	5	0	−3.85443823	15.55408580	−11.70934200	-20.24130228
			−13.91087947	15.80353636	−12.75476392	-21.30312166
		2	−3.70574837	5.73764038	0.31873382	3.71702098
			−13.70229122	5.47104505	−1.02297038	2.02360466
		5	−3.54195831	3.17148490	3.35839299	9.75813296
			−13.91789195	1.55066582	1.65752706	6.55224864

References

[1] Wager H, On the effect of gravity upon the movements and aggregation of Euglena viridis, Ehrb., and other micro-organisms, Phil. Trans. R. Soc. Lond. B, 201: 333-390, 1911 .

[2] Platt JR (1961) "Bioconvection pattern" in cultures of free-swmming organism, Science, 133, 1766-1767 .

[3] Pedley TJ et al. (1988) The growth of bioconvection patterns in a uniform suspension of gyrotactic micro-organisms, Fluid Mech., 195, 223-338.

[4] Hill NA et al. (1989) Growth of bioconvection patterns in a suspension of gyrotactic micro-organisms in a layer of finite depth, J. Fluid Mech., 208, 509-543.

[5] Kuznetsov AV, Avramenko AA (2004) Effect of small particles on the stability of bioconvection in a suspension of gyrotactic microorganisms in a layer of finite depth, Int. Commun. in Heat and Mass Transf., 31, 1-10.

[6] Shaw S. et al. (2014) Bioconvection in a non-Darcy porous medium saturated with nanofluid with gyrotactic microorganism, Int. J. bio-mathematics, 07, 1450005 (15 pages).

[7] Shaw S. et al. (2014) MHD and Soret effects on bioconvection in a porous medium saturated with a nanofluid containing gyrotactic microorganisms, J of Heat Transfer-Trans of ASME, 136(5), 052601 (10 pages).

[8] Taghipour F (2004) Ultraviolet and ionizing radiation for microorganism inactivation, Water Research, 38, 3940-3948.

[9] Johnson D (2003) Response of terrestrial microorganisms to ultraviolet-B radiation in ecosystems, Res. in Microbio., 154, 315-320 .

[10] Wacha R. et al. (2000) Neutron radiography applied to the microorganisms detection, Radiation Measurements, 32, 159-162.

[11] El-Registan GI et al. (2005) The role of microbial low-molecular-weight autoregulatory factors (alkylhydroxybenzenes) in resistance of microorganisms to radiation and heat shock, Advances in Space Res., 36, 1718-1728.

[12] Borick PM, Fogarty MG (1967) Effects of continuous and interrupted radiation on microorganisms, Applied Microbiol., 15, 785-789.

[13] Setlow P (2006) Spores of Bacillus subtilis: their resistance to and killing by radiation, heat and chemicals, J of Appl. Microbiol., 101, 514-525.

[14] Dutta BK. Et al. (1985) Temperature field in the flow over a stretching sheet with uniform heat flux, Int. Commun. Heat Mass Trans., 12, 89-94.

[15] Bhattacharyya K (2011) Boundary Layer Flow and Heat Transfer over an Exponentially Shrinking Sheet, Chin. Phys. Lett., 28, 074701.

[16] Merkin JH (1985) On dual solutions occurring in mixed convection in a porous media, J Eng Math, 20, 171-179.

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ISBN: 978-99968-0-608-7

[17] Nield DA, Kuznetsov AV (2011) The Cheng–Minkowycz problem for the double-diffusive natural convective boundary layer flow in a porous medium saturated by a nanofluid, Int. J of Heat and Mass Trans., 54, 374-378.
[18] Kuznetsov AV (2006) The onset of thermo-bioconvection in a shallow fluid saturated porous layer heated from below in a suspension of oxytactic microorganisms, European J of Mechanics B/Fluids, 25, 223-233.
[19] Wang CY (2008) Stagnation flow towards a shrinking sheet, Int. J. Non-Linear Mech., 43, 377-382.
[20] Bachok N et al. (2010) Melting heat transfer in boundary layer stagnation-point flow towards a stretching/shrinking sheetPhysics Letters A, 374, 4075-4079.

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Correlative Analysis Of Plasmid Mobility And Antibiotic Resistance Within ColE1 Plasmids

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Abstract*— Antibiotic resistance in bacteria remains a major global health challenge in the control of infectious diseases. Antibiotic resistance genes are frequently transferred across bacterial communities by mobile genetic elements such as plasmids. The majority of plasmids possess genes that allow them to replicate and transfer efficiently in various bacterial hosts. The plasmids in the ColE1 family have a series of mobility genes (mbeA, mbeB, mbeC, mbeD, and mbeE), which makes the plasmid mobilizable. However, the relationship between this mobilizable plasmid group and antibiotic resistance genes is not well understood. The mbeC gene, is the biggest and most important of the mobility genes of the ColE1 plasmids, this gene has been shown to display variation of occurrence (presence or absence) in antibiotic resistance plasmids and non-antibiotic resistance plasmids of the same family of plasmids. Using a bioinformatics approach, the differences in DNA sequences available in various online databases can be analysed by comparing the several genes associated with plasmid mobility. The innovative aspect of this research is that it provides the opportunity for development of robust molecular detection tools for tracking of specific types of plasmids with antibiotic resistance genotypes in clinical and environmental samples. This bioinformatics analysis approach is applicable anywhere and particularly important to low income countries as it does not require one to conduct in vivo experiments such as DNA sequencing for the study of plasmids or other genetic elements.

Key words - mbeC-gene, ColE1, Plasmid mobility, Antibiotic resistance, Bioinformatics Introduction

I. Background

Antibiotic resistance genes can be expected to have a correlative relationship with plasmid mobility on the basis that they display a high selective pressure when the environment demands it. In such an instance, plasmids will possibly have a high occurrence of genes that will allow them to spread efficiently by horizontal gene transfer. However in ColE1 plasmids that are mobilizable, antibiotic resistance is surprisingly found to have a negative correlation with plasmid mobility as confirmed by comparative sequence analysis methods. The reasons for this negative correlation is subject for further research, however it is possible that since ColE1 plasmids are small, they may not have tolerance for maintaining the coexistence of many genes that will make them larger.

A. Plasmid Mobility

Conjugation is one of the mechanisms through which horizontal gene transfer occurs in bacteria, and it is probably the most relevant. The appearance of multi-drug resistant bacteria brought horizontal gene transfer to the attention of scientists worldwide; this is because the dissemination of antibiotic resistance genes by conjugative plasmids poses serious health problems. ColE1 is mobilized by a wide range of conjugative plasmids and is the example of a family that encompasses mobilizable plasmids found in gram-negative and gram-positive bacteria [1].

Plasmids can be classified into three categories with regards to mobility. These are conjugative, mobilizable, and non-mobilizable plasmids. The distinction between these type plasmids is the presence or absence of the type of genes that allow the conjugation or mobility to occur. In a scheme described by Smillie and colleagues (Fig 1), there are three types of genes and one recognition site that allow plasmid mobility to occur by conjugation, [2]. The three types of genes are a relaxase protein, a type 4 coupling protein (T4CP) and a type 4 secretion system (T4SS). One of these 3 genes, the relaxase protein is associated with a recognition site called the origin of transfer (OriT).

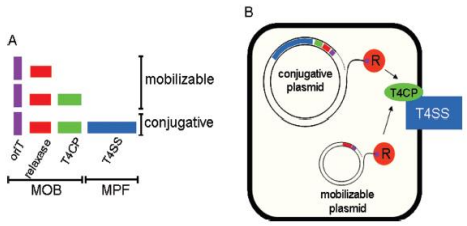

Fig 1. (A) A schematic interpretation of the genetic constitution of transmissible ColE1 like plasmids. (B) A representation of the functions that each gene has during the process of conjugation [2].

The *OriT* is recognized by a relaxase protein which nicks (forms a single stranded break) the plasmid at the particular location. The relaxase protein then attaches to the 3'end of the

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DNA and unwinds it, it then develops affinity to the type 4 coupling protein (T4CP) which has been coupled to the type 4 secretion system (T4SS). TheT4SS is responsible for extending the fertility pilus between two bacterial cells [2].

B. Mobility in ColE1 plasmids

ColE1 are a family of plasmids that have been described by the circumstance that the earliest of these plasmids was found to carry a gene for colicin E1 also called the *cea* gene [3]. These plasmids are not conjugative, that is they cannot move from one cell to another independently, rather they are mobilizable. They only move from one cell to another if there is a conjugative plasmid within the host cell. ColE1 specifically has been reported to be mobilized by conjugative members of various incompatibility groups, including IncIa, IncFI, IncW and IncP. There are five genes of mobilization in ColE1 plasmids, these are (*mbeA*, *mbeB*, *mbeC*, *mbeD*, and *mbeE*). Two of them (*mbeB* and *mbeD*) are entirely overlapping *mbeA*, seen in the schematic;(Fig2).

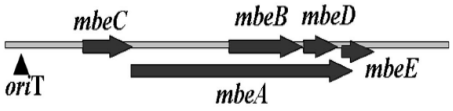

Fig 2. The mobilization region of ColE1 plasmids [1].

The genes *mbeA* and *mbeC* are found conserved in all ColE1 family plasmids whereas the genes *mbeB*, *mbeD*, and *mbeE* are not conserved. From this standing, researchers denote that the common ColE1 ancestral plasmid must have had a mobilization region containing only the *mbeA* and *mbeC* genes [1]. These genes are the most important where mobility is concerned because *mbeC* serves as the functional component of the nicking accessory proteins in the MOBP5 family (previously MOB_{HEN}) that are associated with mobilizable ColE1 plasmids and *mbeA* functions as the central component of the 'relaxation complex' [1], [2]. Initially, in around the 1970s, only 3 relaxase genes had been described for ColE1 plasmids, these were *mbeA*, *mbeB* and *mbeC*, with subsequent Genetic research: [4], [5], [6] 2 more, *mbeD* and *mbeE* were characterised. Of these *mbeE* was considered non-essential.

C. Antibiotic Resistance

Antibiotic resistance, in the general sense refers to the ability of bacteria to evade the bactericidal effects that antibiotics have against them. However, different studies have adopted different definitions for the term "Antibiotic resistance" depending on the objectives of each study. Martinez and colleagues described three general definitions for which the term can be characterized, these are; the clinical definition, which explains it as the MIC (minimum inhibitory concentration) breakpoints denoting therapeutic failure in human patients of a given antibiotic concentration. The epidemiological definition, defines it as the MIC value that corresponds to the upper limit of the wild-type population of a given species. The operational definition defines resistance as the pairwise comparison of a non-resistant strain against a mutant strain that has acquired resistance through HGT [7]. Characteristics of resistance are transmitted through bacterial populations through genes. Antibiotic resistant genes (ARG) have been around along with the prevalence of antibiotics in nature. Subsequent research has since the discovery of the first antibiotics witnessed the documentation of a collection of ARGs from community of bacteria in various environments that are now referred to as the resistome [8], [9]. Antibiotic resistance genes are found in plasmids and this occurs by mechanisms of horizontal gene transfer, these genes transfer from one environment to another depending on the selective pressure. When the selective pressure is high the genetic mechanisms of horizontal gene transfer are elevated including plasmid mobility [10].

II. MATERIALS AND METHODS

1. Data mining

The plasmid sequences are publicly available as part of the NCBI database resources. They were downloaded as a compressed tape-archive gunzip (tar.gz) file from the NCBI ftp directory, index of; (ftp://ftp.ncbi.nlm.nih.gov/genomes/Plasmids/). From this link the plasmids were contained in the file named "plasmids.all.fna.tar.gz". For this research, the file was retrieved in November 15 2015. It comprised a total of 6,090 plasmid sequences in fna (fasta nucleic acid) format and a sequence identification file "Plasmid.ids". The identification file contained a list of 6,197 plasmids, this was 107 more than the total number fna plasmid sequences the compressed file actually contained. The lists pecified the plasmid host bacteria and corresponsive NCBI accession and gi numbers. The above link is out-dated and has since been updated to be accessible at the index of; (ftp://ftp.ncbi.nlm.nih.gov/refseq/release/plasmid/) last accessed October 5 2016. From this new link the plasmids are contained in the file named "plasmid.1.1.genomic.fna.gz" and "plasmid.2.1.genomic.fna.gz" respectively.

2. Preliminary data sorting

Plasmids were sorted to remove irrelevant data to the research. From this sorting procedure, they were distributed amongst the three domains of life, in which those from domain bacteria were selected, these constituted (97%) 5951 plasmids. They were then sorted according to whether the plasmid was submitted into the database completely or incompletely sequenced, these constituted (95%) 5598 plasmids. From the completely sequenced plasmids, plasmids that contained antibiotic resistance genes were selected from the completely sequenced plasmids, these constituted (24.7%) 1406 plasmids. Lastly they were sorted according to whether they were circular or linear plasmids, for this research only circular

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plasmids were required, these constituted (96%) 1347 circular resistance plasmids.

3. Plasmid Analyses

a) Analysis of ColE1 plasmids

ColE1 plasmids have a sequence specific replicon that has been described by García-Fernández and colleagues 2009. This replicon is a generic sequence that extracts all ColE1 plasmids within a given population of any size using the recently developed plasmid based replicon typing (PBRT) technique, as in the case of this research. For this research an amplicon derived *in-silico* from the ColE generic sequence (accession number AM746977) using replicon typing primers oricolE FW (5'-GTT CGT GCA TAC AGT CCA-3') and oricolE RV (5'-GGC GAA ACC CGA CAG GAC T-3'), [11]. This amplicon was used in the Meg-Align pro utility of the DNA-star software using the mauve alignment tool. All positive hit alignments with a consensus sequence determined by default settings of the mauve alignment tool were considered ColE1 plasmids. These were selected from the population of 1347 circular resistance plasmids and 4276 non-resistance plasmids. From this analysis approach, 83 plasmids out of the 1347 plasmids were found to have the ColE replicon within the population of resistance plasmids, and 142 plasmids out of the 4276 plasmids were found to have the ColE replicon within the population of non-resistance plasmids. A representative over-view of plasmids with the ColE1 replicon as a fraction of all (resistant and non-resistant) plasmids is indicated in (Chart 1.1).

b) Analysis of the mbeC mobility gene within ColE like plasmids

The *mbeC* gene is a part of an operon of 4 genes (*mbeC*, mbeA, mbeB, and mbeD) that form the MOB_{P5}. The operon is available on NCBI (accession number X15873.1). It is the only gene that does not overlap with other genes in this operon, it is also considered along with mbeA the most conserved since they are found in all mobilizable ColE family of plasmids. Within the operon, the *mbeC* open reading frame is found at nucleotides position 97-420. This region was extracted within the 83 circular resistant ColE1 plasmids and the 142 circular non-resistant ColE1 plasmids. From the 83 circular resistant ColE1 plasmids 4 contained the *mbeC* gene, (Chart 1.5) and from the 142 circular non-resistant ColE1 plasmids 72 contained the *mbeC* gene, (Chart 1.4).

c) Phylogenetic tree analysis *of mbeC genes in resistance and non-resistance genes*

Multi-sequence alignments (MSA) of the *mbeC* genes found in non- resistance, resistance and all CoE1 plasmids were created on the DNA star software (Lasergene 12.0) using the Clustal Omega function. It was made to determine the diversity of *mbeC* amongst non- resistance and resistance plasmids and determine if there was a notable difference considering lineage associations. Phylogenetic trees were made to map these relationships. A comparative protein multi-sequence alignment of resistant, non-resistant and all ColE1 plasmid *mbeC* gene products were generated to compare with the nucleic acid alignments, trees were generated from these alignments as well. This was done by first using an online tool to reverse transcribe all the inverted sequences so that all sequences read from the leading strand (in the 5' to 3'direction), online, available at; <http://www.bioinformatics.org/sms/rev_comp.html>. The sequences were then translated to amino acid sequences using the EMBL-EBI nucleotide sequence translation tool; Transeq (EMBOSS), online, available at; <https://www.ebi.ac.uk/Tools/st/emboss_transeq/>. These sequences were aligned on the MegAlign Pro tool on the DNA star software using the Clustal Omega function. All trees were used to infer lineages were any were relevant to the aim of this study.

d) Correlative analysis for plasmid resistance and mbeC gene presence by comparative genomics

Plasmids were annotated to determine the arrangement that the mobility gene *mbeC* has within the general structure of the plasmid relative to other genes in the vicinity; synteny. This was done for both resistant and non-resistant plasmids with the ColE1 replicon. Antibiotic resistance genes were then depicted relative to the *mbeC* gene and other associative genes in the vicinity of the *mbeC* for resistance plasmids. This exercise was done solely to determine any form of structural interference or other mutation events amongst resistance genes and mobility genes. This was done using subsequent pairwise alignments using the mauve function of the DNAstar software against all plasmid sequences sequentially. The alignments were then graphically mapped to represent the evolutionary events (from a single locus) that all the plasmids have in common; the ColE1 replicon.

Along with the DNA star software mauve alignment function, an online tool (Pathosystems Resource Integration Center) PATRIC 3.3.38beta / RAST (Rapid Annotations using subsystems technology) was used to annotate resistance genes collectively for both resistance and non-resistance CoE1 plasmids. Online available at: < https://www.beta.patricbrc.org/>. Annotations were made under parameters: {Taxonomy name; [superkingdom] Bacteria, Taxonomy ID; [2]}. Annotations compared resistance and non-resistance ColE1 plasmids collectively in the circular viewer tool.

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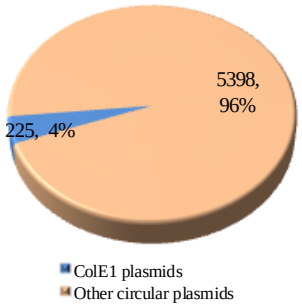
III. Results

1. *Preliminary data sorting*

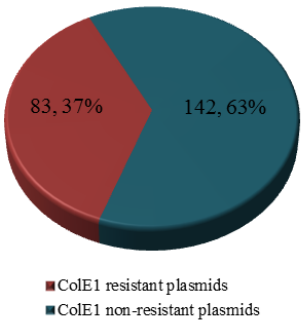
a) Determination of plasmids with the ColE1 replicon.

Chart 1.1. Plasmids with ColE1 replicon with other plasmids



b) Analysis of ColE1 plasmids in resistant and non-resistant plasmids

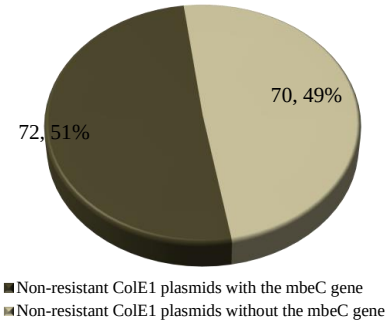
Chart 1.2. Resistant ColE1 plasmids within non-resistant ColE1 plasmids



2. *Analysis of the mbeC mobility gene within (resistant and non-resistant) ColE1 plasmids*

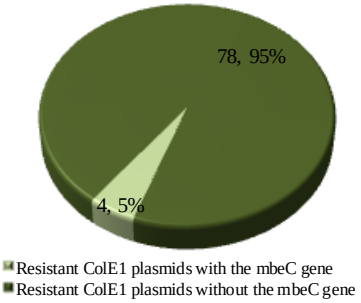
a) Non-resistant ColE1 plasmids

Chart 1.3. Non-resistant ColE1 plasmids with the mbeC gene against those without the mbeC gene



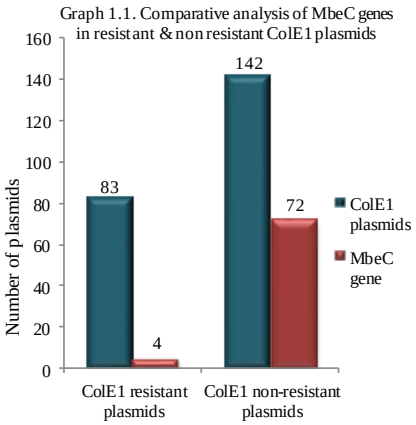
b) Resistant ColE1 plasmids

Chart 1.4. Resistant ColE1 plasmids with the mbeC gene against those without the mbeC gene



3. *Total collection of MbeC mobility genes in resistant ColE1 like plasmids compared to non- resistant ColE1 like plasmids.*

Graph 1.1. Comparative analysis of MbeC genes in resistant & non resistant ColE1 plasmids



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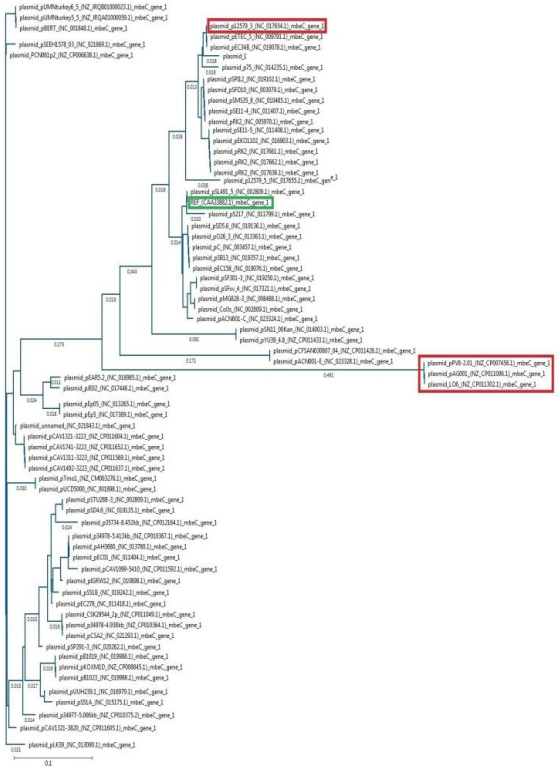

Fig 3. Phylogenetic tree analysis of *mbeC* genes in both resistant and non-resistant ColE1 plasmids, protein sequence phylogenetic tree * Red boxes indicate *mbeC* proteins from resistant plasmids, The Green box indicates the reference outgroup *mbeC* gene.

4. Annotation of antibiotic resistance in ColE1 plasmids.

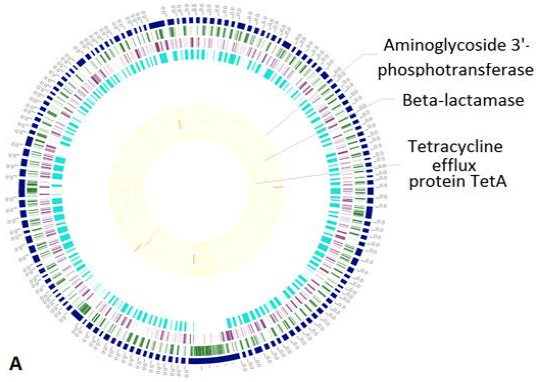

Fig 4. PATRIC 3.2.38beta RAST comprehensive antibiotic resistance annotation, circular viewer. A) CDS annotation of 6 loosely associated genes (These genes are not functional) by CARD on 142 **non-resistant** ColE1 plasmids.

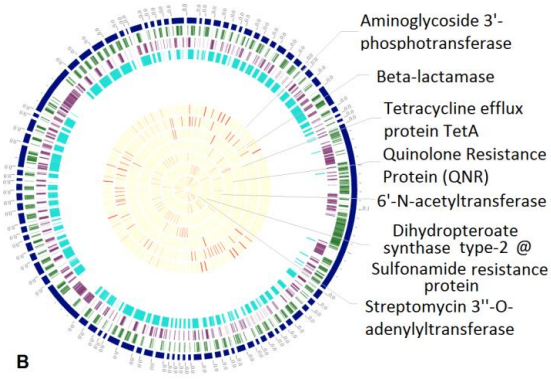

Fig 5. PATRIC 3.2.38beta RAST comprehensive antibiotic resistance annotation, circular viewer. B) CDS annotation of 178 strictly associated genes by CARD on 83 **resistant** ColE1 plasmids.

*NB: (Fig 4 & Fig 5) red slits along a yellow background ring show an annotated antibiotic resistance gene ARG [each ring represent a class of ARG as labelled]. Dark blue (outer) ring = complete plasmid DNA sequences, Dark green slits = forward strand annotated genes/ORF, Purple slits = reverse strand annotated genes/ORF. Light blue ring = non-coding sequences.

IV. DISCUSSION

The correlation of plasmid mobility to antibiotic resistance in ColE1 plasmids set out to be determined by this study was expected to be positive but it has proven otherwise. This disproved assumption was on account of ARGs usually being expected to have a positive selection pressure that would as a consequence incline them to occur in mobilizable plasmids as a matter of accumulation by random chances through mechanisms of MGEs. However this study has shown that the trend followed is actually contrary to that expected. Using the essential MOB_{P5} mobility gene associated with ColE1 mobile plasmids; the *mbeC* gene, the chart 1.3, chart 1.4 and graph 1.1 shows that there is more of the *mbeC* gene found in non-resistant ColE1 plasmids (51%) than in resistant ColE1 plasmids (4%). Upon interrogating the cause of this circumstance by phylogenetic analyses of the gene to infer a possible fitness lineage preference, the results were inconclusive due to fewer *mbeC* genes extracted from resistance plasmids. By ratio, this is 4 genes from resistance plasmids to 72 from non-resistant plasmids. Nonetheless, from these results it was determined that 3 of the 4 *mbeC* genes in resistance plasmids are closely related to one another with the remaining being more divergent from the rest (MSA from the *MbeC* gene ORF amino acid sequences), Phylogenetic tree Fig 3. These results somehow point out the probable fact that the inheritance of resistance genes is not secluded to certain variants of *mbeC*, it is instead random. Despite this, the *mbeC* outgroup lineage (Fig 3., red box) seen in the resistant ColE1 plasmids may be indicative of the possibility that *MbeC* genes may be getting adapted to coexist with resistance genes within

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the plasmid. In any case, the DNA sequence discrepancies observed are the source of the molecular markers that this research aims to highlight. This is to have a potential for development into molecular detection tools in a subsequent applied research. These markers will be useful for tracking of specific types of ColE1 plasmids with antibiotic resistance genotypes in clinical and environmental samples.

As for the diversity of the *mbeC* genes themselves, it is observed that there are more diverse, since they have developed 3 lineage clusters. This as indicative from the phylogenetic trees generated of the non-resistance *mbeC* counterpart genes. There are 3 different clusters deduced from the tree of non-resistance *mbeC* genes in ColE1 plasmids. The first cluster (top in Fig 3) is stagnant or occurs in a few plasmids and is more closely related to the MOB_p family of relaxes that intersect with the ColE1- relaxase super-family (MOB_{P5}). This cluster somehow links both super-families to a common origin, [1]. The second cluster (bottom in Fig 3) is an intermediate lineage of ColE1 *mbeC* genes whilst the third cluster (middle in Fig 3) is a more diversified lineage of ColE1 *mbeC* genes that are indicative of true ColE1 plasmids. According to the distance scale, this cluster has a branch length of more than 0.3 from both the first and second cluster. A slight discrepancy may occur between the protein and DNA sequences lineages but the general representation is matching, as both DNA phylogenetic trees (not shown) and protein phylogenetic trees represent three clusters. When comparing *mbeC* genes of both resistance and non-resistance plasmids, genes are allocated randomly within different clusters and no conclusive judgement can be validated about selective preference of resistance genes for mobile genes. This is due in part because there are fewer *mbeC* genes for plasmids with resistance; results in chart 1.3, chart 1.4 and graph 1.1.

The comparative genomics approach to determine the relevance of *mbeC* with antibiotic resistance was useful in showing relative comprehensive antibiotic presence in the two groups of ColE1plasmids(resistant & non-resistant). Most of the *mbeC* genes were randomly distributed along the plasmid genomes as deduced by mauve alignments. As expected, the genome annotation by PATRIC 3.2.38beta RAST showed greater antibiotic resistance genes in resistant ColE1 plasmids than in non-resistant ColE1 plasmids (Fig 4 & Fig 5). The 6 loosely associated genes observed in the CDS annotation circular viewer, Fig 4 are not functional from the CARD analysis report. The correlation between the two datasets (resistant & non-resistant ColE1plasmids) based on synteny was not clearly represented by both software due to large data processing limitations, and further analyses are yet to be established and described in other subsequent studies.

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REFERENCES

[1] Francia, M. V., A. Varsaki, M. P.,Garcilla´n-Barcia, A.,Latorre, C. D., and F. de la Cruz. (2004). A classification scheme for mobilization regions of bacterial plasmids. FEMS Microbiol. Rev. 28:79–100.

[2] Smillie, C.,Garcilla´n-Barcia, M. P.,Francia, M.V., Rocha, E.P.C and De la Cruz, F. (2010). Mobility of Plasmids. Micro& Mol. Bio Rev. 3: 434 – 452

[3] Hershfield, V., Boyer, H.W., Yanofsky,C., Lovett,M. A. and Helinski, D. R. (1974). Plasmid ColE1 as a Molecular Vehicle for Cloning and Amplification of DNA. Proceedings of the National Academy of Sciences. 71 (9): 3455–59

[4] Blair, D.G. and Helinski, D.R. (1975) Relaxation complexes of plasmid DNA and protein. I. Strand-specific association of protein and DNA in the relaxed complexes of plasmids ColE1and ColE2. J. Biol. Chem. 250, 8785–8789.

[5] Lovett, M.A. and Helinski, D.R. (1975) Relaxation complexes of plasmid DNA and protein. II. Characterization of the proteins associated with the unrelaxed and relaxed complexes of plasmid ColE1. J. Biol. Chem. 250, 8790–8795.

[6] Boyd, A.C., Archer, J.A. and Sherratt, D.J. (1989) Characterization of the ColE1 mobilization region and its protein products. Mol. Gen. Genet. 217, 488–498.

[7] Martinez , J. L., Coque, T. M., and Baquero, F., (2015). What is a resistance gene? Ranking risk in resistomes Nature Reviews Microbiology 13, 116–123.

[8] D'costa, V.M., Mcgrann, K.M., Hughes, D.W., & Wright, G.D. (2006) Sampling the antibiotic resistome. Science 311, 374-377

[9] Wright, G.D. (2007).The antibiotic resistome: The nexus of chemical and genetic diversity. Nature Reviews Microbiology 5, 175-186.

[10] Bennett, P.M. (2008) Plasmid encoded antibiotic resistance: acquisition and transfer of antibiotic resistance genes in bacteria. British Journal of Pharmacology 153, S347-S357.

[11] García-Fernández , A., Fortini, D., Veldman, K., Mevius, D., Carattoli, A.,(2009). Characterization of plasmids harbouring qnrS1, qnrB2 and qnrB19 genes in Salmonella. Journal of Antimicrobial Chemotherapy 63, 274–281

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Threshold dynamics of the plant-herbivore interaction with Allee effect

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***Abstract*—-Different species, like plants and herbivores, that are occupying similar ecosystems and living among each other interact regularly. In this interaction, understanding the conditions in which coexistence equilibrium occurs answers a key question in Ecology. In the interaction between plants and herbivores, plants serve as food for herbivores on the food chain. Then the livelihood of herbivores highly depend on the availability of food, in this case the availability of plants. With this motivation, we reformulated a mathematical model which assumes that the death rate of herbivore population is dependent on plant density. Moreover, the abundance of the plant density alone does not guarantee the non-extinction of the herbivore population as they are assumed to reproduce sexually. Therefore, we also included the concept of Allee effect for the herbivore population in the model. Using the mathematical theory of dynamical systems, threshold conditions and trapping region are obtained to ensure coexistence of the population. Moreover, it has been shown that the dynamics of the population is sensitive to the feeding rate of herbivore.**

***Keywords*—-Predator-prey, Allee effect, Equilibrium points, Threshold, Bifurcation analysis.**

I. Introduction

Interaction between plants and herbivores give information about basic processes of life that are observed in ecological patterns. Plants and animal species have been co-evolving synergically ever since they began to occupy different environments in this world. These two types of organisms have developed relationships of mutual dependence at a number of different levels, in particular those related to the feeding behavior. Relationship of this kind are based on different forms ranging from mutual benefits for both parties such as the control of plant growth by wild ruminants to the parasitic relationships observed. Any event that may cause losing of equilibrium in any herbivore activity, such as changes in the environment, species extinction or bio-invasions, may provoke significant change not only to the species involved in the interaction, but eventually also to the whole system.

Understanding the dynamics between herbivores and plants is important for land management, environmental protection and animal husbandry. The remarkable variety of dynamical behaviors exhibited by plant and herbivore species has stimulated great interest in the development of dynamical system models of populations. Classical approaches to model plant herbivore systems have same analogies with predator prey systems. There is no typical pattern resulting from plant herbivore dynamics. Instead, the evolution strongly depend upon the demographic parameters of the plant and herbivore populations and also the timing, kind and degree of density dependence that they exhibit [2]. There is strong ecological evidence showing that plant population dynamics have more important effects on plant herbivore interactions than herbivore population does [6]. Since the time of Lotka (1925) and Volterra (1926) mathematicians and biologists have been investigating the processes that affect the stability of predator-prey (plant-herbivore) systems us-

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ing tools from mathematical models [1, 2, 4, 5, 6]. Terry [3] presented four predator prey models with Allee effect for predator reproduction. The analysis showed that each of the models has fixed points that represents predator extinction which is always locally stable. In this paper, we will study the plant herbivore interaction by considering logistic growth rate in the plant population and the Holling type II functional response. For birth rate of herbivore population we take the constant multiple of the feeding relation together with the Allee effect. Moreover a variable herbivore mortality rate which is dependent on plant density is formulated and analyzed.

The paper is organized as follows order. In section 2, We define and describe the mathematical model. In section 3, The formulated model is analaysed using the theories of dynamical systems. The existence and stability of equilibrium points is established. In section 4 Bifurcation analysis is discussed. In the last section we give conclusion and some guidelines for future work.

II. Model Description

The basic system we consider in this paper is the classical predator prey ecological model in the version presented in [3], where the Allee effects for the herbivore are taken into account. We are studying two different populations, the plant and herbivore. Therefore, the state variables are given by: Plants, P, and herbivores H. The dynamics is represented by the following system of nonlinear ordinary differential equations:

$$\dot{P} = rP\left(1-\frac{P}{K}\right) - HF(P) \quad (1)$$

$$\dot{H} = H\left[cF(P)\left(\frac{H}{h+H}\right) - D(F(P))\right] \quad (2)$$

$P(0)\geq 0, H(0)\geq 0,$ where the upper dot denotes the time derivative, r, K, c, h are positive constants, denoting the net growth rate of plant population, the carrying capacity, efficacy of giving birth to a new herbivore and Allee constant, respectively. $F(P)=\frac{aP}{b+P}$ is a function representing the value of consumption of plants by herbivores. Here a is the maximum feeding rate of each herbivore and b is the half saturation constant, namely the density of plants at which the predation rate is half of the maximum it may consume to be satisfied at a time. It is assumed that $D(F(P)) = D(F)$ is a continuously differentiable function of the variable $F, F\geq 0$; and also, for $F\geq 0$, we have $dD/dF \leq 0$, and

$$0 < d_1 \leq D(F(P)) \leq d_2, \quad (3)$$

for some constants d_1 and d_2 representing the minimum and maximum herbivore death rate, respectively. It is common in literature to use constant mortality rate for herbivore but this is undefendable assumption, as it ignores the fact that mortality of herbivores is dependent on the availability of food source, that is, plant biomass. The life process of a herbivore is fueled by plant consumption and this includes most fundamentally staying alive [2]. If a herbivore eats little, it will be more likely for the animal to starve and die. On the other hand for all sufficiently high levels of consumption, starvation will not occur. Hence, herbivore mortality should be a decreasing function of consumption $F(P)$. Moreover, regardless of particular factors affecting herbivore mortality, no animal lives forever. So, it is sensible to assume that herbivore mortality is always bounded below by some positive constant. With this motivation we define the term $D(F(P))$ satisfying the following conditions. Let us consider the following form to describe it:

$$D(F) = d_2 - \frac{F}{g+F}, \quad (4)$$

for some parameter g. Then, substituting the values $P=0$ and $P=K$ in (4) and solving for g gives us $g=\frac{aK(1-d_2+d_1)}{(d_2-d_1)(b+K)}$. Then, $D(F(P))$ can have the expression:

$$D(F(P)) = d_2 - \frac{\frac{aP}{b+P}}{\frac{aK(1-d_2+d_1)}{(d_2-d_1)(b+K)} + \frac{aP}{b+P}} \quad (5)$$

The system under study, therefore, takes the following form.

$$\begin{aligned}\frac{dP}{dt} &= rP\left[1-\frac{P}{K}\right] - \frac{aP}{b+P}H \\ \frac{dH}{dt} &= H\left[c\left(\frac{aP}{b+P}\right)\left(\frac{H}{h+H}\right) - D(F(P))\right],\end{aligned} \quad (6)$$

where $D(F(P))$ is defined in equation (5)

A. Region of Positivity

It is important to show positivity and boundedness of the model system (6) as the variables represent population densities. Positivity implies survival, and

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boundedness may be interpreted as a natural restriction to growth as a consequence of limited resources. We will show in this section that all solution for (6) satisfies positivity. That is, for this model to be mathematically and biologically well posed, we need to ensure that for all positive times the state variables $P(t)$ and $H(t)$ must be non-negative for each solution of the system starting with $P(0) \geq 0, H(0) \geq 0$. This is equivalent to saying that the positive quadrant $\mathbb{R}_2^+ = \{(P,H) \in \mathbb{R}_2 : P \geq 0, H \geq 0\}$ is positively invariant. We denote by $\mathbb{R}_2^+$ the non-negative quadrant, and by $int(\mathbb{R}_2^+)$ the positive quadrant.

Lemma 1 (Positivity) *All solutions of system* (6) *starting in* $int(\mathbb{R}_2^+)$*, remain bounded and positive.*

This is obvious from system (6). Using the Cauchy-Lipschits theorem, as the $P-$axis and the $H-$axis are orbits, the positive quadrant $int(\mathbb{R}_2^+)$ is positively invariant. □

Lemma 2 *Let* $\widehat{P} := \max\{P(0), K\}$ *and* $\widehat{H} := \max\{cP(0) + H(0), \frac{\eta}{d_1}\}$ *where* d_1 *is defined as in* (3) *and set* $\eta = \frac{K(r+d_1)^2}{4r}$*. Then, the set on which the model system* (6) *is defined,* $\Omega = \left\{(P,H) \in \mathbb{R}_2 : P \geq 0, H \geq 0, P \leq \widehat{P}, H \leq \widehat{H}\right\}$ *is positively invariant.* i.e.*, all solutions of* (6) *starting in* $\mathbb{R}_2^+$ *are ultimately bounded with respect to* $\mathbb{R}_2^+$ *and enter the attracting set* Ω *for positive time* $(t \geq 0)$*.*

Proof: Let $(P(0), H(0)) \in \Omega$, as $P(t)$ and $H(t)$ are positive for $t > 0$, the basic existence and uniqueness theorem for differential equations (Picard-Lindelof Theorem) ensures that the system has positive solutions that cannot intersect the axes. It remains to show boundedness. We first proof $P(t) \leq K$ for all $t > 0$ since $P > 0$ and $H > 0$ in $int(\mathbb{R}_2^+)$ every solution $(P(t), H(t))$ of the model system (6) which starts in $int(\mathbb{R}_2^+)$, satisfies the inequality $\frac{dP}{dt} \leq rP\left(1 - \frac{P}{K}\right)$. But since we know that $P(0) \geq 0$, by a standard comparison argument we have, $P(t) \leq P_1(t)$ for $t \in [0,T]$, where $P_1(0) = P(0) \geq 0$ and for $t \in [0,T]$, P_1 is a solution of $\frac{dP_1}{dt} = rP_1\left(1 - \frac{P_1}{K}\right)$. Then, $\left(1 - \frac{P_1}{K}\right)$ is strictly decreasing for $P \geq \widehat{P}$ where $0 \leq \widehat{P} < K$, and it follows that $\frac{dP_1}{dt} = rP_1\left(1 - \frac{P_1}{K}\right)$ is negative for $P_1 > K$. Using the Intermediate Value Theorem and Mean Value Theorem we must have $P_1(t) \leq \max\{P(0), K\}$. Hence, $P(t) \leq P_1(t) \leq K$ and P(t) is bounded above. Next, we consider a bound for $H(t)$ from above. We have the emergence (birth) rate of herbivores which is always less than a linear multiple of the functional response. That is, $cF(P)\left(\frac{H}{h+H}\right) < eF(P)$ for a positive constant $e > 0$ and also $D(F(P)) \geq d_1$ for positive constant d_1. From model (6) when $P \geq 0$ and $H \geq 0$ finally we have $rP\left(1 - \frac{P}{K}\right)$ is bounded above by a positive constant (say Q) for $P \geq 0$. Note that, $rP\left(1 - \frac{P}{K}\right)$ is continuous on $[0,K]$ and therefore bounded, by Minmax Theorem and also $rP\left(1 - \frac{P}{K}\right) < 0$ for $P > K$. Combining these observations, the results in Lemma 2, positivity and using equations of the model system (6), we have for $t \geq 0$ $\frac{d}{dt}(eP+H) = e\frac{dP}{dt} + \frac{dH}{dt} \leq erP\left(1 - \frac{P}{K}\right) + d_1 eP - d_1(eP + H)$. Here, we can see that $erP\left(1 - \frac{P}{K}\right) + d_1 eP$ is equal to $-er\frac{P^2}{K} + e(r+d_1)P$ a quadratic expression in P and is easily seen to have a global maximum at $\eta = \frac{Ke(r+d_1)^2}{4r}$. From these we get $erP\left(1 - \frac{P}{K}\right) + d_1 eP \leq \frac{Ke(r+d_1)^2}{4r}$. Which means, $\frac{d}{dt}(eP+H) \leq \frac{Ke(r+d_1)^2}{4r} - d_1(eP+H) \leq \eta - d_1(eP+H)$. Then, it follows from the last step that $eP(t) + H(t) \leq W(t)$ for all $t \geq 0$, where $W(0) = eP(0) + H(0) \geq 0$ and $W(t)$ is a solution of $\frac{dW}{dt} = \eta - d_1 W$. Solving for W we have $W = \frac{\eta}{d_1} - \frac{K}{d_1}e^{-d_1 t}$ and then $W(t) \leq \max\left\{W(0), \frac{\eta}{d_1}\right\} = \max\left\{eP(0) + H(0), \frac{\eta}{d_1}\right\}$. Hence, $eP(t) + H(t)$ is bounded by $\widehat{H}$. Since P satisfies the Positivity condition and is bounded above by $\widehat{P} = \max\{P(0), K\}$, then H itself must be bounded above by $\widehat{H}$. □

III. Equilibrium Analysis

A. Existence of equilibria and stability

Equilibrium points of the system (6) are obtained by putting the right hand side equal to zero. When there is no herbivore, that is, when $H = 0$, P needs to satisfy $Pr\left(1 - \frac{P}{K}\right) = 0$ which implies that existence of two equilibria is possible. One is the trivial equilibrium $(0,0)$ which is unstable and the other is herbivore free equilibrium $(K,0)$, which is locally asymptotically stable. When the herbivore population $H > 0$, from equation (2) the term $c\left(\frac{aP}{b+P}\right)\left(\frac{H}{h+H}\right)$ represents the emergence of herbivore and is an increasing function of P. Similarly the term $D(F(P))$ represents the rate of removal of herbivores from the system and is a decreasing function of P. Moreover from the assumption that $P \leq K$, we have, $\frac{aP}{b+P} \leq$

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$\frac{aK}{b+K}$, and $D(F(K)) \geq d_1$. Now, consider the case $\frac{caK}{(b+K)}\left(\frac{H}{H+h}\right) < d_1$. In this case herbivore mortality would always be higher than herbivore birth rate, the herbivore population would decay until extinction. Therefore, for the non extinction of herbivores we must always have $\frac{caK}{(b+K)}\left(\frac{H}{H+h}\right) > d_1$.

Define $\mathscr{R}_0 = \frac{caK}{d_1(b+K)}$ to be a threshold parameter value for the system, and we shall call it the reproduction number of the herbivore population. Then we have the following theorem

Theorem 3 *Suppose the model system* (6) *is given with the initial plant population is positive* $P(0) > 0$. *If* $\mathscr{R}_0 \leq 1$ *then the equilibrium* $(K,0)$ *is locally asymptotically stable.*

Proof: Let us bound $\frac{dH}{dt}$ from above. To do this, we bound the herbivore death rate from below and the herbivore birth rate from above. In view of positivity (Lemma 1), the herbivore death rate function $D(F(P))$ is bounded below by the parameter d_1. Since the herbivore birth rate is $c\left(\frac{aP}{b+P}\right)\left(\frac{H}{h+H}\right)$, to bound this from above, first, by positivity where $\widehat{H}$ is the maximum value for herbivore population, $H \leq \widehat{H}$ and we have $\frac{H}{h+H} \leq \frac{\widehat{H}}{h+\widehat{H}}$ for $t \geq 0$, where $\widehat{H}$ is a positive constant defined in Lemma 2. Second, note that by positivity for $t \geq 0$ in the proof of Lemma 2 we saw that when $P(0) > 0$, $P(t) \to K$ as $t \to \infty$. Hence we can have the relation $P(t) < K$ for $t \geq T_1$ for some $T_1 > 0$. Using this, Lemma 1, and Standard Comparison argument [3] we have for $t \geq T_1$, $P \leq K$ and which implies that $\frac{caP}{b+P} \leq \frac{caK}{b+K}$. Combining these observations we get,

$$\frac{dH}{dt} \leq \widehat{H}\left[\frac{caK}{b+K}\left(\frac{\widehat{H}}{h+\widehat{H}}\right) - d_1\right]. \qquad (7)$$

Now, for $\mathscr{R}_0 \leq 1$, $\frac{caK}{b+K} \leq d_1$, and $0 < \left(\frac{\widehat{H}}{h+\widehat{H}}\right) < 1$, then the term in the square bracket of equation (7) is negative constant say $-\alpha$ (where $\alpha > 0$). Then, we have $H(t) \leq H_1(t)$ for $t \geq T_1$, where $H_1(t) = H(t)$ for $t \leq T_1$ and H_1 is a solution of $\frac{dH_1}{dt} = -\alpha H_1$. Since H satisfies positivity and is bounded above (by Lemma 2) then $H_1(t_1) = H(t_1)$ is non negative and finite. Hence $H_1(t) \to 0$ as $t \to \infty$, which implies $H(t) \to 0$ as $t \to \infty$, since $0 \leq H(t) \leq H_1(t)$ for $t \geq T_1$.

Finally, we can show that $P(t) \to K$ as $t \to \infty$. We choose any $\varepsilon_1 > 0$. Then there exists $T_2 > 0$ such that $P(t) < K + \varepsilon_1$ for $t \geq T_2$. Now, choose $\varepsilon_2 > 0$ such that $\varepsilon_2 < \max\left\{\frac{r}{a}, \frac{r\varepsilon_1}{2aK}\right\}$, since $H(t) \to 0$ as $t \to \infty$, there exists $T_3 > 0$ such that $0 < H(t) < \varepsilon_2$ for $t \geq T_3$. Using this and also positivity, we have $\frac{aPH}{b+P} < \frac{a\varepsilon_2 P}{b+P} < a\varepsilon_2 P$, for $t \geq T_3$. Hence $\frac{dP}{dt} = rP\left(1-\frac{P}{K}\right) - \frac{aPH}{b+P}$. Thus, $\frac{dP}{dt} \geq rP\left(1-\frac{P}{K}\right) - a\varepsilon_2 P$ or $\frac{dP}{dt} \geq rP\left(1-\frac{a\varepsilon_2}{r}-\frac{P}{K}\right)$. We also know that $P(T_3)$ is bounded and positive. Then $P(t) \geq P_2(t)$ for $t > T_3$ where $P_2(T_3) = P(T_3) > 0$ and P_2 is a solution for $\frac{dP_2}{dt} = rP_2\left(1-\frac{a\varepsilon_2}{r}-\frac{P_2}{K}\right)$. Since by definition $\varepsilon_2 < \frac{r}{a}$, then $1-\frac{a\varepsilon_2}{r} > 0$, so that by solving explicitly for $P_2(t)$ we have $\frac{dP_2}{dt} = rP_2\left(1-\frac{a\varepsilon_2}{r}-\frac{P_2}{K}\right)$ which solves to $\frac{P_2}{\left(1-\frac{a\varepsilon_2}{r}-\frac{P_2}{K}\right)} = Ae^{\left(1-\frac{a\varepsilon_2}{r}\right)rt}$ for some constant A. Now, as $t \to \infty$ since $1-\frac{a\varepsilon_2}{r} > 0$ we have $\left(1-\frac{a\varepsilon_2}{r}-\frac{P_2}{K}\right) \to 0$ or $\lim_{t\to\infty} P_2 = K\left(1-\frac{a\varepsilon_2}{r}\right)$.

In particular, $P_2 > K\left(1-\frac{2a\varepsilon_2}{r}\right)$ for $t \geq T_4$ for some $T_4 \geq T_3$. But by our choice for ε_2, we have $\varepsilon_2 < \frac{r\varepsilon_1}{2aK}$ So that $1-\frac{2a\varepsilon_2}{r} > 1-\frac{\varepsilon_1}{K}$. Hence $P(t) \geq P_2(t) > K\left(1-\frac{\varepsilon_1}{K}\right) = K-\varepsilon_1$ for $t \geq T_4$. Combining our observations, and letting $T_5 = \max\{T_2, T_4\}$, we see that $K-\varepsilon_1 < P(t) < K+\varepsilon_1$ for $t \geq T_5$. Thus $P(t) \to K$ as $t \to \infty$, as required. □

This theorem describes that the herbivore birth rate is less than the mortality rate then more herbivores are dying compared to the new borns. Therefore, in the long run it results in the growth of plant population up to the carrying capacity of the environment while the herbivore population goes to extinction.

Theorem 4 *Suppose that* $\mathscr{R}_0 > 1$ *and define* $H_m = \frac{(d_1)h(b+K)}{caK-d_1(b+K)}$. *Then the following hold.*

(i) If $H(0) < H_m$ *and* $P(0) > 0$, *then* $(P(t),H(t)) \to (K,0)$ *as* $t \to \infty$.

(ii) If $H(0) \geq H_m$ *and* $0 < P(0) < \frac{1}{(ca\beta e^{r\beta})}$, *where* $\beta = \left(\frac{2}{d_1}\right)\left[1+\ln\left(\frac{H(0)}{H_m}\right)\right]$ *is a positive constant; then* $(P(t),H(t)) \to (K,0)$ *as* $t \to \infty$.

Proof: From Lemma 2 we have $P(t) \leq \max\{P(0),K\} = \widehat{P}$ for $t \geq 0$. Let $\sigma(H) = \left(\frac{caK}{b+K}\right)\left(\frac{H}{h+H}\right) - d_1$. Then clearly $\sigma(0) = -d_1 < 0$. Also $\sigma(H)$ is continuous in $H \geq 0$. Moreover $\sigma(H) > 0$ for all H sufficiently large because $\mathscr{R}_0 > 1$. Therefore, by Intermediate Value Theorem there is a least positive solution H_m to $\sigma(H) = 0$, such that we have $\sigma(H) < 0$ for $0 \leq H < H_m$.

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(i) For the first part of the theorem; from the proof of Theorem 3 we find that for $t \geq 0$ that $\frac{dH}{dt} \leq H\left[\frac{caK}{b+K}\left(\frac{\widehat{H}}{h+\widehat{H}}\right) - d_1\right] = H\sigma(H)$. Then by the Standard Comparison argument there exists H_1 such that $H(t) \leq H_1(t)$ for $t > 0$ where $H_1(0) = H(0) \geq 0$, and H_1 is a solution of $\frac{dH_1}{dt} = H_1\sigma(H_1)$. From the hypothesis we have $H(0) < H_m$ and we also saw that $\sigma(H) < 0$ for $0 \leq H < H_m$. Therefore, we have $H_1(t) \to 0$ as $t \to \infty$, which in turn implies $H(t) \to 0$ as $t \to \infty$ since we have $0 < H(t) \leq H_1(t)$ for $t > 0$. In similar manner as in the proof of Theorem(3) one can easily show that $P \to K$ as $t \to \infty$.

(ii) To prove the second part, we suppose $H(0) \geq H_m$. Then since $H_m > 0$, let us define $\beta = \left(\frac{2}{d_1}\right)\left[1 + \ln\left(\frac{H(0)}{H_m}\right)\right]$. Hence, $ca\beta e^{r\beta} > 0$ as $\frac{H(0)}{H_m} \geq 1$. Choose $P(0)$ so that $0 < P(0) < \frac{1}{ca\beta e^{r\beta}}$. Then using the equation for $\frac{dP}{dt}$ and positivity of P we have $\frac{dP}{dt} < rP$ for $t \geq 0$. Moreover, from $P > 0$, it follows that $P(t) < P(0)e^{rt}$ for $t \geq 0$. Using our choice of $P(0) < \frac{1}{ca\beta e^{r\beta}}$, we get

$$P(t) < \frac{1}{ca\beta} \text{ for } 0 \leq t \leq \beta. \tag{8}$$

Now, using the equation for $\frac{dH}{dt}$ and positivity of H we have $\frac{dH}{dt} = H\left(\frac{caP}{b+P}\left(\frac{H}{h+H}\right) - D(F(P)) < H(caP - d_1)\right)$ which means,

$$\frac{dH}{dt} \leq (caP - d_1)H \text{ for } t \geq 0. \tag{9}$$

From (8) and (9) and using positivity of H $\frac{dH}{dt} \leq \left(\frac{1}{\beta} - d_1\right)H$ for $0 \leq t \leq \beta$, after some calculations we arrive at $H(t) \leq H(0)e^{\left(\frac{1}{\beta} - d_1\right)t}$ for $0 \leq t \leq \beta$. Hence, $H(\beta) \leq H(0)e^{(1-\beta d_1)}$. But then from our definition of β we have $\beta = \left(\frac{2}{d_1}\right)\left[1 + \ln\left(\frac{H(0)}{H_m}\right)\right]$, and clearly we can see that $\beta > \left(\frac{1}{d_1}\right)\left[1 + \ln\left(\frac{H(0)}{H_m}\right)\right]$. After simplification of this inequality we arrive at: $H(0)e^{1-\beta d_1} < H_m$. Hence $H(\beta) < H_m$. If we now apply the argument used to prove the first part of the theorem, with the time origin shifted from $t = 0$ to $t = \beta$ we deduce that $(P(t), H(t)) \to (K, 0)$ as $t \to \infty$. □

The above theorem states that when $\mathscr{R}_0 > 1$ then there is a least minimum value of H which is the corresponding solution of $\left(\frac{caK}{b+K}\right)\left(\frac{H}{h+H}\right) = d_1$. Solving for H we obtain the necessary least possible number of herbivore for coexistence. Which is given by $H_m = \frac{d_1 h(b+K)}{caK - d_1(b+K)}$. Then, the first part states that if the initial herbivore population is less than the least number of herbivore population needed to keep the population existing in the system, $H(0) < H_m$, and the initial plant population is positive $P(0) > 0$, then herbivore extinction will always occur and the plant population grows to its carrying capacity. The second part means if the initial herbivore population is greater than the least number of herbivore population needed to keep the population existing in the system then the herbivore population would still go to extinction if there is no enough plant population to feed on and reproduce. In addition it also gives us threshold values or conditions where herbivore extinction can occur. Let us establish conditions for coexistence of plant and herbivore in the ecosystem using the followng theorem.

Theorem 5 *Let L_P, U_P, L_H, U_H be constants satisfying the following conditions $0 < L_P < U_P$ and $0 < L_H < U_H$*

$$L_H F(U_P) > rU_P\left(1 - \frac{U_P}{K}\right) \tag{10}$$

$$U_H F(L_P) < rL_P\left(1 - \frac{L_P}{K}\right) \tag{11}$$

$$cF(L_P)\left(\frac{L_H}{h + L_H}\right) > D(F(L_P)) \tag{12}$$

$$cF(U_P)\left(\frac{U_H}{h + U_H}\right) < D(F(U_P)) \tag{13}$$

Then in model (6) if $H(0) \in [L_H, U_H]$ and $P(0) \in [L_P, U_P]$ we have $H(t) \in [L_H, U_H]$ and $P(t) \in [L_P, U_P]$.

Proof: Assuming the hypothesis of the theorem hold, we need to define $\Sigma = \{(P,H) : P \in [L_P, U_P], H \in [L_H, U_H]\}$, as a trapping region. This trapping region exists if the flow in the phase plane points inwards across all the boundaries of Σ. which is true if:

$$\left.\frac{dP}{dt}\right|_{P=U_P} < 0 \text{ and } \left.\frac{dP}{dt}\right|_{P=L_P} > 0 \text{ for } H \in [L_H, U_H] \tag{14}$$

$$\left.\frac{dH}{dt}\right|_{H=U_H} < 0 \text{ and } \left.\frac{dH}{dt}\right|_{H=L_H} > 0 \text{ for } P \in [L_P, U_P] \tag{15}$$

Using (10)-(13) one can easily show that (14)-(15) are satisfied for $P \in [L_P, U_P]$ and $H \in [L_H, U_H]$ Then we have the existence of a trapping region Σ. □

The phase diagram also agrees with this theorem as it shows (figure not shown) that there is a stable limit cycle as time goes to infinity. This means that there is no specific coexistence equilibrium as it keeps appearing and disappearing but the dynamics is always attracted to this stable limit cycle. Coexistence will occur as long as P and H are in Σ.

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B. *Bifurcation analysis*

The sensitivity of the threshold $\mathscr{R}_0 = \frac{caK}{d_1(b+K)}$ with respect to the maximum feeding rate parameter a was found to be a transcritical bifurcation. The herbivore population remains zero until the feeding rate reaches a certain point when the threshold value $\mathscr{R}_0 = \frac{caK}{d_1(b+K)} \leq 1$, the number of herbivores cannot reach H_m hence it will remain at zero. But once this $\mathscr{R}_0$ is slightly greater than one it means the number of herbivore population is greater than H_m so that they can reproduce and increase the population size.

IV. Conclusion

In this paper a plant-herbivore model with logistic growth rate for the plant population and Holling type II functional response was assumed for the interaction. For herbivore emergence rate a linear multiple of the functional response and the Allee effect were considered. Under the assumption that the mortality of herbivores depends on the availability of food source, instead of constant death rate we used density dependent variable mortality rate which is a decreasing function of the functional response. The mortality rate is bounded below since no animal can leave for ever. Then existence of two herbivore free equilibrium $(0,0)$, which is unstable and $(K,0)$, which is locally asymptotically stable, were found. Furthermore for the reproduction number $\mathscr{R}_0$, if $\mathscr{R}_0 > 1$, the plant population grows to its carrying capacity and herbivore extinction will occur either if the initial herbivore population is less than the least number of herbivore population needed to keep the population existing in the system and the initial plant population is positive or if the initial herbivore population is greater than the least number of herbivore population needed to keep the population existing in the system but there is no enough plant population to feed on and reproduce. In addition, threshold values or conditions where herbivore extinction can occur and when coexistence state can be assured were established. We have found a stable limit cycle for coexistence state inside the trapping region Σ. However, the plant growth rate is dependent on rainfall and temperature, the feeding rate of the herbivores is also dependent on the availability of food and weather conditions. Hence, these parameters require to be reconsidered for the model to be more realistic. Therefore, considering periodic and non-periodic functions of time for the plant growth rate $r(t)$ and feeding rate $a(t)$ is to be done in the future.

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References

[1] A. Lebon, L. Mailleret, Y. Dumount and F. Grognard, "Direct and apparent compensation in plant-herbivore interactions", Ecol. Model., vol. 290, pp. 192–203, 2014.

[2] A.J. Terry; "Dynamics of a structured population on two patches", J. Math. Anal. Appl., vol. 378, pp. 1–15, 2011.

[3] A.J. Terry, "Predator-prey models with component Allee effect for predator reproduction", J. Math. Biol., vol. 71, pp. 1325–1352, 2015.

[4] E.P. Holland, R.P. Pech, W.A. Ruscoe, J.P. Parks, G. Nugent and R.P. Duncan, "Thresholds in plant-herbivore interactions: Predicting plant mortality due to herbivore browse damage", Oecologia, vol. 172, pp. 751–766, 2013.

[5] J.H. Reynolds, J.A. Sherratt, A. White and X. Lambin, "A comparision of the dynamical impact of seasonal mechanisims in a herbivore-plant system", Theor. Ecol. vol. 6, pp. 225-239, 2013.

[6] Y. Kang ,D. Armbruster and Y. Kuang, "Dynamics of plant-herbivore model", J. Biol. Dyn., vol. 2, pp. 89–101, 2008.

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The contribution of Building Information Management to Structural Engineering

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Abstract

It is noted worldwide that, the construction industry is faced with challenges of mismanagement, miscommunication and low quality products. Further, the construction players are investing their funds in dangerous projects and significant challenges with respect to site coordination and collaboration between the different disciplines. The introduction of Building Information Modeling (BIM) technologies can positively contribute to the structural engineering industry. BIM contributes to improved problem solving, development of innovative ideas as well as creation of complex designs. BIM as well enables structural engineering students to improve on structural design documentation as well as minimize errors during the design phase. The current research paper describes the benefits of implementing BIM to the construction industries in Botswana and other Africa countries. In addition, challenges to the adoption of BIM to the construction industry are discussed and strategies to address the constraints are proposed. A qualitative phenomenological approach was used to conduct the study and a thematic analysis facilitated data analysis. Findings indicate that BIM technology can help the construction players improve communication, coordination and collaboration in management of construction projects. Also, BIM enables structural engineers to improve on visualization and simulation of problems and enhance consistency of data. BIM software has made life easier in structural engineering by helping engineers visualize, design, analyze, document and build projects more efficiently, accurately and competitively. The collaboration of BIM tools such as the Autodesk tools, Revit architecture, Advanced Steel, Revit Structure, Revit MEP, Bentley System and CSI tools such as SAP 2000 has helped structural engineers overcome construction challenges such as clash designs, delays and project costs overruns. In conclusion, BIM tools should be highly advocated in structural engineering to help improve the design and structure of buildings and architects.

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Keywords—Construction industry, building information modeling, technology, strategies, constraints, construction projects.

INTRODUCTION

The construction projects can be considered by their nature to be uncertain, risky and complicated. These attributes are evident in remote construction projects which have unique problems caused by factors such as remoteness of the project site itself that also contributes to loss of control over management and communications [1]. The aspects of little managerial skills as well as lack of human resource and infrastructural input contribute to challenges in construction projects. Coordination and communication have been the main challenges in remote and poorly managed construction projects [1]. The conventional management methods have been found to be defective in handling such problems which forced scholars to suggest approaches such as advanced computer based management system that ensures effective information management and communication.

The construction industry has long been observed to contribute to the economy of a country. However, the construction industry is faced with issues such as poor quality of work, dirty construction sites, occurrences of accidents, delays and dangerous sites conditions. The advent of ICT and increased technology innovation such as Building Information Modeling (BIM) has helped manage most construction projects and contribute to the success and productivity of the construction industry [2]. The BIM technology has been observed to be suitable for both risky and complex construction industries. The BIM has been applied in various countries such as United Kingdom, Malaysia, Australia, HongKong and Denmark among others. BIM awareness is on the rise as those who have not adopted it intend to. Data show that BIM awareness is on the rise in UK which is observed to the most common project design in UK in the next five years from 2017. Data show that 97% of the communities in UK have the awareness in BIM as depicted by figure 1 [3].

In addition, BIM adoption in the Middle East countries is also rising. Countries like Dubai, UAE are increasingly integrating BIM in their construction industries due to the increased development of the countries' economy. However, BIM adoption in Africa is low as most of the countries are in their developing states. Despite the increased awareness of BIM in Nigeria, the adoption is still low due the constraints in the implementation of both process and technology [4]. The implementation of BIM in South Africa is a challenge due to constraints in personnel inadequacies in terms of training, education and skills development. Figure 1 and 2 demonstrates the adoption of BIM in European countries and Middle East countries.

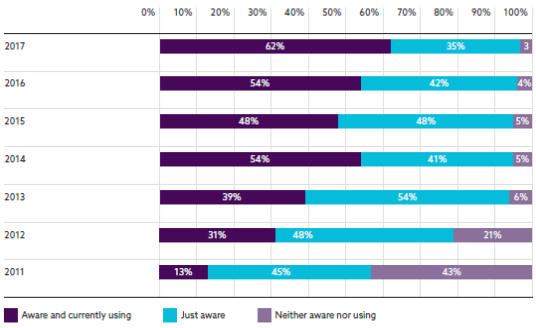

Figure 1.BIM Awareness in UK community. Source: [3].

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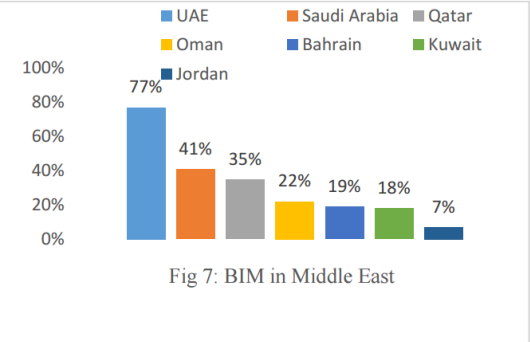

Figure 2.BIM adoption in Middle East countries. Source: [5]

Reference [2] describes that the Malaysian government is advocating for the implementation of the of the BIM in construction projects due to its benefits of facilitating solving problems in the construction industry such as preventing disputes between construction players, minimizing project delay as well as decreasing construction cost. BIM has helped structural engineers to stay competitive and keep pace with today's economy. BIM has helped structural engineers to better handle and visualize components as well as ensuring data accuracy and reduction in drafting errors [6].

Business Information Modeling is described as "digital representation of physical and functional characteristics of a facility that serves as a shared knowledge resource that forms a reliable basis for decisions during its life cycle, from inception onward" [7]. BIM involves the characteristics of collaboration between distinct stakeholders at varying phases of facility lifecycle to insert, extract, update or modify information in the model to reflect the roles of that stakeholder. BIM combines different threads of information into one operating environment thus, reducing different documents needed in the site [7]. The BIM is observed as an incorporation of software tools and techniques in the lifecycle of building and construction process. BIM focuses on enabling viewing and visualizing of buildings in 3D entities. The rapid technology advancement has led to the adoption of BIM in the construction industry including emerging Smart Building Environments (SBE) that incorporates embedment of smart objects such as sensors and actuators leading to intelligent interaction between humans and computing and communication technology in day-to-day activities [8].

The BIM software is based on Object Oriented Programming. The presence of new 3D tools is allowing structural engineers and designers to create models for documentation and coordination. The BIM software helps in developing buildings in 3D dimensions that utilize the X, Y and Z dimensions [6]. The Autodesk Revit is considered as the market leader in building and construction that utilizes BIM. The Autodesk Revit is greatly compatible with civil engineering software such as SAP2000, ETABS and Robot Structural Analysis. Revit allows the user to develop walls and assign attributes to it such as exterior texture among others [6]. Figure 3 demonstrates the use Revit architecture in modeling. Despite the popularity and domination of Autodesk Revit, several other modeling systems such as Bentley Systems are applied. Figure 4 describe the awareness and usage of various BIM modeling tools and software among UK residents.

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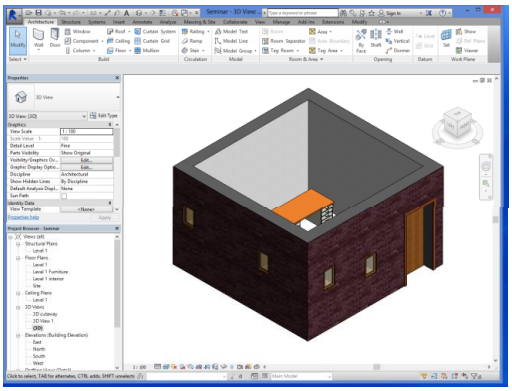

Figure 3.Use of Revit architecture in modelling of buildings. Source: [6]

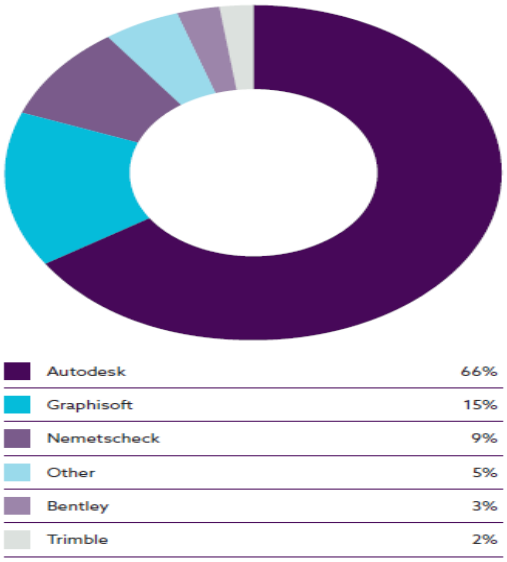

Figure 4. Mainly used BIM models among communities in UK. Source [3].

Problem Statement

The construction industry is facing huge challenges forcing structural engineers to improve quality, value and productivity. Challenges in the construction industry include delays, production of low quality products, cost overrun as well as dependence on old technology [9]. In addition, challenges in poor management and miscommunications have resulted in low quality drawings and architects. Also, issues such as inadequate project pre-planning and uncertainty in project process integration contributes to misinterpretation and miscommunication that lead to misguided and inappropriate decision making process [1]. There has been slow adoption of BIM technologies in the construction industry due to challenges of its implementation. The adoption of BIM in Botswana is still a challenge due to constraints in technology and people. Local companies owned by Botswanans are not familiar with BIM however, only few international companies know a little about BIM. There is need for the awareness of adoption of BIM among structural engineers. Increase in training activities on the use of BIM tools will contribute to the increase in the adoption of BIM and its contribution to the structural engineering. Moreover, several international companies have adopted BIM and given testimonials on its importance and contribution to positive results.

Purpose

The purpose of conducting this study is to develop a framework and a plan for initiating Building Information Modeling to the Botswana's structural engineers. Botswana is among the developing countries with minimal integration of technology in the construction industry [10]. The initiation of the BIM in the construction industry will aim to boost the production and quality of products and services in the construction industry and contribute to structural engineering in Botswana.

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Research Questions

1. What benefits does the Building Information Modeling have to the structural engineers in Botswana?
2. What are the constraints to the adoption of the Building Information Modeling among structural engineers in Botswana?

MATERIALS AND METHODS

Research Methodology

The research methodology provides framework that helped the researcher to structure and execute the data collection and analysis process. The research approach used was the qualitative research method. Qualitative research method was chosen as it focuses on exploring and interpreting a phenomenon. In addition, qualitative research focuses on non-numerical data [11]. Qualitative research study focuses on theoretical findings and discoveries as well as deals with a small number of non-representative samples [12]. The design also used was the phenomenology research design that focuses on describing people's perceptions about their surrounding environment. The phenomenology as well describes human experience of the world people lives in [13]. The study thus, used primary qualitative data selected from structural engineers in Botswana.

Population and Sampling

The target population is identified as a defined whole accumulation of units from which sampling takes place [14]. The target population of the study was structural engineers in the building and construction industry in Botswana. The sampling process that entails extracting a sample from the population used was the purposive sampling. Reference [15] indicated that purposive sampling is suitable for the phenomenological qualitative research where participants are expected to meet specific criteria during the selection moment. The criteria used in this study were that the structural engineers must have worked in the construction industry for more than 3 years in Botswana and managed a team of at least 5 people. The purposive sample considered to sample 3 structural engineers.

Procedures

Interview processes were used for the collection of information as it helps in exploring details from participants and encourages participants to express their own thoughts and feelings [16]. The participants were given an informed consent that stated the purpose of the study and the contributions of every respondent to the study. The consents were sent via email and respondents invited to attend to interviews via emails and phone calls. The interviewer controlled the interviewing process.

Data Analysis

Data was analyzed by use of thematic analysis. Thematic analysis concerns itself with identifying common themes among various participants [17]. The themes were identified and categorized manually based on researchers informed knowledge. Thematic analysis helped to categorize related information and the contributions of Building Intelligence Modeling to construction industry was identified.

Ethical considerations

The ethics of confidentiality and anonymity of participants was adhered. The ethics were achieved by not including personal details in the research study. In

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addition, biasness was minimized when reporting and interpreting the data.

RESULTS

This section focuses to present the results from the interviewed respondents. The first section focuses to present the overall demographic characteristics of respondents while the other section discusses the objectives of the study. The results indicate that sample consisting of three participants two were males while one was a female structural engineer. The mean age for the respondents was 43 years with the minimum age of35 years and the maximum age of52 years. In addition, the mean years of work experience was seven years with the minimum of4 years and the maximum of10 years of work experience.

Research Question One

The research question focused to assess the benefits of Building Information Modeling to the structural engineers in the construction projects in Botswana. The results indicate that the participants were aware of Building Information Modeling and had implemented in their projects. Additionally, the participants viewed the Building Information Modeling as a digital representation of building project and work flow that helps in designing buildings. The representation and workflow is facilitated by use of software package. The participants added that BIM facilitates collaboration to enable project success. The participants indicated that BIM have numerous advantages that facilitate the progress of construction projects.

The main theme emerging in this question is that BIM have facilitated improved communication and collaboration among project team members. Effective communication and collaboration among team members results in efficient handling and sharing of tasks that facilitates success of the project. The participants added that BIM have helped their construction projects by lowering ofproduction costs as well as total reduction in cost of other infrastructures. BIM have facilitated provision of quality products, services and operations. One of the participant described that using the 3D architecture in BIM have facilitated provision of quality drawings, architects and buildings as compared to the old technology. The participants demonstrated the necessity of BIM to structural engineering field as to help engineers reduce drafting errors as well lower designing cost. Also, participants indicated that BIM enables structural engineers improve on visualization and simulation of problems and enhance consistency of data. BIM software has made life easier in structural engineering by helping engineers visualize, design, analyze, document and build projects more efficiently, accurately and competitively. The collaboration of BIM tools such as the Autodesk tools, Revit architecture, Advanced Steel, Revit Structure, Revit MEP, Bentley System and CSI tools such as SAP 2000 has helped structural engineers overcome construction challenges such as clashes in designs, delays and project costs overruns.

Research Question Two

The research question identified the constraints hindering the adoption of Building Information Modeling among structural engineers in the construction industry in Botswana. Participants gave various responses although themes were identified from the responses. The main theme addressing the constraints to BIM adoption was inadequate training and skills in

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operating the Business Information Modeling. The training constraints have resulted in slow adoption and awareness of the BIM technology. Structural engineers lack Revit training which is considered as essential in the construction industry. In addition, participants indicated constraints to BIM adoption was inadequate infrastructural resources and finances for funding implementation of BIM projects. One of the participants indicated that inadequate finances have resulted to challenges in purchasing BIM tools such as Revit Architectural. The training courses available are inadequate and are also expensive to enroll in. The participants called for immediate intervention to the constraints by the government of Botswana.

DISCUSSION

The section discusses the results of the findings in relation to the research questions. There were two research questions which focused to discuss the benefits of the Building Information Modeling technology to the construction industry and also the constraints to the adoption of Building Information Modeling. The participants first described Building Information Modeling as a digital representation of workflow of building designs and projects that is facilitated by software packages. The findings are confirmed by several scholars [7] [8] [18]. The participants indicated that Building Information Management has helped them excel in the building and construction industry. BIM has been attributed to have numerous benefits including facilitating communication and coordination of team members in the construction projects [2] [7].

In addition, BIM technology integration in the construction industry has helped in reducing construction costs and also facilitated in engaging in risky ventures. Reference [2] indicated that BIM technology has enabled construction players to venture their projects in dangerous sites and also engage in risky ventures. BIM has also enabled reduction of infrastructural costs. Reference [8] indicated that BIM technology through the integration of 3D architecture has facilitated the improvement of quality of architectural designs and buildings. Participants indicated that BIM help in reduction of design and drafting errors as well lower designing cost. BIM has facilitated rise in visualization and problem simulations in structural engineering field thus contributing to data consistency [6].

The study also assessed the constraints to BIM adoption of construction players whereby inadequate training and skills to operate BIM was the main challenge. The findings are consistent with several studies [9] [2]. Moreover, participants described constraints to BIM adoption as inadequate finances to purchase BIM tools. Similar findings were observed by [2].

CONCLUSIONS

There is recent increase in challenges in construction industry such as mismanagement, miscommunication and low quality products. In addition, construction players are investing their funds on projects located in dangerous sites, occurrence of accidents, increase in delays, and experiencing poor coordination and collaboration which requires intervention. Structural engineers indicated increased benefit associated with BIM integration in the building and construction industry. BIM has facilitated effective communication, collaboration and coordination of team players which have resulted to success of projects. In addition, with the integration of 3D architecture in BIM, the quality of products, designs of buildings and architects is also

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increasing. Additionally, BIM has enabled easy handling of problems among structural engineers which results in data stabilization. The collaboration of BIM tools such as the Autodesk tools, Revit architecture, Advanced Steel, Sost-X, Revit MEP, Bentley System and CSI tools such as SAP 2000 has helped structural engineers overcome construction challenges such as clash designs, delays and project costs overruns. However, despite the increased benefits of BIM in the construction industry, the pace of adopting BIM is very low in Africa compared to European counterparts due to the challenges of adopting BIM that is attributed by structural engineers viewing BIM as disruptive technology that transforms construction industry to a new direction. The adoption of BIM to eradicate traditional methods is facing huge challenges such as making construction players understand how BIM offers more benefit compared to 2D drafting, education and training as well as process of upgrading technology.

RECOMMENDATIONS

The increased constraints to BIM adoption are hindering its adoption rate in the construction industry, the progress of construction projects and in overall economic conditions which thus, requires adequate intervention. The participants described several intervention measures that would help in increasing adoption of BIM. The participants indicated that the government should heavily intervene by providing training opportunities and courses and also providing funding and finances to support BIM projects. Similarly, the researcher plans to intervene on the issue by proving training courses in Building Information Modeling. This can be achieved by the researcher advancing on the skills by enrolling in short training courses in Revit Structure, Robot Structural, ETABS/SAP2000 as well as programming languages such as Python and Dynamo.

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I also want to thank my supervisors Prof Dundu and Prof Malumbela for their support. Not forgetting Mr Moremi for assisting in technical English.

REQUEST FOR TRAINING BY THE AUTHOR

Similar initiatives are conducted in Malaysia whereby the Malaysian government is giving grants to undergraduate students to obtain training on BIM. The government ensures that undergraduates receive training in using BIM tools such as Revit Architectural, Revit Structural and Navisworks and are awarded BIM certificates [2]. The author thus, focuses to enroll in short training courses to advance the skills and knowledge about BIM tools. The author therefore, plans to enroll in training webinars at Graitec whereby the university in which the author is attached will help in developing a budget to enroll in BIM training.

REFERENCES

[1]Arayici, Y, Egbu, C, & Coates, P 2012, 'Building information modelling (BIM) implementation and remote construction projects: Issues, Challenges and Critiques', *Journal of Information Technology in Construction*, 17, pp. 75-92.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

[2] Latiffi, AA, Mohd, S, Kasim, N, &Fathi, MS 2013, 'Building information modeling (BIM) application in Malaysian construction industry,' *International Journal of Construction Engineering and Management*, 2, 1, pp. 1-6. doi: 10.5923/s.ijcem.201309.01.

[3] National Building Specification 2017, National BIM Report 2017, Retrieved from https://www.ecoprod.co.uk/wp-content/uploads/2016/10/BIM-Report-2016.pdf

[4] Gerges, M, Austin, S, Mayouf, M, Ahiakwo, O, Jaeger, M, Saad, A, &Gohary, TE 2017, 'An investigation into the implementation of Building Information Modeling in the Middle East', *Journal of Information Technology in Construction (ITcon)*, 22, 1, pp.1-15.

[5]Shaikh, AA, Raju, R, Malim, NL, &Jayaraj, GK 2016, 'Global status of building information modeling (BIM) - A review,' *International Journal on Recent and Innovation Trends in Computing and Communication*, 4, 3, pp. 300-303.

[6] Bhusar, AA, &Akhare, AR 2014, 'Application of BIM in structural engineering', *SSRG International Journal of Civil Engineering*, 1, 5, pp. 12-20.

[7]Enegbuma, WI, Aliagha, GU, Ali, KN, &Badiru, YY 2016, 'Confirmatory strategic information technology implementation for building information modeling adoption model', *Journal of Construction in Developing Countries*, 21, 2, pp. 113–129.

[8] Zhang, J, Seet, B-C, & Lie, TK 2015, 'Building information modeling for smart built environments,' *Buildings*, 5, pp. 100-115. doi:10.3390/buildings5010100

[9] Zahrizan, Z, Ali, NM, Haron, AT, Marshall-Ponting, A, & Hamid, ZA 2013, 'Exploring the adoption of building information modeling (BIM) in the Malaysian construction industry: a qualitative approach', *International Journal of Research in Engineering and Technology*, 8, 2, pp. 384-395.

[10] Shangodoyin, DK 2011, 'The role of statistics in national development with reference to Botswana and Nigeria statistical systems', Journal of Sustainable Development, 4, 3, pp. 131-135. doi:10.5539/jsd.v4n3p131

[11] Castellan, CM 2010, 'Quantitative and qualitative research: A view for clarity', *International Journal of Education*, 2, 2, pp. 1-14.

[12] Park, J, & Park, M 2016, 'Qualitative versus quantitative research methods: Discovery or justification?', *Journal Of Marketing Thought*, 3, 1, pp. 1-7.

[13] Kafle, NP 2011, 'Hermeneutic phenomenological research method simplified', *Bodhi: An Interdisciplinary Journal*, 5, pp. 181-200.

[14] Banerjee, A, &Chaudhury, S 2010, 'Statistics without tears: Populations and samples', *Industrial Psychiatry Journal*, 19, 1, pp. 60–65. http://doi.org/10.4103/0972-6748.77642

[15] Padilla-Diaz, M 2015, 'Phenomenology in educational qualitative research: Philosophy as science or philosophical science?' *International Journal of Educational Excellence*, 1, 2, pp. 101-110.

[16] Alshenqeeti, H 2014, 'Interviewing as a data collection method: A critical review', *English Linguistics Research*, 3, 1, pp. 39-45.

[17] Alhojailan, MI 2012, 'Thematic analysis: A critical review of its process and evaluation', *West East Journal of Social Sciences*, 1, 1, pp. 39-47.

[18] Merschbrock, C, &Munkvold, BE 2012, 'A research review on building information modeling in

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ISBN: 978-99968-0-608-7

construction—an area ripe for IS research', *Communications of the Association for Information Systems*, 31, 10, pp.207-228.

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The study of the multi-line-signal s_2 state of the oxygen evolving complex of the photosystem-II.

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Abstract

The world is currently facing an increased need for clean and renewal energy sources due to global warming and rapid depletion of crude oil reserves. Production of hydrogen fuel from water could be a possible future solution as it is renewable and burns cleanly to produce only energy and water. Current hydrogen production techniques including water electrolysis have been rendered uneconomical due to high energy requirement, however looking at natural processes; green organism can oxidize water to oxygen and hydrogen using sunlight by oxygenic photosynthesis. Understanding the photo oxidation mechanism of water could enable mimicking the reaction in laboratory and ultimately a full scale production plant. Oxygenic photosynthesis is a process whereby organic compounds especially sugars and molecular oxygen are produced, the latter as a waste product, while consuming water and carbon dioxide in the presence of sunlight. Understanding the structure of oxygen evolving complex (OEC) fully still remains a challenge. The aim of this study was to characterize the multiline signal in detail, which can help increase our understanding of how the manganese atoms in the catalytic cluster of the PSII magnetically interact. Photosystem II contains the water oxidizing complex (WOC), which utilizes the interaction of four manganese ions and calcium ion (Mn_4/Ca catalytic cluster) for its function. The WOC (also known as Oxygen Evolving Complex- OEC) proceeds via five redox intermediate states known as 'S' states, categorized into four meta-stable states (S_0, S_1, S_2 and S_3) and one transient state (S_4). The subscripts in the 'S' states correspond to the stored oxidizing equivalents. The S_1 state is normally called the dark stable state of the WOC. Specific low temperature illumination procedures were applied to set the PSII samples into the S_2 state, without advance to the S_3 state in this study. The S_2 state was studied using Electron Paramagnetic Resonance (EPR) spectroscopy at X-band frequencies. The S_2 state generates a visible "**g2** multiline" signal (ML), unstructured "**g4**. **1**" EPR signals known to involve the Mn ions in the +3 and +4 oxidation states. The manganese ions in the OEC are known to be anti-ferromagnetically coupled, yielding a net spin ½ ground state in the illumination induced S_2 intermediate (associated with the Mn ions) of the catalytic cycle and are therefore paramagnetic. The experimental temperature dependence of the ML signal is observed to be essentially that for the S= ½ ground state of a simple Mn^{III}-Mn^{IV} dimer, with estimated exchange coupling, J ~-2.0 cm^{-1}.

Keywords: Oxygen evolving complex, Photosystem II, multiline, temperature, exchange coupling

I. INTRODUCTION

Photosystem II is a large protein complex found in the thylakoid membranes of oxygenic photosynthetic organisms, including algae, cyanobacteria and higher plants. Photosystem II (PSII) is believed to perform the photo-oxidation of water to dioxygen through the action of the manganese containing catalytic site, within the membrane-bound protein complex [1]. The oxygen-evolving complex (OEC) is located within PSII and is where oxidation of water occurs. The OEC is found within the luminal side of PSII, and it consists of four manganese atoms, cofactors Cl^{-1} and Ca^{2+} [2, 3]. During the oxygen formation reaction, the OEC cycles through five redox intermediate states (S states) named the Kok cycle [4], labelled $S_0 \rightarrow S_4$, where the subscript represents the number of stored oxidizing equivalents in the cluster.

The S_1 state is normally called the dark stable state of the OEC, and at low temperatures the Mn cluster becomes diamagnetic for dark-adapted samples [5]. The resolution of the X-ray crystallographic structures corresponds to the S_1 "dark stable" state [6, 7, 8, 9, 10, and 11]. The mean oxidation state of S_1 dark stable state of OEC has long been predicted to be above +2 from X-ray absorption near edge structure (XANES) and photo-assembly measurements [12]. The S_1 state is predicted to have the oxidation of $Mn^{III}4$ or $Mn^{III}2$-$Mn^{IV}2$ or equivalent combinations described as 'low' and 'high' oxidation possibilities respectively [13]. The S_0 state is Mn^{III}-Mn^{III}-Mn^{III}-Mn^{II} as well approximated by the 'low' oxidation state paradigm, evident by the pronounced peak at 6447 eV, which is characteristic of Mn^{II} in an aqua like environment [14]. The mean Mn oxidation level is assumed to be +3.0 in the S_1 state according to the computational studies by Gatt et al., (2012), therefore oxidation state pattern Mn^{III}-Mn^{III}-Mn^{III}-Mn^{III} (1.9Å resolution structure) or Mn^{III}-Mn^{IV}-Mn^{III}-Mn^{II} (2.9Å resolution structure), and their calculated model is in favor of 1.9Å XRD structure [15].

The $S_0 \rightarrow S_1$, $S_1 \rightarrow S_2$, $S_2 \rightarrow S_3$ transitions are activated by photochemical oxidation of $P680^+$. $P680^+$ is highly unstable, and is stabilized by donation of electrons from the donor side of PSII, from the catalytic cluster Mn_4Ca via a mediator. The mediator is redox active tyrosine residue (Tyr Z) located in the

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D1 peptide which in turn oxidizes the OEC [16, 17]. S_4 is a transient state, while S_0 up to S_3 states are called metastable states, can be freeze trapped by rapid freezing after exposing PSII samples (cores and membranes) to different number of laser flashes [18]. Water remains exchangeable up to S3 in the catalytic site and molecular oxygen released after the final oxidation of two water molecules in the four electron concerted steps [19]. The S0 and S_2 states have net odd spin ½ ground states arising from antiferromagnetic coupling of the four Mn ions [20], hence are paramagnetic and EPR active.

Dismukes and Siderer discovered the S_2 "multiline" signal (Mn hyperfine structured signal), which is centered on ≈2 featuring many hyperfine peaks [21]. The existence of the newly found multiline signal by Dismukes and Siderer, was again confirmed by Hansson et al., (1982) who generated the signal through continuous illumination of the broken chloroplast. The confirmation that multiline signal arose from S_2 state was made by Brudvig et al., (1983), who used increased intensity xenon flashes and continuous illumination on multiline signal formation at cryogenic temperatures up to 160K, and single flash illumination was less effective at temperatures below 240K in forming MLS. The S_2 state X-band CW-EPR generated multiline signal exhibits between 18 and 20 peaks with superhyperfine structures observed. The Mn hyperfine structured signal at Q-band exhibits the same number of peaks with less superhyperfine structure, which indicates the increase in dominance of the Zeeman interaction as well as linewidth effects [22, 23].

Il. MATERIALS AND METHODS

A. PSII sample preparations.

The protocol used in isolating the PSII containing thylakoids membranes was based on Bricker et al., (1985) with modifications by P. Smith [23]. The homogenization, incubation steps as well as centrifugation were carried out in dim green light cold room, with temperature of about 4ºC. The chlorophyll concentration determination was determined by using the method by Porra et al., (1989). The light haversting complex (LHC II) contains almost 80% of chlorophyll in PSII membrane, and the separation of this LHC II will result in attaining the PSII core complex, which is embedded inside. The isolation of the PSII core and reaction center was done following the protocol by van Leeuwen et al., (1991) with modifications by Smith et al., (2002). The PSII core complex samples were isolated from freshly thawed PSII membranes. The eluted PSII core complexes were then concentrated using a Centriprep 30Kda cut-off concentrators to concentration of 1.5-4 mg/ml chlorophyll a in the eluting buffer containing 400mM sucrose, 20mM Bis Tris pH 6.5 and 0.3% β-D-DDM (BTS 400) and stored at -80 ºC for later use. The total chlorophyll of 3-5% was yielded in the eluted PSII core complexes. The chl a/b and Chl content were determined following Porra et al., (1989) protocol, using 80% acetone as a solvent. The oxygen evolution measurements were carried out using a Hansatech Oxygen electrode thermostated at 25 ºC. The p-phenylbenzoquinone (pPBQ-350µM) was used as electron acceptor which results in considerable enhancement of the multiline signal, [24] while the oxygen evolution buffer consisted of the Elution fraction buffer without DDM and $MgSO_4$.

B. Illumination

The PSII samples prepared as above were thawed on ice/water mix (0 ºC/273K) for 1 hour before use. Aliquots of 250 µl were carefully loaded into 4 mm O.D. quartz EPR tubes (Wilmad quartz), and subsequently frozen in liquid nitrogen. If bubbles were found in the sample, it was immediately thawed, the bubble removed then re-frozen in liquid nitrogen (about 77 K). The annealing of PSII sample was done by storing the sample in ice/water mix (0 ºC/273K) covered with a black cloth to minimize stray light entering. The sample was annealed for approximately 10 to 30 minutes, this ensured a full relaxation to the S_1 state, and subsequently freeze trapped in the S_1 state using liquid nitrogen. The S1 state generates the background EPR spectrum, which is subtracted from an illumination spectrum to achieve the difference spectrum. The tyrosine radical (YD) signal was also removed from the difference spectrum. Otherwise the remaining tyrosine radical signal was subtracted using the Bruker WIN EPR system software package.
To generate the S_2 state through $S_1 \rightarrow S_2$ turnover, from PSII core complexes, the temperature of the sample was monitored and controlled by a nitrogen gas flow system. Samples were subjected to 12 seconds illumination (PSII core samples ~240 K) using a Kodak Ektalite 1500 slide projector fitted with Halogen lamp. The light was passed through a 10cm water path IR filter, filtered using a combination of yellow and blue filters to allow a narrow window green light to pass. The sample was rapidly freeze trapped in the S_2 state immediately after illumination in liquid nitrogen (77 K).

C. EPR Measurements

The experiments were performed using the X-band continuous wave (CW) Bruker Biospin ELEXSYS E500 spectrometer using Bruker SHQX resonant cavity and super X-EPR Microwave Bridge. The spectrometer was fitted with Oxford - ES900 continuous flow helium cryostat with temperatures controlled using Oxford Instruments ITC-4 temperature controller. The experiments were carried out at cryogenic temperatures (~5 K to ~20 K). The EPR parameters used are listed in the figure legends; the magnetic field was calibrated with Bruker ER035M NMR Gauss meter.

D. X-band CW-EPR spectra analysis and simulations

The acquisition and control of the EPR spectra using the Bruker ELEXSYS-II E500 spectrometer as well as some level of processing was done using the proprietary Bruker Xepr

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software. The majority of the spectra analysis was performed using the Bruker WinEPR system software package.

III. RESULTS AND DISCUSSIONS

X-Band CW-EPR generated signals generated by ~240K green light illumination.

The temperature dependence plots of both the ML signal was generated using sucrose cryoprotectant PSII core samples in the S2 state (~240 K illuminated), which will give an indication on the spin states of excited states detected as well as the exchange interaction associated with each signal. The temperature dependence plot of ML signal (Fig.1), demonstrate that the multiline signal arises from center showing a strict ground state behavior over the temperatures range from 5 K to ~14 K. The energy at 15 K (where the depopulation of the spin ½ state is evident from Fig.1) can be obtained by solving the following Boltzmann equation 1:

$$\text{ML spin} = \frac{(2S_1+1)e^{-\Delta E(1)/kT}}{(2S_1+1)e^{-\frac{\Delta E(1)}{kT}}+(2S_2+1)e^{-\Delta E(2)/kT}} (S_1= ½, S_2=3/2) \quad (1)$$

Where ML spin is the multiline spin population, ΔE(1) is the energy of the spin ½ (ML) state, relative to some reference and ΔE(2) is the energy of the next higher spin state, assumed S = 3/2 (e.g. the g4.1[1]). For convenience we may take ΔE(1) = 0 and ΔE = ΔE(2).
A simple analysis then gives, from Fig.1 and equation 1

$$\text{Relative ML} = \frac{2}{2+4e^{-\Delta E/kT}} \quad \text{let } x = e^{-\Delta E/kT} \quad (1b)$$

$$= 1/(1+2x) \sim 0.4 \text{ at } 25K$$

$$1 = 0.4 + 0.8x$$

$$x \sim 0.7 \text{ at } 25K \text{ (from Fig. 5)}$$

$$\ln x = -0.3567$$

$$= -\Delta E/k * 25$$

$$\Delta E = 25 * 0.0083 * 0.3567$$

$$= 0.07401 KJ/mol \sim 74.01 J/mol$$

$$= 6.17 \text{ cm}^{-1}$$

NB: 1 cm-1 = 12 J/mol, k = 8.3 J K^{-1}/mol, therefore

$$1 \text{ cm} - 1 = 1.44 \text{ K} \left(\frac{12 J/mol}{8.3 JK^{-1}/mol}\right)$$

Using the simplest Mn magnetic exchange system, which may give rise to MLS and the g4.1[1] signals (first excited state g4.1 signal), the anti-ferromagnetically coupled Mn^{III}-Mn^{IV} dimer (total spin 7/2), can give rise to their respective temperature dependence behavior. The MLS results from the ground state (S= ½) state while the g4.1[1] signal, also generated at ~240 K by green light, is the first excited state (S=3/2). Fig.2 below shows the experimental temperature dependence plot of the multiline signal compared with the calculated spin populations using the Boltzmann distribution law for the Mn^{III}-Mn^{IV} dimer model developed below (equation 4). Firstly however, the above value of ΔE, which is the energy difference between the spin ½ and 3/2 states can be used to obtain an initial estimate of the exchange constant J for this effective dimer model, using Heisenberg spin Hamiltonian:

$$\mathcal{H} = -\sum_{ij} 2\boldsymbol{J}_{ij}.\mathbf{S}_i.\mathbf{S}_j \qquad i \neq j \quad (2)$$

For the dimer, take i = spin 1 (Mn1) and j = spin 2 (Mn2). Since the two spins are coupled into S= ½ and S= 3/2 states, it will be convenient to express everything in terms of the total spin. Therefore for the ground state spin ½ MLS excited state spin 3/2 g4.1[1] ($\mathcal{H} = -\sum_{ij} 2\boldsymbol{J}_{ij}.\mathbf{S}_i.\mathbf{S}_j$)

ST= total spin

$$\mathbf{S_T^2} = (\mathbf{S_1} + \mathbf{S_2})^2 = (\mathbf{S_1} + \mathbf{S_2})(\mathbf{S_1}+\mathbf{S_2}) = \mathbf{S_1^2}+\mathbf{S_1}.\mathbf{S_2} + \mathbf{S_2}.\mathbf{S_1} + \mathbf{S_2^2} \quad (2a)$$

$$\boldsymbol{S_T^2} = 2\,\boldsymbol{S_1}.\boldsymbol{S_2} + \boldsymbol{S_1^2} + \boldsymbol{S_2^2}$$

$$\boldsymbol{S_1} = S_{1x} + S_{1y} + S_{1z}$$

$$\boldsymbol{S_2} = S_{2x} + S_{2y} + S_{2z}$$

$$\boldsymbol{S_T} = S_x + S_y + S_z$$

$\boldsymbol{S_T^2} = S_T(S_T+1)$, $\boldsymbol{S_1^2} = S_1(S_1+1)$ and $\boldsymbol{S_2^2} = S_2(S_2+1)$.

Therefore using the expression above, the energy of the ground state spin ½ can be calculated (i.e. the value of 2 $S_1.S_2$), for the simple Mn^{III}-Mn^{IV} dimer considered here: where Mn^{III} is S_1= 2; Mn^{IV} is S_2=3/2, hence

$\mathbf{S_T^2}$ = ½ (½ + 1) = ¾

$\mathbf{S_1^2}$ = 2(2 + 1) =6

$\mathbf{S_2^2}$ = 3/2 (3/2 + 1) = 15/4

Energy for the MLS spin ½ will be

$$2\,\mathbf{S_{1a}}.\mathbf{S_{2a}} = \mathbf{S_T^2} - \mathbf{S_1^2} - \mathbf{S_2^2} = ¾ - 6 - 15/4 = -36/4 = -9. \quad (2b)$$

The same method can be used again in calculating the energy of first excited g4.11 state spin 3/2, which will be

$$2\,\mathbf{S_{1b}}.\mathbf{S_{2b}} = \mathbf{S_T^2} - \mathbf{S_1^2} - \mathbf{S_2^2} = 15/4 - 6 - 15/4 = -6$$

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Hence having calculated the energy difference from above in equation 2b to be 74.01 J/mol, then using the expression below, the value of J can be obtained:

$$\Delta E = -2J\,(S_{1b} \cdot S_{2b} - S_{1a} \cdot S_{2a}) \qquad (3)$$

74.01 J/mol = -J (-6 + 9)

J= -24.6. J/mol = ~ -2.0 cm-1.

This estimated J value, using the method above, perfectly fit the ML signal, as will be seen later. Therefore other energy differences can be calculated using the J-value above, and following the same procedure in calculating the value of 2 S_1S_2.
Energy difference between S= ½ and S = 5/2:

$$E\left(\frac{5}{2}\right) - E\left(\frac{1}{2}\right) = -2J(S_{1c} \cdot S_{2c} - S_{1a} \cdot S_{2a})$$

$$= 24.6 \text{ x } (-1 + 9) = 197 \text{ J/mol} = 16.4 \text{ cm}^{-1}$$

Energy difference between S= ½ and S = 7/2:

$$E\left(\frac{7}{2}\right) - E\left(\frac{1}{2}\right) = -2J\,(S_{1d} \cdot S_{2d} - S_{1a} \cdot S_{2a})$$

$$= 24.6 \text{ x } (6 + 9) = 370.2 \text{ J/mol} = 30.8 \text{ cm}^{-1}.$$

Knowing the energy differences between the states, then the Boltzmann distribution law was applied to calculate the spin populations for all the states based on the fact that the EPR signal intensities (Initial slopes) multiplied by temperature is proportional to spin population:

$$\text{Spin population (Spin i)} \propto \frac{S(S_i+1)e^{-\Delta E_i/kT}}{\sum_{\frac{1}{2}}^{\frac{7}{2}} S(S_i+1)e^{-\Delta E_i/kT}}$$

$$\text{Spin population (Spin i)} = A\,\frac{S(S_i+1)e^{-\Delta E_i/kT}}{\sum_{\frac{1}{2}}^{\frac{7}{2}} S(S_i+1)e^{-\Delta E_i/kT}} \qquad (4)$$

(Where i = ½, 3/2, 5/2, 7/2). The program in "Fig.S_1 in supporting material" of this paper was developed and used in computing the theoretical values using sigma plot software, which were later compared with experimental values. The theoretical values correspond to the spin ½ systems; hence clearly from the Fig.2, MLS arises from the ground spin ½ state of the assumed simple Mn^{III}-Mn^{IV} dimer, which is anti-ferromagnetically coupled. The curve (orange circles) through the experimental data points (red circles) in Fig.2 was generated with an estimated value of J = - 24.6 J/mol value, which was the best overall fit, with a scaling factor of 14×10^5, which is arbitrary due to the different methods of signal quantification used for the individual signal types. The other anti-ferromagnetically coupled dimer (Mn^{III}-Mn^{III} or Mn^{IV}-Mn^{IV}) of the OEC gives net spin zero (or close to it). Although other candidates have been proposed to generate these signals (tetramer $3Mn^{III}Mn^{IV}$ or $3Mn^{IV}Mn^{III}$) [53, 57] in the S_2 state.

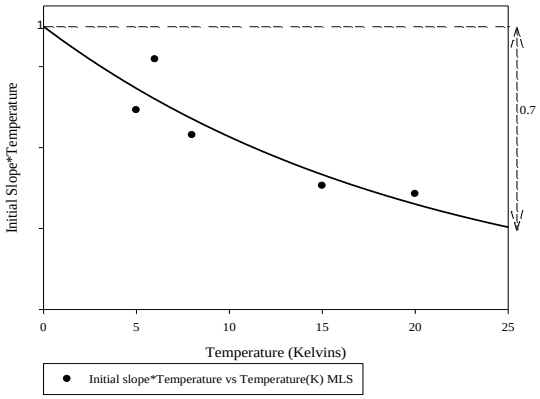

Figure 1: Showing the initial slope data of the multiline signal multiplied by temperature in Kelvins, plotted against temperature in Kelvins.

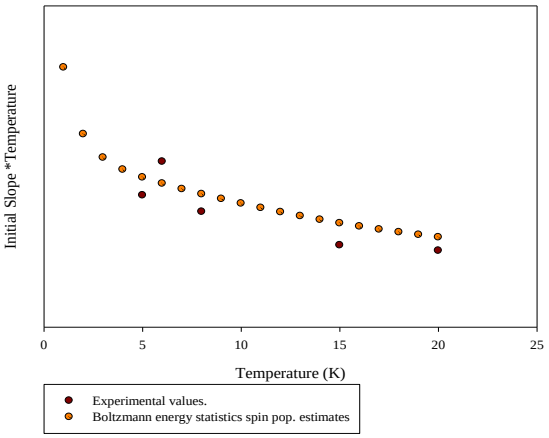

Figure 2: Temperature dependence plot of the Curie corrected (Initial slope * T) S2 multiline signal (S= ½) generated in PSII cores using sucrose buffer as cryoprotectant, illuminated at ~240 K. The experimental values were taken from Fig.1 above, and Boltzmann energy statistics spin population values were estimated for MLS with J = - 24.6 J/mol (~-2.0cm-1), and an arbitrary value of 14x10^5 as a scaling factor.

lV CONCLUSIONS

The temperature dependence plot of MLS (figure 1), demonstrates that the multiline signal arises from a centre

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showing a strict ground state behaviour over temperatures ranging from 5 K to ~14 K. However the presence of a nearby excited state is evident from the non-Curie behavior seen at temperatures above ~ 10K, where depopulation of the spin ½ state is evident. The energy gap to this excited state (assumed to be spin 3/2) at 15 K can be estimated by solving the Boltzmann equation 4. This energy was estimated to be equivalent to 15 degree Kelvin (~0.12 kJ/mol). This estimate is similar to that obtained from fitting the simple Mn^{III}-Mn^{IV} dimer model to the temperature dependences of the ML signals, as discussed above, with the effective exchange coupling value, J_{12} of – 2.0 cm^{-1}.

V REFERENCES

1. Dismukes, G.C. *Photochem.Photobiol*.1986, *43*, *99*-115.
2. Debus, R.J. *Biochim.Biophys.Acta*, 1992, *1102*, 269-352.
3. Yachandra, V.K.; Sauer, K.; Klein, M.P. *Chem.rev.* 1996, *96*, 2927-2950.
4. Debus,R.J.; Barry, B.A.; Babcock, G.T.; McIntosh, L. *Proceedings of the National Academy of Science, USA*.1988a, *85*, 427-430.
5. Kok, B.; Forbush, B.; McGloin, M. *Photochem.Photobiol*.1970, *11*,457.
6. Brudvig, G. W.; McEvoy, J. P. *Water splitting Chemistry of Photosystem II*.2006, *106*, 4455-4483.
7. Styring, S.;Rutherford, W.*Biochim.Biophys.Acta*.1988,*933*,480-483.
8. Hillier, W.; Wydrzynski, T. *Biochim.Biophys. Acta*, 2001, *1503*, 197-209
9. Åhrling,K. Pace, R.J.; A.;Evans, C.W., In *Photosystem II: The Light –Driven Water: Plastoquinone Oxidoreductase*, Wydrzynski,T.J ., Satoh,K.,Eds, Advances in Photosynthesis and Respiration 22:Springer-Verlag:Dordrecht,The Netherlands, The Netherlands, 2005,285-305.
10. Dismukes, G.C.; Siderer, Y. *Proceedings of the National Academy of Science, USA*.1981, *78*,274.
11. Åhrling, K.A.; Pace, R.J. *Biophysical Journal*. 1995, *68*, 2081-2090.
12. Smith, P.J.; Åhrling,K. A.;Pace, R. J. *J Chem Soc,Faraday Trans*, 1993, *89*, 2863-2868.
13. Koulougliotis, D.; Hirsh, D.J.; Brudvig, G.W. *J.Am.Chem.Soc*. 1992, *114*, 8322-8323.
14. Loll, B.; Kern, J.; Saenger, W.; Zouni, A.; Biesiadka, J.*Nature* 2005, *438*, *1040*-1044.
15. Ferreira, K.N.; Iverson, T.M.; Maghlaoui, K.; Barber, J.; Iwata, S.*Science* 2004,*303*,1831-1838
16. Zouni, A.; Witt, H.T.; Kern, J.; Fromme, P.; Krauss, N.; Saenger, W.; Orth, P. *Nature (London)*. 2001,*409*,739.
17. Kamiya, N.; Shen, J.R. *Proceedings of the National Academy of Science, USA*.2003, *100*, 98.
18. Guskov, A.; Kern, J.; Gabdulkhakov, A.; Broser, M.; Zouni, A.; Saenger, W. *Nature Structural & Molecular Biology*. 2009, *16*,334-342.
19. Umena, Y.; Kawakami, K.; Shen, J. –R.; Kamiya. N. *Nature*. 2011, *473*, 55-60.
20. Yachandra, V. K.; Sauer, K.; Klein, M. P. *Chem.Rev*.1996, *96*, 2927.
21. Petrie, S.; Pace, R.J.; Stranger, R. J.*Chem.Eur.J*. 2010, *16*, 14026-14042.
22. Pace, R.J.; Stranger, R. *Aust. J. Chem*. 2012, *65*,597-607
23. Gatt, P.; Petrie, S.; Stranger, R.; Pace, R.J. *Angew.Chem.Int.Ed*.2012, *51*, 12025-12028.
24. Hansson, O.; Andreásson, L. –E. *Biochim.Biophys.Acta*. 1982, *679*, 261-268.
25. Brudvig, G.W.; Sauer, K.; Casey, J. L. *Biochim.Biophys.Acta*. 1983, *723*, 366-371.
26. Bricker, T.M.; Pakrasi, H.B.; Sherman, L.A. *Archives of Biochemistry and Biophysics*.1985, *237*,170-176.
27. Porra, R.J.; Thompson, W.A.; Kriedemann, P.E. *Biochim.Biophys.Acta*.1989, *975*,384-394.
28. van Leeuwn, P.J.; Maaike, C.N.; van de Meent, E.J.; Dekker, J.P.; van Gorkom, H.J. *Photosynthesis Research*.1991,*28*,149-153.
29. Smith, P.J.; Masters, V.M.; Peterson, S.; Wydrzynski, T.; Styring, S.; Pace, R.J.; Krausz, E. *Biochemistry*. 2002, *41*, 1981-1989.

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Pyrolysis Of Coal Dust For The Production Of Tar And Useful Products

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***Abstract*— Coal mining for electricity production at Morupule coal mine in Palapye generates a considerable amount of fines or dust. The fines are generated through coal disintegration during various processes such as drilling, blasting, crushing and grinding. These coal dust fines have built-up over the years and have now become a nuisance and a health and environmental hazard to the community. If this is not dealt with accordingly, it can pose as a serious health threat as mineral dust can possibly cause diseases such as asbestosis and anthracnosis. This work addresses the potential hazards by assessing the feasibility of utilizing the coal through the process of pyrolysis for the production of useful products such as tar/bitumen. Pyrolysis is a viable process as it is a widely used in waste utilization practices including refinery sludge, plastic waste, biomass, rubber from scrap tyres, as well as in metallurgical processes for coke formation. The amount of gaseous emissions (NOx and SOx) and heavy metals are less than those released through other processes. The tar will be produced mainly for the construction of roads and pavements. The benefits of such a project, include the reduction of the health and environment hazard, additionally, there will be socio-economic benefits such as job creation and better roads in the village of Palapye.**

Keywords—coal, pyrolysis, tar

I. INTRODUCTION

With a record of 212 billion tonnes of coal resources in Botswana, the country relies solely on this resource for electricity, in addition to imported electricity from neighboring South Africa and Namibia. Coal mining for electricity production from the Morupule coal mine in Palapye generates a considerable amount of fines. The fines are generated through the disintegration on the coal during different processes such as drilling, blasting, crushing and grinding [1]. These coal dust fines have built-up over the years and have now become a nuisance and a health and environmental hazard to the community. If this is not deal with accordingly, it can pose as a serious health threat as mineral dust such as this can possibly cause diseases such as asbestosis and anthracosis [1]. This work addresses these issues by looking into utilizing the coal dust build-up through the process of pyrolysis for the production of useful products such as tar/bitumen. The goal is to improve the infrastructure (roads) in the village of Palapye. Such a project will solve the health and environmental concern which is caused by the coal mining activity. Furthermore, jobs will be creating at the tar production plant as well as during road construction. The primary products of coal pyrolysis include char, tar and inorganic gases [2]. All these products can be utilized in a variety of applications in the chemical metallurgical industries. These range from activated carbon or carbon nanotubes from the solid residue to products of refined coal tar/oil which are chemicals such as creosote oil, naphthalene, phenol and benzene [3].

II. BACKGROUND

A. Health Hazards caused by coal mining

The pyrolysis process in this work is employed to convert coal dust to tar. This has been motivated by the build-up of coal dust at the Morupule Coal mine in Palapye. Coal dust is respirable, and exposure to it by mine workers and inhabitants in the locality of the mine are at risk of lung diseases due to prolonged exposure.

Figure 1: Coal dust from mining environment

B. Benefits of the project

The process was selected as a coal utilization process to eliminate this problem. Pyrolysis is a viable process for this as it is a widely used in waste utilization practices including refinery sludge, plastic waste, biomass, rubber from scrap tyres as well in metallurgical processes for coke formation [4]; [5]. The amount of gaseous emissions (Nitrogen oxides and

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Sulphur oxides) and heavy metals are less than those released by other processes [6]. The tar will be produced mainly for the construction of roads and pavements. The benefits of such a project, include the elimination of the health and environment hazard, additionally, there will be socio-economic benefits such as job creation and better roads in the village of Palapye.

III. Pyrolysis Process

The main products from pyrolysis include vapors, tar, mixture of gases and charcoal [7]. These pyrolysis vapors can be condensed into light and heavy oils. They can also be converted into syngas via steam reforming, and further processing for synthetic liquid fuels. More applications of the vapors include conversion to non-energy products [8]. This is an indication of the versatility of the products of coal pyrolysis.

Coal → Gas (CH_4, CO, H_2, etc.)+*Liquid (tar) + Solid (coke)*

The yields and nature of the products are influenced by a number of factors including; the coal type/ characterization, coal particle size, carrier gas, pressure, temperature, residence time and heating rate [2]. These parameters also determine the reaction pathway that occurs during the process [9].

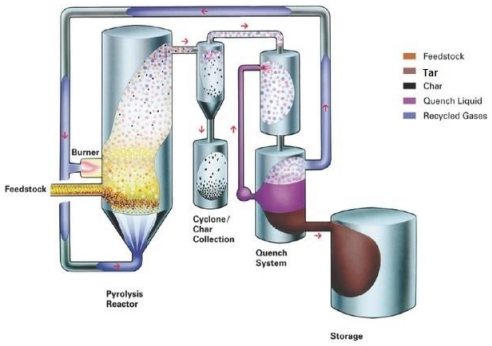

Figure 2: Coal pyrolysis process

A. Pyrolysis process stages

Heydari et al. [10] describe the process to occur in two main stages. The primary stage which occurs at 600°C and below includes the softening of coal, coke formation, release of vapors and development of plasticity. The aromatic carbon retained at this stage causes the coke formation while the hydro-aromatic carbon forms tar. Cracking that occurs in the secondary stage results in gas formation, low mass molecules and poly-condensation products [9]. This is consistent with Serio et al. [11]explanation which is summarized on the figure below.

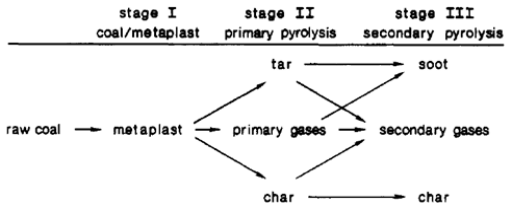

Figure 3: Coal pyrolysis model by Chemin and van Krevelen

Temperature is the most influential factor in pyrolysis, which according to Song et al. [12] enables compartmentalizing when it rises. Thermal degradation reactions start occurring at temperatures ~400°C through the cracking of bridge carbons possessing the lowest bonding energies [9]. Song et al. [11] described the five stages of pyrolysis according to the elevation in temperature as follows; drying stage, slow pyrolysis stage, fast pyrolysis stage, fast poly-condensation stage and slow poly-condensation stage. This information is important in considering coal utilization technology and product of interest.

B. Product evolution

Knowledge on the evolution of species as the process progresses provides understanding of the mechanisms and its relation to coal structure. This can also be used as a guide for selecting suitable parameters leading to high yields of product of interest, which is tar. The previously mentioned parameters influence species evolution and product distributions by altering the reactions occurring in the different stages pyrolysis [2].

The formation of tar results when larger ring fragments become hydrogen-saturated and distil as tar of medium molecular weight [9]. In a number of coals, this is primarily the first species released in pyrolysis reaction therefore it occurs at relatively low temperatures [13]. The tar however is prone to experience secondary vapour-phase reactions forming hydrocarbon carbons, soot and modified tar. As temperature rises, the composition of tar diminishes [6]. Ladner [5] found that at temperature above 1000°C negligible tar is produced because the volatiles would have cracked into gaseous components. Furthermore, rapid heating supports high tar yield as opposed to slow heating. However, in this work, the product of interest is a thick form of the tar which is produced as slow heating rates. High pressure opposes tar production but supports the methane and other hydrocarbon gas production. Table 1 shows the composition of pyrolysis products obtained with slow and rapid heating which were findings by Peters and Betling [7].

C. Tar formation

The The formation of tar occurs in a series of stages which includes, a) depolymerisation by rupture of weaker bridges in the coal macromolecule to release smaller fragments, b) re-polymerization of metaplast molecules, c) transport of lighter molecules away from the surface of the coal particles by combined vaporization and gas phase diffusion d) internal transport of lighter molecules to the surface of the coal particles and finally, the liquid phase in softening coal [14]. Figure 4 illustrates the reaction processes that occur in coal pyrolysis [13].

Tar formation occurs as molecular fragments broken down from the particle are released and transported out of the char particle without experiencing cross-linking reactions in the char particle. However in this work, the process should be designed

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in a way that cross-linking is promoted in order to produce a thicker form of the tar [15].

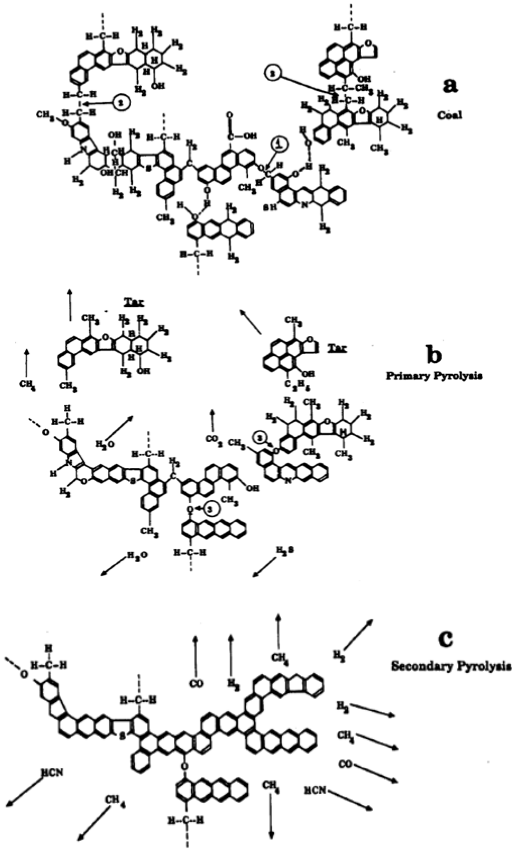

Figure 4: Hypothetical coal molecule during stages of pyrolysis [14]:

IV. Reaction Kinetics

The study of reaction rates in relation to time, concentration and temperature is carried out through the determining the kinetics of a reaction from experimental data [16]. Kinetic evaluation of the pyrolysis varies with different models. Pyrolysis reactions fall under the solid-state reactions, kinetic data from this type of reactions are conventionally obtained using discrete isothermal methods analysis [17]. However, more vigorous methods have been adopted, which are operated under non-isothermal conditions. They have gained much popularity due to their superior ability in terms of speed and efficiency. The single order reaction model is most commonly applied for coal weight-loss and species evolution [14]. In this model, the rate of total volatile species evolved dWi/dt is proportional to the instantaneous value of the source material [18].

$$dW_i/_{dt} = k_i(W_{oi} - W_i) \quad (1)$$

Where W_{oi} is the ultimate yield and W_i is the amount already evolved, k, the proportionality constant, is the rate constant obtained from the Arrhenius expression:

$$k_i = k_{oi}e^{\left[\frac{E_i}{RT}\right]} \quad (2)$$

This model is applicable to homogeneous systems where the decomposition of the source is caused by a single process with single activation energy E_i. More advanced models have been applied [18]. The kinetic parameters are determined through a set of thermogravimetric experimental data.

The thermal decomposition of coal predicted on a single reaction under isothermal conditions is predicted by the following equation ([16]; [12]):

$$\frac{dx}{dt} = k(T)f(x) \quad (3)$$

From the Arrhenius law:

$$k = Aexp\left(-\frac{E}{RT}\right) \quad (4)$$

Where t denotes time, *x* is the degree of conversion, *dx/dt* is the rate of the isothermal process, *f(x)* is the conversion function which represents the reaction model applied, it depends on the controlling mechanism:

$$\chi = \frac{w_0 - w_t}{w_0 - w_\infty} \quad (5)$$

Where w_0 and w_∞ are the initial sample weight and final weight respectively, w_t is the remaining sample at time t ([16] ; [11])

In the case of non-isothermal conditions, the rate expressions which are defined as a function of temperature at a linear heating rate *v* can be expressed through a superficial transformation of equation (3) to give ([15]; [17]; [19]).

$$\frac{dx}{dT} = \frac{A}{v}exp\left(-\frac{E}{RT}\right)f(x) \quad (6)$$

and;

$$v = \frac{dT}{dt} \quad (7)$$

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The non-isothermal method employs a heating rate,ν which is linear, to raise the temperature. The linear heating follows the equation:

$$T = T_0 + vt \quad (8)$$

Where T_0 is the starting temperature, ν is the linear heating rate (K/min) and T is the temperature at time, t.

Now, the following relationship is defined for non-isothermal experiments:

$$\frac{dx}{dT} = \frac{dx}{dt} \cdot \frac{dt}{dT} \quad (9)$$

Substituting (9) in (3) gives (6) [10].

According to the Freeman-Carroll hypothesis:

$$f(x) = (1-x)^n \quad (10)$$

$$\frac{dx}{dT} = \frac{A}{v} exp\left(-\frac{E}{RT}\right)(1-x)^n \quad (11)$$

Where Ea is the activation energy, R is the gas rate constant 8.314, n is the reaction order, T is the temperature and t is the time ([16]; [20]) . This relation (11) represents the differential form of the non-isothermal rate law.

Integrating (11), eq. (12) is obtained:

$$\int_0^x \frac{dx}{(1-x)^n} = \frac{A}{v}\int_0^T \exp\left(-\frac{E}{RT}\right) dT = -\frac{AR}{vE}\left(1-\frac{2RT}{E}\right)\exp\left(-\frac{E}{RT}\right) \quad (12)$$

Natural logarithm on (12) after integration the (13) or (14) is obtained;

$$ln\left[-\frac{\ln(1-x)}{T^2}\right] = ln\left[\frac{AR}{vE}\left(1-\frac{2RT}{E}\right)\right] - \frac{E}{RT} \quad (n=1) \quad (13)$$

$$ln\left[-\frac{\ln(1-x)^{1-n}}{T^2(1-n)}\right] = ln\left[\frac{AR}{vE}\left(1-\frac{2RT}{E}\right)\right] - \frac{E}{RT} \quad (n\neq 1) \quad (14)$$

The value of E is usually very large, which makes the term 2RT/E very small (~0). Therefore in the case for a first order reaction, X = (1/T), a= ln[(AR/vE)(1-(2RT/E))], b= -(E/RT), Y= ln[(ln(1-x))/T^2]. This leads to a linear equation of Y= a+bx, which enable the activation energy and pre-exponential factor A to be calculated by slope and line intercept respectively [15]; [11].

The single order model has been applied by a number of researchers, including Song et al. [11] who used the model to study the kinetics of low rank coal from different locations in China. Kok [21]applied this method when determining the kinetic parameters in the pyrolysis of alsphaltite from Silopi, Turkey. Gao et al. [15] also used this model in their work in which they were determining the properties and reaction kinetics of low rank coal from Western China. Dai et al. [20] in their study, which was aimed at determining the kinetics of blended from China in a fluidized bed reactor, used the model.

V. Effects of Process Parameters on Reaction Kinectics

A. *Effect of heating rate and final temperature on pyrolysis process*

The A number of researchers have found that the heating rate has an effect on the oil yield in coal pyrolysis. Seebauer et al. [22] found that high heating rate promotes high yield of volatile matter. However, there was no significant difference in the ultimate yield of the oils, which they attributed to the small range of heating rate used in their work. The high heating rates enhance the tar production process in that, it allows less time for tar cracking which culminated to more tar and less methane [23]. Gao et al. [15] explain that an increase in heating rate, influences the kinetic parameter in that is causes an increase in the activation energy and the pre-exponential factors. The heating rate affects the fracture speed of the coal molecule [16]. Altun et al. [24]studied the effect of heating rate on asphaltite from Silopi. They report that at lower heating rates, heat transfer was more effective in the particles, which was caused by the slow rate of heating. Effective heat transfer results in better cracking in the molecules which led to the release of more volatiles.

B. *Effect of particle size*

In their work, Gao et al. [15] stated that the kinetic parameters seemed to not show an obvious change with the increase of particle size. They explained that with regards to particle size, pyrolysis is governed by the mass and heat transfer, as well as the physical properties of the raw material. These findings were consistent with Altun et al. [23] who find no significant change in the kinetic parameters with the size of particle. The theory of secondary reactions in coal pyrolysis suggests that as the tar is cracked as it transports in the pores of the coal molecule [22].

C. *Effect of pressure*

A high pressure in the system promotes gas production more than liquid production [21]. This is due to the fact that pressure influences reactions in the metaplast which produces methane and carbon dioxide [21].

VI. Crosslinking in Coal Pyrolysis

The break-up of the macro-molecular network in coal structure is controlled by rates of bond breaking, mass

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TABLE 1: EXPRESSIONS FOR THE MOST COMMON REACTION MECHANISMS IN SOLID STATE REACTIONS [25]

Reaction model	***f(x)=(1/k)(dx/dt)***	***g(x)= kt***
Reaction order		
Zero order	$(1-x)^n$	X
First order	$(1-x)^n$	-ln(1-x)
nth order	$(1-x)^n$	$(n-1)^{-1}(1-x)^{(1-n)}$
Nucleation		
Power law	$n(x)^{(1-1/n)}$; n=2/3, 1,2,3,4	x^n; n=3/2, 1,1/2,1/3,1/4
Exponential law	Lnx	X
Avrami-Erofeev(AE)	$n(1-x)[-\ln(1-x)]^{(1-1/n)}$; n=1,2,3,4	$[-\ln(1-x)]^{1/n}$; n=1,2,3,4
Prout-Tompkins(PT)	x(1-x)	$Ln[x(1-x)^{-1}]+C^a$
Diffusional		
1-D	1/2x	x^2
2-D	$[-\ln(1-x)]^{-1}$	(1-x)ln(1-x)+x
3-D(Jander)	$3/2(1-x)^{2/3}[1-(1-x)^{1/3}]^{-1}$	$[1-(1-x)^{1/3}]^2$
3-D	$3/2[(1-x)^{-1/3}-1]^{-1}$	$1-2/3x-(1-x)^{2/3}$
Contracting geometry		
Contracting area	$(1-x)^{(1-1/n)}$; n=2	$(1-x)^{(1-1/n)}$; n=2
Contracting volume	$(1-x)^{(1-1/n)}$; n=3	$(1-x)^{(1-1/n)}$; n=3

[a] Integration constant

transport and crosslinking. Cross linking reactions determine the ultimate tar yield as well as the molecular distribution of the tar product [15]. This means that the greater the extent of these reactions, the higher the molecular weight of the tar, which would mean a more viscous product. Crosslinking can be associated with the decomposition of carboxyl groups in the coal molecule to form carbon dioxide [26]. In order to promote cross-linking, the heating rate should be slow as rapid heating has proven to substantially reduce the occurrence of these reactions [27] . Additionally, they can be promoted by oxidation [25].

A method of monitoring crosslinking reactions in coals works by measurement of solvent swelling ratio as described by Green [27]. It is used to determine the crosslinking changes during pyrolysis. The extent of crosslinking reactions is dependent on the coal rank. Bituminous coal is said to crosslink at higher temperatures than lignites. Coal from Morupule coal mine is sub-bituminous to bituminous [28]; therefore it is expected to crosslink at relatively high temperatures based on the latter statement.

VII. COAL CHARACTERIZATION

In order to apply the most efficient clean coal utilization technology, the coal must undergo analysis to determine its physiochemical properties. The results are crucial in identifying the most suitable utilization technology [29]. These tests include the proximate analysis, ultimate analysis and miscellaneous analysis [3].

The proximate analysis involves determining the moisture, ash content, volatile matter and fixed carbon content. The ultimate analysis provides information on the elements present in the coal sample which include carbon, nitrogen, hydrogen, sulphur, oxygen as well as the ash content [27]; [28]. This can be used to evaluate combustion characteristics and approximate sulphur and nitrogen oxides [30]. Miscellaneous analysis is commonly carried out for coal buyers, at their request. It comprises of determining the calorific value, swelling index, grindability, ash fusibility and plastic properties of coal.

TABLE 2 adopted from Gupta [29] shows a summary of important bulk properties of coal which influence conversion as well as the analysis required for the estimation of the properties.

TABLE 2: PHYSICAL PROPERTIES OF COAL AND RESPECTIVE ANALYSIS

Properties	**Analysis**
Chemical properties	Proximate analysis, ultimate analysis and ash analysis
Physical properties	Density, specific gravity, pore structure, surface area, reflectivity
Mechanical properties	Hardness/abrasiveness friability, grindability, dustiness index
Thermal properties	Calorific value, heat capacity, thermal conductivity, plastic, agglomerating index, free swelling index
Electrical properties	Electrical resistivity, dielectric constant, magnetic susceptibility

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VIII. Conclusion

Coal pyrolysis products carry the potential to be used in a wide range of applications; these include tar for road construction and synthesis of useful chemicals such as benzene. Improving this process to an efficient one which yields quality tar suitable for road construction and other chemicals will broaden the usefulness of the process. This in turn promises viability, which would validate the purpose of this work.

Acknowledgment

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References

[1] N. Demirel and C. Karpuz, "Health and Safety Issues in Coal Mining," in *Coal Production and Processing Technology*, R. Gupta and M. Riazi, Eds. 2016, pp. 209–227.

[2] W. C. Xu and A. Tomita, "The effects of temperature and residence time on the secondary reactions of volatiles from coal pyrolysis," *Fuel Process. Technol.*, vol. 21, no. 1, pp. 25–37, 1989.

[3] B. Saikia, A. Saikia, and B. Baruah, "Nature and Chemistry of Coal and its Products," in *Coal Production and Processing Technology*, M. Riazi and R. Gupta, Eds. Boca Raton: Taylor and Francis Group, LLC, 2016, pp. 3–32.

[4] C. Dorado, C. A. Mullen, and A. A. Boateng, "H-ZSM5 catalyzed co-pyrolysis of biomass and plastics," *ACS Sustain. Chem. Eng.*, vol. 2, no. 2, pp. 301–311, 2014.

[5] J. D. Martínez, R. Murillo, and T. García, "Production of carbon black from the waste tires pyrolysis," *Bol. Grup. Español Carbón*, no. i, pp. 10–14, 2013.

[6] K. Luo, C. Zhang, S. Zhu, Y. Bai, and F. Li, "Tar formation during coal pyrolysis under N2 and CO2 atmospheres at elevated pressures," *J. Anal. Appl. Pyrolysis*, vol. 118, pp. 130–135, 2016.

[7] W. R. Ladner, "The products of coal pyrolysis: properties, conversion and reactivity," *Fuel Process. Technol.*, vol. 20, no. C, pp. 207–222, 1988.

[8] R. Hawkins, J. O. N. Nilsson, R. Oglesby, and D. Day, "Biomass Pyrolysis Technology Biomass Pyrolysis vs . Conventional Biomass to Energy Systems," vol. 5, no. 7, pp. 381–387, 2007.

[9] H. Jüntgen, "Review of the kinetics of pyrolysis and hydropyrolysis in relation to the chemical constitution of coal," *Fuel*, vol. 63, no. 6, pp. 731–737, 1984.

[10] M. Heydari, M. Rahman, and R. Gupta, "Kinetic study and thermal decomposition behavior of lignite coal," *Int. J. Chem. Eng.*, vol. 2015, 2015.

[11] M. A. Serio, D. G. Hamblen, J. R. Markham, and P. R. Solomon, "Kinetics of Volatile Product Evolution in Coal Pyrolysis : Experiment and Theory," *Energy & Fuels*, vol. 1, no. 21, pp. 138–152, 1987.

[12] H. Song, G. Liu, J. Zhang, and J. Wu, "Pyrolysis characteristics and kinetics of low rank coals by TG-FTIR method," *Fuel Process. Technol.*, vol. 156, pp. 454–460, 2017.

[13] K. R. Doolan, J. C. Mackie, and R. J. Tyler, "Coal flash pyrolysis: secondary cracking of tar vapours in the range 870-2000 K," *Fuel*, vol. 66, no. 4, pp. 572–578, 1987.

[14] P. R. Solomon, M. A. Serio, and E. M. Suuberg, "Coal pyrolysis: Experiments, kinetic rates and mechanisms," *Prog. Energy Combust. Sci.*, vol. 18, no. 2, pp. 133–220, 1992.

[15] V. Deshpande, Girish, R. Solomon, Peter, and A. Serio, Michael, "Cross-linking reactions on coal pyrolysis," *Energy & Fuels*, vol. 59, pp. 310–321, 1988.

[16] Z. Gao, M. Zheng, D. Zhang, and W. Zhang, "Low temperature pyrolysis properties and kinetics of non-coking coal in Chinese western coals," *J. Energy Inst.*, vol. 89, no. 4, pp. 544–559, 2016.

[17] J. E. White, W. J. Catallo, and B. L. Legendre, "Biomass pyrolysis kinetics: A comparative critical review with relevant agricultural residue case studies," *J. Anal. Appl. Pyrolysis*, vol. 91, no. 1, pp. 1–33, 2011.

[18] L.-P. Wiktorsson and W. Wanzl, "Kinetic parameters for coal pyrolysis at low and high heating rates—a comparison of data from different laboratory equipment," *Fuel*, vol. 79, no. 6, pp. 701–716, 2000.

[19] S. Vyazovkin, A. K. Burnham, J. M. Criado, L. A. P??rez-Maqueda, C. Popescu, and N. Sbirrazzuoli, "ICTAC Kinetics Committee recommendations for performing kinetic computations on thermal analysis data," *Thermochim. Acta*, vol. 520, no. 1–2, pp. 1–19, 2011.

[20] C. Dai, S. Ma, X. Liu, and X. Liu, "Study on the pyrolysis kinetics of blended coal in the fluidized-bed reactor," *Procedia Eng.*, vol. 102, pp. 1736–1741, 2015.

[21] M. V. Kok, "Coal Pyrolysis: Thermogravimetric Study and Kinetic Analysis," *Energy Sources*, vol. 25, no. February 2015, pp. 1007–1014, 2003.

[22] V. Seebauer, J. Petek, and G. Staudinger, "Effects of particle size, heating rate and pressure on measurement of pyrolysis kinetics by thermogravimetric analysis," *Fuel*, vol. 76, no. 13, pp. 1277–1282, 1997.

[23] J. Gibbins-Matham and R. Kandiyoti, "Coal pyrolysis yields from fast and slow heating in a wire-mesh apparatus with a gas sweep," *Energy & Fuels*, vol. 2, no. 4, pp. 505–511, 1988.

[24] N. E. Altun, C. Hicyilmaz, and M. V. Ko, "Effect of particle size and heating rate on the pyrolysis of Silopi asphaltite," vol. 67, pp. 369–379, 2003.

[25] A. Khawam and D. R. Flanagan, "Role of isoconversional methods in varying activation energies of solid-state kinetics: II. Nonisothermal kinetic studies," *Thermochim. Acta*, vol. 436, no. 1–2, pp. 101–112, 2005.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

[26] P. R. Solomon, D. G. Hamblen, R. M. Carangelo, A. Michael, and G. V Deshpande, "Models of Tar Formation During Coal Devolatilization," *Combust. Flame*, vol. 71, pp. 137–146, 1988.

[27] R. Solomon, Peter, A. Serio, Michael, V. Deshpande, Girish, and E. Kroo, "Cross-linking reactions during coal conversion," *Energy & Fuels*, vol. 4, pp. 42–54, 1990.

[28] R. Grynberg, "Coal Exports and the Diversification of Botswana's Economy," 2012.

[29] L. Yi, J. Feng, Y. Qin, and W. Li, "Prediction of elemental composition of coal using proximate analysis," *Fuel*, vol. 193, pp. 315–321, 2017.

[30] R. Gupta, "Advanced coal characterization: A review," *Energy and Fuels*, vol. 21, no. 2, pp. 451–460, 2007.

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Energy Audit of a Meat Processing Plant

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Abstract **- The study has come up with energy saving solutions for different sections or equipment of a meat processing plant in Botswana. Much of the old original equipment at the abattoir is still in place and there exists an opportunity to lower energy consumption through the adoption of modern energy saving measures. Modern engineering instruments were used to determine the efficiencies of various manufacturing equipment so that cost-benefit analysis could be carried out. The use of premium efficient motors and variable speed drives can significantly lower motor power use. 25 motors were analysed and it was ascertained that the adoption of premium motors could save P71702 annually with payback periods of less than 3 years. An ultrasonic detector pointed out leaks in the compressed air system however a leakage test estimated that 35% of the air in the system is lost to leaks while about P11000 could be saved annually by reducing the discharge pressure. The water and energy consumption figures are benchmarked against those from modern plants. It was found that the plant's electricity and water consumption are much higher compared to modern plants. Software analysis shows that insulating certain surfaces in the plant's thermal systems can be economically viable. Installation of efficient sterilizers could save about P780000 annually in water and coal. Retrofitting light fixtures was found to have a potential to save about P66000 in electricity costs annually. Maintenance practices were scrutinised as adequate maintenance could lead to energy savings, lower overall maintenance costs and higher machine availability.**

Keywords: Energy audit, efficiency, abattoir

I. INTRODUCTION

The Industrial sector is the largest users of energy around the world [1] . In order for countries to develop and grow economically, they need a sound industrial sector and the growth is closely related with the growth in its energy consumption [2]. A systematic approach, to monitor industrial energy consumption and pin-point sources of wastage, is known as energy audit [1]. On the other hand the European Committee for Standardization defines an energy audit as a systematic procedure to obtain adequate knowledge of the existing energy consumption profile of a building or group of buildings, of an industrial operation and/or installation of a private or public service, identify and quantify cost-effective energy saving opportunities and report the findings [3]. In order to reduce energy consumption for sustainable and energy-efficient manufacturing, continuous energy audit and process tracking of industrial machines are essential. Meanwhile, industrial application of energy efficiency technologies have shown a promising potential to reduce energy consumption and associated costs [4]. First world countries have started implementing and enforcing energy saving measures within their industrial sectors. China has introduced many policies, programs, reporting requirements in support of the achievement of this goal, as its industrial sector consumes between 60% and 70% of China's primary energy [5]. Europe in 2006 launched the ESD (Energy Service Directive 2006/32/EC) aimed at reducing energy consumption by 9% in the European Union. Further they introduced stricter 20-20-20 energy savings policy in 2008 aimed at reducing energy consumption in all sectors of European society by 20% by the year 2020 [6]. The US has been at fore front energy efficiency regulation (EER) and energy research. The fundamental guidelines provided by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) are a useful reference for energy professionals worldwide. In the US, there are many other high-quality publications on energy auditing and energy management [7]. The situation in Africa is different, as the continent generally lags behind in formulating and implementing energy laws and policies aimed at enhancing energy efficiency. Therefore in African countries energy audits are not mandatory while various companies voluntarily conduct energy audits. A few published literatures on energy management and audit in Africa have been identified. These audits are mainly carried out by universities [8]. Therefore there is a need for African countries to emulate first world countries by ensuring industrial plants carryout mandatory energy audits.

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II. BACKGROUND OF THE PLANT

The company was created in 1965 to buy and slaughter livestock, promote the livestock industry and interests of livestock producers, and export the beef sector's products. Beef has made a significant contribution to the Botswana economy. In the early years of independency beef was the only foreign exchange earner. In 2013, its total beef exports were US$116.6 million, representing a world export market share of 0.3% making Botswana Africa's largest beef exporter. The company has 3 plants in Botswana located in Lobaste, Maun and Francistown. The plant studied is in Francistown, has about 200 employees and has a slaughtering capacity of 400 cattle per day.

III. THE SYSTEMATIC ENERGY AUDIT

A systematic approach is required in order to carry out energy audits effectively. Fig. *1* shows the steps taken in carrying out the audit.

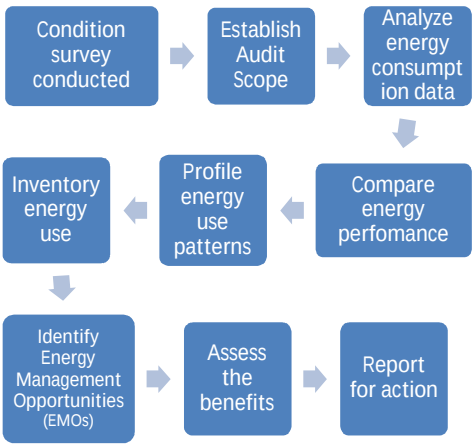

Fig. 1 Summary of the energy audit process

During the condition survey data was collected and analysed. Following the analysis the plant's energy and water consumption data were compared to benchmark figures from other abattoirs mostly from industrialised countries. The benchmark specific energy and water consumptions are shown in TABLE 1 according to the advancement of the technology in place.

TABLE 1 BENCHMARKS FOR ABATTOIRS-250KG BODIES [9]

	Traditional technology	Average technology	Latest technology
Energy (kwh/head)	5000	2500	1000
Water (L/head)	300	125	70

COWI [9] quotes rendering energy consumption benchmarks at 1800 to 7000kj/kg of rendered material such as blood meal and carcass meal.

TABLE 2 PLANT SPECIFIC ENERGY CONSUMPTION RATES

Figure	Consumption
Electricity (KWH/head)	155
Water (KL/head)	5600
Rendering (Kwh/kg)	0.11
Heat energy (KWH)	880

A. Motors

The plant's motors were studied and an inventory of the largest motors was made. Measurements and motor information was taken in order to:

1. Ascertain if the motors should be replaced with more efficient motors

2. Determine if VSDs can be installed to lower energy costs

3. Determine if the motors are overloaded so they can be replaced with smaller motors.

Other factors such as voltage imbalance, over/under voltage were checked to see if they were within IEEE standards. The maintenance program was scrutinised to check if proper maintenance practices were followed. Saidur, (2009) gives some recommendations on motor maintenance. A power meter was used to measure voltage, current, harmonics and power factor and a tachometer measured motor speed. Motormaster software was used to help determine the cost effectiveness of motor retrofits. 25 motors were studied and it was found that 23 could be retrofitted with premium motors economically with paybacks of less than three years. The retrofits could result in of P54993 in electricity savings annually.

A 40 KW blood cooker motor is considered for replacement with an ultra-efficient motor. The present motor has an efficiency of 89.8% and the proposed motor

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has an efficiency of 94%.The load factor is 0.82 and the motors are estimated to operate for 5500 hours. The differential cost of the ultra-efficient motor versus the standard motor is P3000. In order to decide the economic viability of changing the motor the payback period is computed as follows.

$$\text{Saved KWH} = \text{N.P.Lf.} \left(\frac{1}{\eta_{std}} - \frac{1}{\eta_{eff}}\right) \quad [1]$$

Where:

N is the total number of operating hours annually

P is the rated power of the motor

Lf is the average load factor

η_{std} and η_{eff} are the efficiencies of the old motor and the proposed motor respectively.

Therefore the energy saved by changing motors is calculated as follows:

$$\text{Saved KWH} = 5500.40.0.82 \left(\frac{1}{0.898} - \frac{1}{0.94}\right) = 10327 \text{ KWH/yr}$$

$$\text{The payback period} = P3000\left(\frac{3000}{10327 \times 0.8}\right) = 0.36\ years$$

B. Lighting

The plant has three types of bulbs fluorescent tubes, sodium high pressure bulbs, and mercury vapour bulbs. A lightmeter was used to determine lighting levels and the areas that were overlit were recommended for delamping. The company had begun replacing its outdated T12 lamps with the more efficient and modern T8 lamps. The following retrofits were recommended:

- Replacing 250 W mercury vapour lamps with 215 W Sodium High Pressure lamps. This retrofit represents a savings of 65W per lamp including ballast savings [10]
- Replacing 40W T12 lamps with T5 lamps that use 40% less energy.
- Delamping selected lamps
- Retrofitting 65W T12 lamps with 58W T8 lamps.

In total about P69000 in electricity costs could be saved annually by employing these measures. Motion sensors and dimmers could provide significant electricity savings in areas that are scarcely occupied or are partly lit with daylight such as the storerooms, chiller rooms and the administration block. Refrigerated areas could save additional energy from the reduced heat loads.

C. Compressed air systems

The plant's air requirements are met by one 132 KW compressor. The compressor supplies production equipment such as the bone crusher blower, vacuum packaging machines, pneumatic valves, splitting saws, and dehorning tools. The compressor discharge pressure is 7.5 bar while most equipment require pressure around 6 bar.

In one audit at a Vietnamese plant 65% of compressed air was being lost to leakages [11].Therefore it is prudent to establish the leakage rate of a compressed air system. In order to determine the leakage rate all the air consuming equipment was switched off and the onload and offload times were recorded. The leakage rate was found as follows:

$$\text{Leakage rate} = \frac{\text{time loaded}}{\text{loaded time+unloaded time}} \quad [2]$$

$$\text{Leakage (\%)} = \frac{13.8 \times 100}{(13.8+24.8)} = 35\%$$

About 35% of all air produced by the compressor is lost to leaks. An ultrasonic leak detector was used to locate leaks on the air distribution system. Considering that 90% of the lifecycle costs of compressor are due to electricity costs a program to repair leaks should prove to be highly economical. About P95000 in electricity costs could be saved annually by repairing the leaks. Compressors are often oversized to meet to anticipated future air system growth and safety allowances. The demand for compressed air is highly variable and is very low on weekend as less than 5% of compressed air capacity is required. Underloaded compressors are less efficient. Therefore a modular combination of VSD controlled compressors of different sizes was recommended. The smaller compressor(s) would run during periods of low air demand. The pressure requirements of each air drawing equipment was noted to ascertain if some of the equipments pressure requirements were low enough to be supplied by blowers but almost all equipment have high pressure requirements that are above 6 bar that can only be met by compressors.

D. Thermal Systems

The plant has two boilers that supply superheated steam at 133°C to a heat exchanger and process equipment. The heat exchanger indirectly supplies hot water for cleaning, sterilisers and other uses. Sterilisers require water at 82°C and hand wash water at 42°C. Recommendations for improved efficiency include the fitting of an economiser, installation of flue gas analysers, fitting of insulation on the boiler and bare steam pipes. Blowdown is carried out periodically however sensors that test boiler water should be can be installed to lower the amount of blowdown

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water and consequently save coal. An infrared thermometer was used to find surfaces that could benefit from insulation or added insulation and generally these are surfaces above 50°C. A software called 3E plus was used to determine the payback period of installing insulation on the surfaces that were considered. The software can give economic analysis of various types of insulation of varying thicknesses for a given surface. Software analysis shows that insulating any of the surfaces has short payback periods of between 0.5 to 4 years with a potential to save tens of thousands of pula in

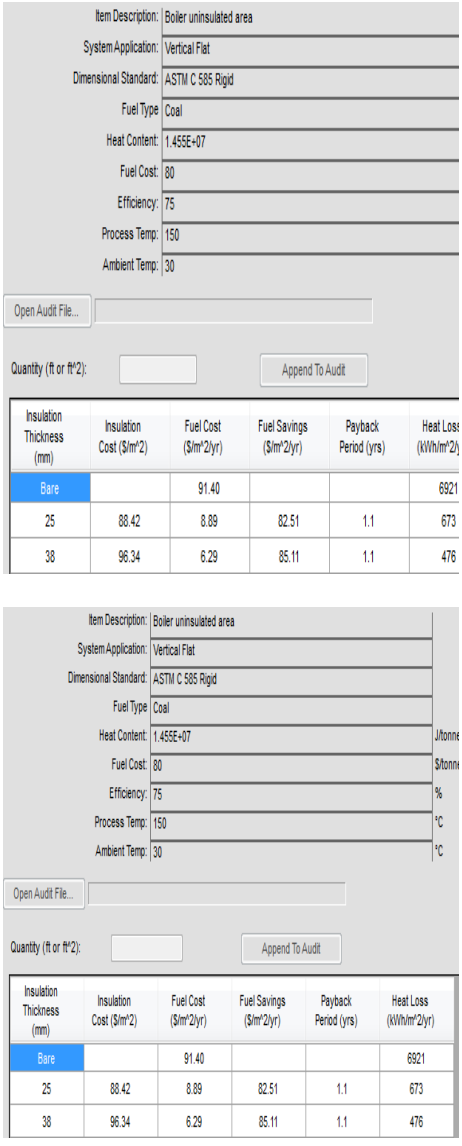

Fig. 2 Insulation software analysis

E. Water Audit

Cutting water use will also help lower energy costs as all the water is pumped at pressure, while some water is heated and some will end up in the wastewater treatment facility. The 32 sterilizers in the deboning and slaughter were studied and found to use hot water (82°C) at a rate of 12L per minute while the most efficient sterilizers on the market use water at rate as low as 0.5L per minute. It was estimated that about P484000 could be saved annually in water costs and P296000 saved in heating or coal costs. Over 50% of the cold water consumed at the plant is dedicated to cleaning. However pressurized water is used for sweeping the floor. Dry cleaning before hosing could save up to 30% of water used for cleaning. The plant can adopt better hose nozzles that could save water by creating a more diverging stream at stream at higher pressure and lower flow rates as illustrated by Fig. 4.The plant could also save water by adopting low flow shower heads, cisterns and faucets. However this strategy is most economical when the above-mentioned fittings need to be replaced with new ones.

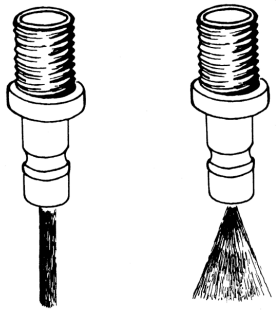

Fig. 4 Diverging angle of flow

F. Processes

Carcassmeal and bloodmeal are cooked in cookers heated by superheated steam. Hot condensate water at around 88°C is released into the sewer system while exhaust vapour is released into the atmosphere. A recommendation was made to fit an exchanger that would recover heat from the condensate and vapour and transfer it to boiler make up water. This retrofit was estimated to save about 116 tons of coal annually.

G. Pumps

The plant has three pumps that supply the plant with cold water. The pumps have old rewound motors and are manually controlled by an operator who switches them on and off depending on the demand. To improve efficiency the pumps should be fitted with a VSD that would operate the necessary number of pumps at any given point and run the motors at the ideal speeds. The

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VSD is coupled to a pressure transducer as shown in Fig. 5 and it runs the pumps depending on the pressure in the system.

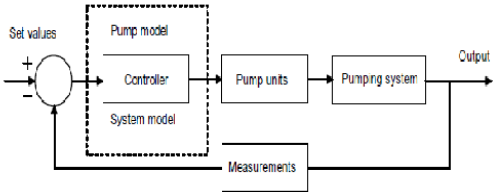

Fig. 5 Proposed water system logic

Poor maintenance practices at the plant result in significant energy losses. An example is a worn out impeller as shown in Figure 4 which would result in the pump working inefficiently and performing poorly. Replacing the existing pump motors with modern premium efficiency motors would also save a significant amount of energy.

Fig. 6 A worn out impeller

H. Refrigeration and HVAC systems

The plant has a 1200 ton refrigeration system which provides cooling power to the chillers and plate freezers and refrigerated zones namely the deboning section, storage and offal sections. Following analysis of the refrigeration system the following recommendations were made:

- The system is 27 years old and suffers from repeated ammonia leaks which have caused injury to some employees. The system needs a major overhaul or replacement
- The refrigeration temperatures in the deboning zone and the plate freezers are 5°C and -15°C respectively. However the required temperatures for the deboning section and plate freezers are can reach 7°C and -12°C respectively meaning the refrigeration system is working harder than it should and wasting energy
- VSDs should be installed on motors on the evaporators, condensers and ammonia pumps
- Doors were left open for extended periods. Door openings should be minimized to save energy especially when freezer temperatures are concerned
- It is not common for companies to recover the heat from condenser water. However this is possible and the heat can be used to heat water. In this case boiler feedwater can be preheated by condenser heat. The system currently employs open circuit condensers which release water as waste into the drainage system. A closed circuit system which recycles all the water could save a significant amount of water
- The system should be reverted back to automatic control
- The plant has old louvred windows which create infiltration resulting in higher air-conditioning load
- In hot and humid areas make up air can account for between 20-40% of the total energy consumed in air-conditioning systems [12]. Therefore a significant amount of heat can be recovered by means of heat exchangers or heat wheels.

I. Other recommendations

Some buildings' roofs are not coated resulting in them having low reflectivity and consequently higher cooling loads. A coating with high albedo needs to be applied to the necessary buildings. Thermal imaging cameras can be used to perform thermal analysis of the buildings and thermal equipment to provide the basis for recommending insulation of relevant areas. Tallow can be used to power the boiler or create biodiesel that can fuel the plants' vehicles. A compressor capacity measurement test can be used to ascertain the prevailing performance of the compressor. Compressors that are faulty or too old normally suffer a significant drop in performance therefore comparing the present capacity to the design capacity can highlight wasteful energy consumption. Experienced technicians would then determine the cause of the wastage.

FUTURE SCOPES

The author intends to publish more works on energy auditing and energy efficiency. Work on a paper on

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energy efficiency regulation is currently underway. Future works on energy auditing will focus on specific applications such pumps, compressors and motors. Case studies will conducted on companies in Botswana especially energy intensive mines. Collaborations with energy experts on future projects will be sought.

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REFERENCES

[1] R. Saidur, 'A review on electrical motors energy use and energy savings', 2009.

[2] M. Thirugnanasambandam, M. Hasanuzzaman, R. Saidur, M. B. Ali, S. Rajakarunakaran, D. Devaraj, and N. A. Rahim, 'Analysis of electrical motors load factors and energy savings in an Indian cement industry', *Energy*, vol. 36, no. 7, pp. 4307–4314, Jul. 2011.

[3] European Commission, *The Energy Efficiency Directive*. http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027.

[4] P. Ghadimi, W. Li, S. Kara, and C. Herrmann, 'Integrated Material and Energy Flow Analysis towards Energy Efficient Manufacturing', *Procedia CIRP*, vol. 15, pp. 117–122, 2014.

[5] B. Shen, L. Price, and H. Lu, 'Energy audit practices in China: National and local experiences and issues', *Energy Policy*, vol. 46, pp. 346–358, Jul. 2012.

[6] S. Backlund and P. Thollander, 'Impact after three years of the Swedish energy audit program', *Energy*, vol. 82, pp. 54–60, Mar. 2015.

[7] G. Dall'O', A. Speccher, and E. Bruni, 'The Green Energy Audit, a new procedure for the sustainable auditing of existing buildings integrated with the LEED Protocols', *Sustain. Cities Soc.*, vol. 3, pp. 54–65, Jul. 2012.

[8] O. T. Masoso and L. J. Grobler, 'The dark side of occupants' behaviour on building energy use', *Energy Build.*, vol. 42, no. 2, pp. 173–177, 2010.

[9] UNEP, 'Cleaner Production Assessment in Meat Processing', 2000.

[10] B. . Capehart, W. . Turner, and W. . Kennedy, *Guide to Energy Management*, 7th ed. Lilburn: Fairmount Press, 2012.

[11] M. Yang, 'Air compressor efficiency in a Vietnamese enterprise', *Energy Policy*, vol. 37, no. 6, pp. 2327–2337, Jun. 2009.

[12] L.-Z. Zhang, 'Progress on heat and moisture recovery with membranes: From fundamentals to engineering applications', *Energy Convers. Manag.*, vol. 63, pp. 173–195, 2012.

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Utilization of indigenous knowledge systems in water management in Hurungwe District, Zimbabwe

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Abstract

Culture is a way of life which pervades all aspects of people's existence wherever they are situated. Thus the study explores the Korekore culture in a bid to show its vitality and relevance to modern society's water management in Zimbabwe. The article posits that the Korekore people have indigenous knowledge systems (IKS) that can be tapped and integrated not only in water management but in all sectors of the economy of Zimbabwe and perhaps elsewhere. Adopting a qualitative research design in a case study approach, purposive sampling was used to select community elders and traditional practitioners who are associated with in-depth knowledge of traditional beliefs and practices. The data collection techniques included interviews, questionnaires participant observations and peer reviewed journal articles analysis. Findings show that Korekore beliefs and practices on water resources management can be used as effective water management tools. The paper argues that if blended with modern approaches, IKS can be an effective intervention strategy to mitigate the challenges faced in water management, particularly in arid environments where the dearth of water is commonplace. The paper also posits that the Korekore cultural beliefs and practices are not only relevant at local level but are consistent with the principles of Integrated Water Resources Management (IWRM) and thus must be strengthened and integrated into different sectors of the economy as part of a people's heritage.

Keywords Korekore, water management, indigenous knowledge, culture, heritage, integration

Introduction

There has recently been a surge of interest worldwide in the way indigenous people interact with their environment and the value of their knowledge systems. Many international organizations, such as the Convention of Biodiversity, the United Nations Working Group on Indigenous Populations, the United Nations Educational, Scientific and Cultural Organization (UNESCO), and the Working Group on Traditional Resource Rights, have called for the recognition of indigenous peoples rights to self-determination, the value of their knowledge, and the need for strategies to protect and preserve this knowledge [1]. The position taken by these international bodies has largely been precipitated by the global environmental crisis, which revealed the shortcomings of an exclusively scientific approach, often within the western economic development paradigm, in solving the multitude of environmental problems facing present and future generations. Indigenous societies just like any other society possess rich experiences, understanding and explanations which they have long acquired in relation to their specific social and ecological contexts [2]–[4]. Rural and indigenous people use local knowledge to inform decision-making about fundamental aspects of day to day life [5]. This knowledge is integral to a cultural complex that also encompasses resource use practices, social interactions, ritual and spirituality. These unique ways of knowing are important facets of the world's cultural diversity, and provide a foundation for locally-appropriate sustainable development. The paper identities key features of the Korekore IK in water management in Zimbabwe; (ii) examines the relevance of the Korekore IK in water conservation; and (iii) provides suggestions for policy-makers on how to appropriate IK in water conservation in Zimbabwe.

Methodology

The study area

This study was carried out in Hurungwe District in Zimbabwe. The population of Hurungwe is 329 197 of which 164,711 are males and 164,486 are females [21]. The Mashonaland West province in which the Hurungwe District is situated has a total population of 1,501,656 constituting 747,475 males and 754,181 females. The district is located in southern Africa on latitude 16° 24' South of the Equator and longitude of 29° 35' East of the Greenwich Meridian, and placed at an altitude of 1165 metres. The district covers an area of 19 843.26 km^2 [21]. Estimations of religious identity in the country indicate that Christianity is the most popular religion having 85% of the population as its adherents [1]. While African Traditional Religion constitutes only 3% of the population, other religions account for 12% of the people. Although the Zimbabwean government does not make it mandatory to register a religious group, estimates vary on how much of the population is syncretic. There are few Zimbabweans who have not encountered Christianity in some form, but many Christians also associate themselves with traditional practices on certain occasions (e.g. *Kurova Guva (ritual)* ceremonies). This, therefore, gives syncretism a strong status in the country. Indeed, those who constitute this

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category of worshippers account for 50% of the entire population. Pure Christians are estimated at 24% while other religions constitute 26% [6]. A good number of indigenous churches have developed from the mainstream Christian churches and some of them practise both Christianity and traditional beliefs and practices. Amongst the Christian churches in Hurungwe District, the Zimbabwe Assembly of God (ZAOGA) seems the only one which strictly adheres to Christianity tenets and opposes the incorporation of traditional practices and belief systems. Others such as the Seventh Apostle provide a mixture of traditional religious practices and beliefs and Christianity. The belief in and practice of traditional religion is wide spread in the district as it is sometimes practised in conjunction with other religion.

Sample size and data analysis

The study used the qualitative research method through structured interviews and observation. One hundred and twenty (120) participants selected through snowball sampling technique were interviewed on their views on the role played by taboos and totemism on water management in Hurungwe District in Zimbabwe. Site visitations (field work) and observations were undertaken by the researchers to validate the responses given by the respondents. Data were also obtained from secondary sources. This was achieved by employing electronic data search from goggle scholar where relevant peer-reviewed articles were identified. Analysis of the paper focuses on the role and uniqueness of totemism and taboos in water management in Hurungwe district, Zimbabwe.

The uniqueness of indigenous knowledge

Practical and research needs inform how the concept of indigenous knowledge (IK) is defined [7]. Whereas IK denotes a general umbrella concept meaning the participants' knowledge of their temporal and social space, indigenous knowledge system (IKS) "delineates a cognitive structure in which theories and perceptions of nature and culture are conceptualized". On the other hand, indigenous technical knowledge (ITK), which is practical-oriented, is "concerned with operationalised local thinking in such fields as agriculture, fisheries, health, horticulture, and forestry" [7], [8]. IK also refers to skills and philosophies developed by societies with long histories of interaction with their natural surroundings [9]. Defined from another perspective, Kolawole conceives IK to mean the knowledge developed by grassroots people in a geographical location, and which they have acquired over many years of constant observations, experimentations and validations of phenomena within their immediate environment [5]. Consequently, IKS develops as a consequence of practical engagement in everyday life, through trial and error, and are constantly reinforced by local people's experience [10]. This experience is characteristically the product of many generations of intelligent reasoning, and since its failure has immediate consequence on the lives of its practitioners its success is very often a good measure of Darwinian fitness [9]. It is, as the author neatly puts it, "tested in the rigorous laboratory of survival" [9]. It is thus locally rooted to a particular set of experiences and is generated by people living in those places. The general belief among practitioners is that transferring it to other places runs the risk of dislocating it [11]. IKS is orally transmitted through imitation and demonstration. Thus, the general consensus is that writing it down changes some of its fundamental properties [9]. IKS is characteristically shared to a much greater degree than other forms of knowledge, including global science [7]. This is why it is sometimes called the "people's science", an appellation which also arises from its generation in the contexts of everyday production. However, its distribution is still segmentary, that is socially clustered [4], [9]. It is usually asymmetrically distributed within a population, by gender and age, for example, and preserved through distribution in the memories of different individuals. Specialists may exist by virtue of experience, but also by virtue of ritual or political authority. It focuses on particular individuals and may achieve a degree of coherence in rituals and other symbolic constructs. Its distribution is always fragmentary; it does not exist in totality or individually [4]. To a considerable extent, it devolves not in individuals themselves, but in the practices and interactions in which people engage them. Indigenous people view the world as an integral whole; their beliefs, knowledge and other forms of cultural expressions have been handed down through the generations [4], [12]

Role of indigenous knowledge system

IKS is an integral part of the development process of local communities [13]. The 1998/99 World Development Report recognises knowledge, not capital, as the key to sustainable social and economic development. Building on local knowledge system (LKS) is the first step to mobilise such capital. Thus, IKS plays a profound role in societies as it helps shape and defines their very existence and provides the foundation for their beliefs and traditional practices. IKS provides the basis for problem-solving strategies for local communities, especially the poor [2]. It represents an important component of global knowledge on development issues. Unfortunately, IKS is an underutilised resource in the development process [14]. Learning from IKS, by investigating first what local communities know and have, can improve understanding of local conditions and will provide a productive context for activities designed to help the communities [2], [5], [15]. Understanding IKS can increase responsiveness of development agents to local level challenges. Sharing IKS within and across communities can help enhance cross–cultural understanding and promote the cultural dimension of development. IKS can help promote biodiversity conservation by characterising resource uses that are appropriate for the particular local landscape. Indeed, incorporating IK into conservation and development activities is believed to be an important mechanism for ensuring the most efficient and productive use of natural resources in the short-term without jeopardising the long-term capacity of nature to continue producing these resources [16], [17]. IKS can help develop sensitive and caring values and attitudes, thereby promoting a vision of sustainable future. Indigenous communities have lived in harmony with the environment and have utilised resources without impairing nature's capacity to regenerate them. Their ways of living were sustainable and

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IKS shaped their values and attitudes towards the environment. These attitudes and values have thus guided their actions and considerably made their way of living sustainable.

Water management in rural Zimbabwe

Unlike in urban Zimbabwe where Western science is officially used exclusively for natural resources conservation, rural Zimbabwe deploys a myriad of traditional strategies enshrined in IKS to conserve water [4]. Religious and traditional beliefs, cultural folklores and practices play a crucial role for the successful conservation of water especially in the remote parts of the country. These include, among many others *zviera* (taboos) and *mitupo* (totemism) and conception of water as common property. In rural Zimbabwe, environmental conservation was and is always a common practice with taboos being one of such strategies [3], [4]. For some scholars taboos are a useful way of keeping checks on children as each taboo has two parts in water conservation, namely a surface meaning (a lie) and the truth.[18]. Buttressing this point one author has this to say:

Shona people often use zviera (taboos) as one of the way of teaching young members of their society. The Shona had and still have, unique ways of transmitting social values which are crucial to the development of their society. Zviera, among other practices encourage conformity [12].

The author further argues that taboos are not only sanctions to correct behaviour of children or teach members of the society but also the adult about how they should conduct and behave themselves towards water and other aquatic resources [12]. While taboos had two parts, there were and are still true taboos and false taboos [1], [4]. Taboos have been classified into five categories with regard to their role in water management [19]. According to Gelfand, there are taboos that talk about living in acceptable manner with water, avoidance of aquatic danger, good behaviour in water, healthy water teachings and those conveying religious teachings [19]. Taboos are thus meant to teach people to be at harmony with nature especially water. Some water related taboos in this category are immediately explained in the following paragraph.

The most commonly known taboos in Zimbabwe is *usaitira tsvina mutsime* literally translated to mean *do not excrete in a well* and *ukawetera mumvura, unozorwara nechirwere chehozhwe*, meaning "if you urinate in a water source, you will suffer from bilharzia". The consequence for violating these taboos is that first, the reservoir would dry up and second, the perpetrator will suffer from bilharzia. It is a truism that everyone deserves good health. As the consequence of abuse is undesirable to the perpetrator and would possibly cause health problems to the entire community members who use the urine-polluted water for domestic purposes, it means that people are obliged to avoid vicious characters that may result in ill health. In these taboos, instilling the fear of contracting a disease (and perhaps contracting the disease itself) is used as deterrent for those who may be tempted to urinate in water sources thereby polluting them. Therefore, this taboo implicitly teaches people to act in a way that is compatible with the pursuit for a livable environment even though fear of contracting a disease is used as a deterrent. The taboo is coined in order to foster environmental awareness among the Shona people. In this regard, it has been noted that, "as human beings, we carry the whole weight of moral responsibility and obligations for the whole world on our shoulders" [3]. Besides being the habitat for the various aquatic creatures that also need clean water, rivers and other water points are important sources of water for domestic, agricultural and industrial purposes in any human society. It is for this reason that the Shona people have devised various taboos that are aimed at safeguarding the well-being, not only water sources and aquatic life, but also human community and the environment. Thus, by discouraging members of the community from urinating in rivers, the Shona people are simply trying to prevent the consequences of urine-contaminated water and also how it affects other aquatic creatures, like fish, given the fact that urine contains some component of nitrates that causes the accumulation of algae, which is dangerous to aquatic life. In reality, there is no causal relationship between urinating in water sources and contracting bilharzia. Hence, Shona environmental taboos are simply instruments that are aimed at protecting nature.

Another taboo among the Shona is *usauraya datya* translated to mean *do not kill a frog*. In Shona culture, killing an animal which is not edible is considered as cruel. In reality, frogs are inedible in the Shona culture and taboos such as this were put in place to protect the lives of such sentient beings. Besides, frogs usually live in clean, unpolluted water. The presence of frogs simply entails that the water is pure and safe to drink. In this manner, the taboo is a way of conserving frogs which would easily act as indicator species to tell people which water to drink or not without necessarily reverting to Western methods of water quality detection which are very expensive to acquire and use. Furthermore, there is a taboo like *usaraure mutsime* meaning, do *not fish in a well or any shallow waters.* The consequence of violating such a taboo is that such water sources will dry up. Whilst fishing itself is not prohibited, doing so in a well is a taboo because usually people in rural areas catch fish by using the leaves of a tree locally known as *mushambise* to poison the fish. In reality, such fishing method pollutes water and drastically reduces the number of fish therein, especially considering the size of a well. Thus, by making it a taboo to not fish in a well because the reservoir would dry up portrays a method of safeguarding the pollution of water. Drying up of the shallow waters is not a desirable consequence given that water is indispensible for sustenance of human beings, particularly so in an arid environment. The consequence is indeed a curse to the entire community and perpetrators are severely punished once caught [12].

There are also sacred wells and water bodies in rural Zimbabwe. Water from such sources is fetched through the use of *mukombe* (gourds) because metal objects and blackened clay pots are traditionally illegal to collect water from such sources. The belief among indigenous Zimbabweans is that such dug out wells and water bodies have got *njuzu*

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(mermaids) such that if offended by using unaccepted utensils to collect water, the mermaids will either make the water dirty or the offender would be drowned or disappear into the waters [20]. Whilst this might not be true, such myths and beliefs help maintain sacredness of water bodies thereby keeping the waters unpolluted and conserved. The use of water gourds to fetch water is not only economic but clean and free of rust as opposed to blackened pots which leave the water somewhat polluted after collection.

Besides taboos, totemism is one other traditional water conservation strategy in rural Zimbabwe. By definition, totemism is a form of identity created by a particular clan of people [4] to maintain their cultural boundary. A totem is an animal or parts of it that anyone who uses it [as totem] is forbidden from killing and eating it. This is noticeable in the case of Shona people's care for open water sources like wells, rivers and dams. Since, the indigenous people are those who are the original inhabitants of an area, who have lived in a traditional homeland for a number of generations [9], it is easier for them to pass on the knowledge about their environment from one generation to another. Researches have shown that traditional institutions provide considerable protection of water resources without government juridical restrictions [9], [12].

Results, discussions and recommendations

Interviews with participants were largely based on the use of totemism and taboos as practised by the community members in the management of water sources. The taboos and rituals that are being practised in Hurungwe District include totemism, observance of sacred places, and rain making ceremonies. The findings that emerged from both the interviews and observations indicated that taboos and totemism play a very critical role in the district. The research participants stressed that the community has managed to instil into people the sense of "sacredness" of water sources in the district. An elderly participant affirmed that *Matsime nezvitubu zvinoera hazvibvumirwe kusvikwa nevanhu saka naizvozvo zviera izvi zvinototevedzwa nemunhu wese mudunhu rino* meaning, *the sacred wells and pools are kept out of people by strict taboos and all the community members adhere to this view religiously* (Village elder, October 2016, informal interview). Seventy six (76) out of one hundred and twenty (120) participants stressed that it is a taboo to enter into *Kadangwe pool (*a sacred deep water pool in Hurungwe) to fetch water with metal objects. The reason given by these elderly men was that use of metal objects angers spirit mediums (*zvinotsamwisa midzimu*) and dry up the pool as punishment for the Korekore community. Furthermore, the killing of snakes and frogs from *Kadangwe* was also noted as a taboo. The idea behind this as narrated by the elders was that Hurungwe District spirit mediums dwell in that pool in the form of creatures like snakes and frogs among others, thus killing them would amount to literally killing the gods that safeguard the Korekore community and the water in the pool. This is because *Kadangwe* is traditionally a place for the gods of Hurungwe. Therefore, no dirty or any pollution should be put into that pool. Thus, it is a taboo among the Korekore of Hurungwe to use any black container or dirty metal object to fetch water from or do laundry in *Kadangwe.* Most of the participants (100 out of 120) indicated that mysterious events have occurred on individuals who attempted to disregard the taboos. The most preferred water drawing utensils from the pool are *mikombe* (water gourds). Observations by the first author in October 2016 revealed that there were eight water gourds (*mikombe*) neatly placed at the edge of the pool. While the majority among the elderly felt that the taboo play a pivotal role on water management in the district, there were few participants particularly the youth and Christians who felt that the taboo is a *baseless myth and lacks scientific evidence which is only perpetuated by a certain group of primitive elderly people (*A youth interviewee). The youth and the Christians felt that the Hurungwe community, especially the Korekore ethnic group should adopt the modern water management skills instead of clinging on taboos. Among those calling for the move towards modern water management were Christians and young people who felt that they were forced to observe certain taboos that are contrary to their Christian belief and are always being threatened by ostracism from the district if they do not comply with the existing taboos. An interview with a ZAOGA church elder revealed that two *vabvakure* (foreigners*)* from Masvingo (a province in Zimbabwe) were expelled from the district as they were disregarding traditional ethics of the Korekore community over water use. Interviews with key informants showed that totemism is still very intact in the village. The study also showed that there was no one whose totem is water related among the Korekore people. Most of the people identify with the *moyo* (heart) totem. This implies that they do not eat the heart of any animal. However, there were a few people whose totem is *dziva* (pool) and these do not eat fish and therefore is a taboo for them to catch, eat or sell fish.

The study, therefore, recommends that there is need to carry out further research in other districts to find out the role of IKS in various ethnic groups in relation to water conservation. The cultural symbols and IKS in water management need to be brought into public domain and knowledge frontiers. This can be achieved by introducing programmes in schools that focus on teaching of IKS in primary, secondary and tertiary institutions [8]. In line with the findings and conclusion, it is recommended that IKS framework and policy be put in place in Zimbabwe. This would guide the activities relating to the application of IKS in development practice. Government allocation of financial and human resources in support of IKS within communities is, therefore, plausible. Presently, Zimbabwe does not have a policy specifically on IKS. There is need to ear-mark funds to assist institutions that carry out programmes on IKS in areas that would allow local communities to appreciate local traditions and culture on water conservation. The study further recommends the integration of IKS in school curriculum to enhance the entrenchment of the positive aspects of the knowledge system. The current school curriculum does not

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have an IKS component on water conservation. As some traditional practices are peculiar to specific geographical areas, there is need to produce IKS literatures on water conservation for different districts in Zimbabwe. Government Ministries, particularly Ministry of Environment and Natural Resources Management, need to work together with local communities and traditional leaders on water management issues. Indigenous ways of water conservation could be infused into modern methods of water conservation in order to achieve sustainable use of water-related resources. Traditional leaders need to be empowered through legislations to enable them assume a recognized status as custodians of traditions and water resources within their communities. Also, policy makers need to also promote the inclusion of IKS and its implications in water management. In summary, it is recommended that African government policy makers in general need not just adopt straightjacket policies that only work in more economically developed countries, but would do well to implement appropriate strategies that would enhance sustainable conservation of natural resources in African countries [22].

References

[1] P. Bernard, "Ecological implications of water spirit beliefs in Southern Africa: The need to protect knowledge, nature and resource rights," *USDA For. Serv. Proc. RMS27*, 148-153, 2003.

[2] O. Kolawole, "Twenty reasons why local knowledge will remain relevant to development," *Dev. Pract.*, 25(8), pp. 1189-1195. 2015.

[3] G. Makaudze and P. Shoko, "The Re-conceptualization of Shona and Venda Taboos: Towards An Afrocentric Discourse," *J. Pan African Stud.*, *8*(2) 2015.

[4] M. Mawere, "Traditional environment conservation strategies in pre-colonial Africa: Lessons for Zimbabwe to forget or to carry forward into the future," *Afro-Asian J. Soc. Sci.*, *4*(4), 1-23. 2013.

[5] O. Kolawole, "Local knowledge utilization and sustainable rural development in the 21st century," *Indig. Knowl. Dev. Monit.*, 9(3), pp. 13-15. 2001.

[6] J. Kriss, J. Goodson, and Z. Machekanyanga, "Vaccine receipt and vaccine card availability among children of the apostolic faith: analysis from the 2010-2011 Zimbabwe demographic and health survey," *Pan African*, *24*. 2016.

[7] J. Brouwer, "IK, IKS and ITK," *Indig. Knowl. Dev. Monit.*, 6 (3), p. 13. 1998.

[8] O. Kolawole, "Mainstreaming local people's knowledge and implications for higher education in the South," *South African J. High. Educ.*, Vol. 19, Special Issue, pp. 1427-1443. 2005.

[9] R. Ngara and R. Mangizvo, "Indigenous knowledge systems and the conservation of natural resources in the Shangwe community in Gokwe district, Zimbabwe," *Int. J. Asian Soc.*, *3*(1), 20-28. 2013.

[10] M. Chemhuru and D. Masaka, "Taboos as sources of Shona people's environmental ethics," *J. Sustain. Dev. Africa*, *12*(7), 121-133. 2010.

[11] K. Opoku, "West African traditional religion," 1978.

[12] J. Risiro, D. Tshuma, and A. Basikiti, "Indigenous knowledge systems and environmental management: A case study of Zaka District, Masvingo Province, Zimbabwe," *Int. J. Acad. Res. Prog. Educ. Dev*, 2013.

[13] O. Kolawole, "Whither sustainable rural development?: A critical exploration of remote communities in and around the Okavango Delta, Botswana," 5(3), pp. 99-114, 2014.

[14] N. Sikhanyiso, "Community Development Projects and Food Security: The case of Zanyokwe Irrigation Project Eastern Cape Province, South Africa," University of Fort Hare, 2013.

[15] L. Manyozo, "The day development dies," *Dev. Pract.*, 20 (2), pp. 265-269, 2010.

[16] O. Kolawole, "Situating local knowledge within development agenda: Some reflections," *Cons. J. Sustain. Dev.*, 2(1) 2010.

[17] M. Murimbika, "Sacred powers and rituals of transformation: An ethnoarchaeological study of rainmaking rituals and agricultural productivity during the evolution of the Mapungubwe," Doctoral dissertation, Faculty of Humanities, University of the Witwatersrand, Johannesburg, 2006.

[18] E. Chiwome, Z. Mguni, and M. Furusa, "Indigenous Knowledge and Technology in African and Diasporan Communities: Multi-disciplinary Approaches," 2000.

[19] Gelfand M, "Shona Religion with special reference to the Makorekore, - Google Scholar." Juta & Co, ltd, Cape Town, pp. 23–33, 1962.

[20] C. Ndlovu and L. Manjeru, "The influence of rituals and taboos on sustainable wetlands management: The case of Matobo District in Matabeleland South Province," *Int. J. Sci.*, *4*(4), 1-3. 2014.

[21] Zimbabwe National Statistical Agency Facts and Figures, Government Printers Harare 2014

[22] E..Mogende & O. Kolawole. Dynamics of local governance in natural resource conservation in the Okavango Delta, Botswana. In *Natural Resources Forum* (Vol. 40, No. 3, pp. 93-102). Blackwell Publishing Ltd. (2016, August).

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Quantitative devolatilization of Botswana coal in a pilot scale plant*

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***Abstract*— Coal gasification is a new and clean coal conversion technology that converts coal to liquids and synthetic gas to be used in power generation and chemical products. Botswana coal was studied in a pilot plant to produce synthetic gas which can be used for power generation and chemical products (dyes, detergents, plastic, synthetic fibers, fuels). Pilot plant provides information on the amount of gas produced per mass of feed, and the amount of synthetic gas produced per variation of parameters (temperature and pressure). Every kilogram of coal produces about 95 liters of raw synthetic gas per day.**

Keywords: Botswana coal gasification, new coal technology, synthetic gas

I. INTRODUCTION

Coal is considered a non-renewable energy source as it was formed hundreds of millions of years ago from plants and ferns that died and buried in swamps. The reserves that exist now cannot realistically be replaced. Coal makes one of the greatest energy sources getting its energy from the buried plant remains.

Botswana has 212 Billion tonnes of coal resources which is covering about 70 percent of its geographical strata (Paya, 2010). It is in the region of what is called the Karoo Supergroup which is the most widespread stratigraphic area in Africa south of the Sahara desert (Johnson M. R., 1996). These reserves have been found to have high ash, medium calorific value, and low-medium quality bituminous coal (Grynberg, 2012). With all these reserves, Botswana has only one coal fired power plant (combustion) that generates and supplies electricity to the whole country. This is only able to meet 30 percent of the demand in the country. Botswana is developing at a high rate with a lot of infrastructure being erected which calls for more power supply.

In 2012, Botswana demand for electricity was 530 MW, of this power 70 percent was supplied by Eskom in South Africa (Abi, 2011) and the rest by Morupule Power Plant using a coal fired power generator to produce only 132 MW from four 33 MW coal fired units (Mawson, 2006) with coal supplied from adjacent Morupule Coal Mine. The demand has been increasing with an average of 10 percent a year (Mawson, 2006) due to developments in the country putting the country on deficit and worsening after Eskom has cut its supply. Despite the failed plans to build more power stations in the country (Benza, 2014), the current process is harmful to the environment and less efficient, therefore calls for new coal conversion technologies.

Coal gasification includes two distinct processes; devolatilization followed by char gasification. Devolatilization normally occurs at temperatures above 400 C in the absence of oxygen to give away moisture and volatiles (Basu, 2006). This process allows coal structure to be changed to produce tar (a gas mixture of heavy molecular weight hydrocarbons at high temperatures and condensible at room temperature), solid char, condensible liquids and light gases. The process of char gasification depends mainly on gasification medium (inert gas/ hydrogen).

Coal gasification is the process in which coal is partially combusted. It involves the reaction of solid coal with air and steam to yield gaseous products that are able to be used as fuel gas, chemical feedstock and other products (Sha, 1995). The three processes that occur in a typical gasifier being drying and pyrolysis, combustion then gasification. In drying and pyrolysis, water that is fed with coal and moisture with the coal is driven off by heat introduced. Then the weak bonds in coal start breaking producing gases, tar and char. Oxygen supplied to the reactor reacts with combustible substances in the system forming carbon dioxide and water. These two products then undergo reduction when they get in contact with char to produce carbon monoxide and hydrogen. The system goes through a series of endothermic and exothermic reactions which need to be balanced otherwise there will be a low carbon conversion in the gasifier.

Gasification is cleaner than combustion in terms of the amount of pollutants produced. Combustion converts N and S containing compounds to SOx and NOx while gasification converts them to H2S and NH3 that are cleaner. In terms of energy efficiency, syngas produced from gasification contains heating value as a chemical energy which can be liberated at a later stage in contrast with CO2 from combustion which only contains energy as a hot gas and limited to use in steam turbines (Yun and Chung, 2006).

Other coal based power plants utilize only 30 percent of the energy produced from coal for power generation. A coal gasification plant however utilizes most of the gases it produces. Firstly, the gases are cleaned of any pollutants to put them in a state very close to natural gas. The hot exhaust of the gas turbine, and some of the heat generated in the gasification process are then used to generate steam for use in a steam turbine generator (US Department of Energy, 2016). Coal gasification produces heat that is used to turn gas turbines and produce electricity. Gasification is a component of a complete system called Integrated Gasification Combined Cycle (IGCC) that feeds row coal that is dirty.IGCC is much more efficient than the coal fired power plants to due to the heat recovery feature it has.

The focus of this paper will be on the first process of devolatilization at 500 degrees Celsius. Gas and differ-

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ent density liquids collected will be measured in different measuring cylinders. Botswana coal produced relatively satisfactory amount of gas by mass of coal fed into the reactor. Subbituminous coals have been determined as the best suitable coals for coal gasification due to high volatility and content of volatile matter.

Another subbituminous coal from Indonesia yielded 55 and 67 liters of gas from the two runs that were carried out in a pilot gasifier. The feed contained a lot of moisture that was visible through the bubbler and the last condenser measuring cylinder. Indonesia produces high quality synthetic gas from subbituminous coal through the process of gasification. Except for too much moisture, Indonesian coal portrays the same characteristics as Botswana coal.

II. EXPERIMENTAL

A. Coal samples

Five samples were used in these experiments; four of which came from Morupule colliery mine, and one from Indonesia and were all ranked as subbituminous. The samples allow a comparison between Botswana coal and coal from Indonesia in terms of quantity of gas produced during pyrolysis/ gasification. Samples were of size range 1-20 mm and stored in lid sealed containers until used. Table 1 shows proximate and ultimate analysis done on Botswana coal.

B. Sample preparation

A representative sample that will be enough to fit into the gasifier is taken from the whole sample. The total mass of the sample is measured and recorded. Voidage of the sample is determined by the ratio between volume of water in an empty bucket take out volume of water with coal filled in and using the formula below;

$$\epsilon = Volume(sand)/Totalvolume(bucket) \quad (1)$$

C. Loading the reactor and start-up

A batch type dry feeding laboratory scale plant that is located in Gaborone, Botswana and can treat coal of 1.2 kg/ day with feed size range 20 mm to 100 mm. The facility of 4 by 5 by 1.5 m is located in a 8 by 7 by 5 m room shown in figure 1.

The system is initially purged using nitrogen to create inert atmosphere before coal can be fed into the plant. System is flushed with acetone to wash away any condensed liquids from previous runs. Gasometer is primed by filling it up with water so that there is zero liters left for the gas produced to fill up.

Coal is fed into a mesh cylinder that is placed into a reactor. Mesh gives allowance between the walls of the reactor and coal for uniform burning of coal. Reactor lid is then bolted and properly sealed. Insulation is provided around reactor to avoid too much heat loss. An electrical heater is used in heating the gasifier, no preheating is done. There are three condensers operating at 150, 100 and room temperatures for heavy oils, light oils and clear liquid

Fig. 1. Overview of the pyrolysis plant at Pyro carbon energy laboratory

respectively. A bubbler is used to check for any gas produced in he system. It gets filled with water of 200 mL and a bubbler pipe with two holes inserted. The top hole indicates a low gas flow rate while the bottom hole signifies high gas flow rate. The gas is then passed to a gasometer to be measured with an application of the Bernoulli's principle. The gas kinetic energy increases as more gas is produced which causes water to be displaced due to difference in pressure.

Gasometer is connected to a u-tube. Left end of the u-tube is connected to the reactor and receives gas at 95 kPa pressure, while the right end is connected to a water tank for drainage. Right side is closed to a water tank therefore vapour pressure is acting on the right side of the u-tube. Vapour pressure was calculated as 2.5 kPa considering room temperature of 25 degrees Celsius using Antoine's formula below;

$$\log P = A - B \div (C + T) \quad (2)$$

where A = 8.07, B = 1730.63 and C = 233.43 (AJ Design software, 2011)

Temperature is calculated in degrees Celsius and Pressure in mmHg with the above constants.

There is a valve at the bottom where water that is displaced by gas is drained out.

Normal operation consists of leak test, purging, transient operation, devolatilization and shutdown process.

The feed coal was Morupule Colliery Mine (MCM) ROM coal and conventional analysis was done on it with results presented in Table 1. Coal was air dried to about 1 percent moisture content before feeding into a reactor. Ash content in Morupule coal is around 28 percent ash.

In a pilot scale dry feeding plant, nitrogen used for purging is present during the pyrolysis process therefore reaction atmosphere can be considered as nitrogen atmosphere.

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TABLE I

TABLE 1: ANALYSIS DATA OF COAL FEED

	Item	MCM ROM
Proximate analysis	Moisture (air-dried)	1.1
	Ash content (air-dried)	27.9
	Ash content (dry basis)	28.2
	volatile matter (air-dried)	13.5
	volatile matter (dry basis	13.7
	fixed carbon (by calculation)	57.5
	total sulphur	1.32
	gross calorific value (MJ/kg)	22.42
Ultimate analysis	Carbon content (air-dried)	59.09
	Hydrogen content (air-dried)	2.43
	Nitrogen content (air-dried)	1.48
	Oxygen content (by calculation)	6.68

D. Devolatilization reactions

When coal is gasified under practical conditions the following coal gasification processes take place;

- Syngas is produced from the first stage of coal gasification which is devolatilization.
- The process that follows is char gasification. There are secondary processes observed during gasification.
- Coal molecules break down at weak aliphatic and ether bonds in the process of pyrolysis during which volatile matter is released [all gases, tar(liquid hydrocarbons), light gaseous hydrocarbons].

$$coal \longrightarrow char(C) + coalvolatiles(VM) - \Delta H \quad (3)$$

- Pyrolysis is then followed by hydrocracking which is the addition of hydrogen to the tar molecules present in the volatile matter. This process produces methane.

$$VM + H2 \longrightarrow CH4 - \Delta H \quad (4)$$

- Tar then undergoes gasification process producing carbon monoxide and hydrogen

$$VM + H2 \longrightarrow CO + H2 + \Delta H \quad (5)$$

III. RESULTS AND DISCUSSION

The gasifier pressure was controlled at 95 kPa while gasifier temperature was maintained at 500 degrees Celsius that was enough for devolatilization of coal.

The parameters are required for devolatilization and liberation of gases contained in coal. Temperature shown in the Table II was average temperature in the gasifier. There are 7 points (TT-03 to TT-09) where temperature is measured throughout the gasifier (Figure 3), an average of the middle 3 temperatures was taken to represent coal temperature as it was assumed to be a point where coal was.

Each experiment ran for about 3 hours in which run 1 produced 55 liters of gas while run 2 measured 67 liters. Bubbler was used to estimate end of reaction by observation when bubbles were no longer produced. Gasifier operating parameters with corresponding gas produced are illustrated in Table II. Data was arranged in order of increasing sample mass. With increasing sample mass it was observed that gas volume increased proportionally with around the same operating temperature and pressure.

TABLE II

TABLE OF COMPARISON OF OPERATING PARAMETERS TO PRODUCT GAS

Operation time time (2017)	Sample mass mass (kg)	Gasifier pressure (kPa)	Gasifier temperature (C)	Gas volume (L)
20-Mar	0.5	93.0	570	55
21-Mar	1.0	93.0	520	123
22-Mar	1.5	96.7	570	125
23-Mar	2.2	95.0	530	194

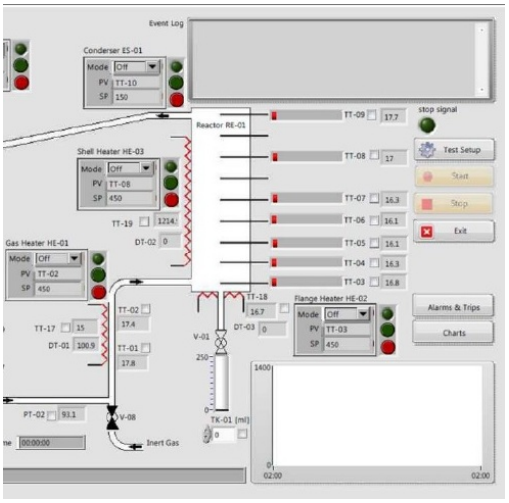

Fig. 2. SCADA screenshot showing gasifier temperature transmitter points

Besides gas produced, gasifier has liquid products (heavy oils, light oils and clear liquids), three cylinders hanging from right to left in Figure 2.

Syngas produced was measured in a gasometer which is proportional to the mass of the coal sample fed into the reactor. The more the sample the more gas it produces. The tests only focused on the quantity of gas produced.

IV. CONCLUSIONS

Botswana coal is promising to have enough synthetic gas that can be used for power generation and chemical products. This was observed in comparison with Indonesian subbituminous coal that yielded similar amount of gas and liquids as Botswana coal. 1.0 kg of coal produced an average of 95 liters of gas. Botswana coal is subbituminous as Indonesian coal. Indonesian coal synthetic gas content is 36-38 percent CO, 14-16 percent H2, and 5-8 percent CO2 concentrations on dry basis.

ACKNOWLEDGMENT

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Fig. 3. liquids products, from right to left; heavy oils, light oils, clear liquid. On the counter is a bubbler

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REFERENCES

[1] Abi, K. (2011). The Need for Clean Coal in Africa. Gaborone: Department of Mines; Ministry of Minerals, Energy and Water Resources.
[2] AJ Design Software. (2011). Water Vapor Pressure Calculator - Antoine Equation . Retrieved May 30, 2017, from http://www.watervaporpressure.com/
[3] Basu, P. (2006). Combustion and Gasification in Fluidized Beds. Taylor and Francis Group.
[4] Benza, B. (2014). Total blackout at Morupule B . Retrieved February 27, 2017, from Mmegi Online: http://www.mmegi.bw/index.php?aid=7169
[5] Grynberg, R. (2012). Coal Exports and the Diversification of Botswana's economy. Gaborone: Botswana Institute for Development Policy Analysis.
[6] Johnson M. R.,(1996). Stratigraphy of the Karoo Supergroup in southern Africa: an overview . Journal of African Earth Sciences, 3-15.
[7] Mawson, N. (2006). Coal: Botswana mulls power expansion plan. Retrieved February 27, 2017, from Mining Weekly.
[8] Paya, B. (2010). THE COAL ROAD MAP PITSO An Overview of the Botswanas Coal Resources and Future Plans. Gaborone: Ministry of Minerals, Energy and Water Resources.
[9] Sha, X. (1995). Coal Gasification and its Utilization . Encyclopedia of Life Support Systems (EOLSS).
[10] US Department of Energy. (2016). Clean Coal Research: Gasification. Retrieved April 5, 2017, from ENERGY.GOV: Office of Fossil Energy: https://energy.gov/fe/science-innovation/clean-coal-research/gasification
[11] Yun, Y., and Chung, S. W. (2006). Gasification of an Indonesian subbituminous coal in a pilot-scale coal gasification system. Chemical Engineering, 628-632.

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Removal of heavy metals using treated- waste material (Moringa oleifera seed pods)

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***Abstract*— The use of waste materials as low-cost adsorbents is attractive due to their contribution in the reduction of costs for waste disposal, therefore contributing to environmental protection and most importantly, offers an attractive potential alternative to conventional methods of removal of toxic ions from the environment. A study to investigate the possible use of powdered *Moringa oleifera* seed pods (MOSP) was conducted. Removal of selected metal ions were studied including Pb, Cd, Cu, Fe and Zn. Quantification of the extracted metal ions was done using flame atomic absorption spectroscopy (FAAS). One variable at a time optimization method was employed. Using 50 mL of aqueous sample prepared from the metal standard, the optimized parameters were 60 minutes contact time, 1 g of powdered MOSP, pH 8, 100 µm particle size and at 35°C. To determine the functional groups in the sorbents, Fourier Transform Infrared spectroscopy (FTIR) was used. SEM-EDX was used to determine the morphology and the elemental analysis of the sorbents. The optimized parameters were applied on aqueous water samples and the efficiency was in the range of 65.9 ±3.5 to 99.6 ± 6.69%. Moringa oleifera seed pods were proposed as a cheap, simple and an effective alternative for purification of water contaminated with metals.**

Keywords: waste-material, heavy metals, *Moringa oleifera*, seed pods, efficiency

I. INTRODUCTION

Pollution of aqueous environments by heavy metals is a worldwide environmental problem due to their toxic effects and accumulation through the food chain [1]. The rate at which these pollutants enter the environment has been an upward trend due to rapid development of industrial activities [2]. Due to bioaccumulation of these metals, scientists have been motivated to develop treatment methods using various techniques that have been successful but are challenged in some ways. Such methods include chemical and surface chemistry processes such as precipitation, membrane processes, ionic exchange and reverse osmosis [3]. However, these methods have limitations such as poor efficiency, sensitive operating conditions, they incur high installation and operating cost; and have detrimental effects on the environment due to production of secondary sludge. These challenges together with the need for economical and effective methods for recovering the metals have resulted in the development of alternative treatment technologies. This justifies the need to investigate alternative methods such as biosorption, in which certain types of biomass are able to bind and concentrate metals from even dilute aqueous solutions. Biosorption has gained important credibility during recent years as a low-cost, readily available and efficient treatment technology for effective removal of heavy metals [4]-[6] due to their several advantages such as (i) readily available, (ii) require little processing, (iii) can be regenerated iv) Metals can be recovered from biomass [7].

For this reason, use of low cost materials for metal removal from water has been investigated. Using agricultural waste has advantages since it uses what is considered waste product. Several waste material have been used to remove toxic metals such as apple waste [8]; corn cobs [9]; cereal crops [10] woody materials such as bark, leaves and sawdust [11] and banana peels [12]. These materials were successful in removing heavy metals to varying degrees. *Moringa oleifera* has also been used for such purposes.

Moringa oleifera (MO) is multipurpose plant of the developing world, as it can easily be cultivated and adaptable in semi-arid climates. Biomass from Moringa Oleifera tree has been used for water purification as a coagulating agent and to remove heavy metals. However, limited work has been done on application of *Moringa oleifera* seed pods (MOSP). Therefore, this study focused on use of treated MOSP for removal of selected heavy metals.

II. MATERIALS AND METHODS

A. Materials

All reagents were of analytical grade. Acids were used for digesting and adjusting pH. HNO3 (69%, Skylabs), HCl (32%), Minema Chemicals, Double deionized water (Millipore-Q Millipore 18.2 MΩ/cm resistivity) was also used for dilutions of samples to be analysed with FAAS. Elemental standards solutions used for calibration were prepared from 1000 ppm of stock solutions supplied by Minema Chemicals (Pb and Fe) , Merck Pty Ltd (Cu, Cd and Zn) NaOH (≥97.0%, Rochelle chemicals) was used to adjust pH, Hanna Instruments HI 991001 pH, orbital shaker (scigenics), agate pestle and mortar was also used for reducing the particles further. A 100

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µm, 200 µm, 500 µm stainless steel sieves were used for sieving the sorbents. The filter papers used were ash less Whatmann filter paper no.1 from England. The filter papers were used to filter the mixtures of sorbents and solution.

B. Instrumental analysis

A Varian 220FS atomic absorption spectrometer operated with air/acetylene was used for determination of seven selected metal ions which included lead (Pb),), iron (Fe), zinc (Zn), copper (Cu), and cadmium (Cd). Varian hollow cathode lamps for each of the analysed metals were used as radiation source. 1000 mgL^{-1} ppm stock solutions of metals were used to prepare working standards (in the range 0.0 to 5.0 mgL^{-1}) in deionized water. The instrument was calibrated manually by aspirating the prepared working standards of the cations of interest one by one into the flame. The samples were also aspirated manually into the flame for atomization. The instrumental conditions applied were according to AAS manual.

FTIR spectroscopy was used to characterize the sorbents to determine the functional groups responsible for metal removal. The FTIR spectra were recorded in the wavenumber range 400-6 4000 cm^{-1} on a Perkin Elmer system 2000 FTIR. The sorbents were kept at ambient temperature. 1 mg seed powder per 200 mg of KBr was weighed. The powder was pressed into pellets by using a 15 ton hydraulic press. The data were collected at 2.0 cm^{-1} resolution, and each spectrum was a result of 256 scans. In order to observe the surface morphology of the sorbents, a Philips XL 30 ESEM model environmental scanning electron microscope (ESEM) was used.

C. Preparation and characterization of Moringa Oleifera seed pods (MOSP)

The seed pods (deseeded) were obtained from various sampling points in Artesia, Botswana. Dried MOSP were washed with double deionized water, further dried in an oven at 65 °C for 24 hrs. The dried samples were ground then sieved to different mesh sizes (100, 200, and 500 µm) and stored in glass bottles until further analysis. The MOSP were also characterized by Fourier Transform Infrared (FTIR) spectroscopy and Scanning Electron Microscope (SEM) as described in section B.

D. Acid treatment of MOSP

15 g of powdered MOSP was weighed and put in a conical flask, 200 mL of 0.1M HNO3 was added and the mixture was soaked for 24 hrs. The mixture was then filtered and the sorbent washed several times with deionized water until the pH of the sorbent was neutral (around pH 7). The sorbent was then dried in an oven at 50 °C overnight and then put in glass bottle until further use.

Using the optimized sorption parameters (section E), the ability to remove heavy metals from water samples by the acid treated was conducted.

E. Biosorption of heavy metal ions

Batch experiments were used for the biosorption of Cd, Cu, Fe, Zn, and Pb. Stock solutions at various concentrations were prepared from 1000 mgL^{-1} of each metal standard. Solution of known metal ion concentration was prepared and known amount of sorbent (MOSP) was added. The mixture were shaken with a controlled orbital shaker and the concentrations of the unadsorbed metal ions in solutions were determined after separation of the sorbent by filtration using whatman paper No.1 filter papers. The effects of contact time (0-240 min), initial metal concentration (1-20 mgL^{-1}), pH (2.0-10.0), sorbent dose (0.5-2.5 g, in 50 mL^{-1}), particle size (100-500 µm) and temperature (298-333 K) were studied. Analysis and instrumentation were done using FAAS with air/acetylene. The amount of the metal adsorbed (% removal) by the sorbent was calculated using equation 1 below

$$\% \text{ Removal} = (Ci - Cf) / Ci \times 100 \qquad (1)$$

Where Ci is the initial concentration before adsorption and,

Cf is the concentration after adsorption of metal ions. All experiments were done in replicates and reported as the average of the experiments.

III. RESULTS AND DISCUSSION

A. Scanning Electron Microscopy

Scanning electron Microscope (SEM) is used to determine the morphology of a sample. It produces images of a sample by scanning it with focused beam of electrons and produces information about the sample surface topography and composition. Fig. 1 image reveals the surface texture and morphology of MOSP.

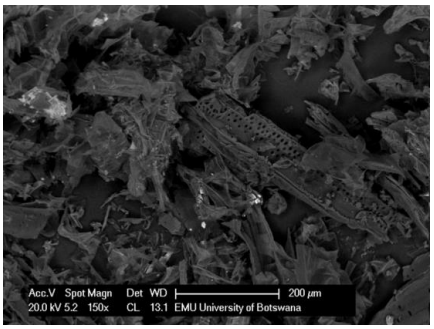

Fig. 1: SEM image of Moringa Oleifera seed pods (MOSP)

The results show that the materials have relatively porous surface. The micrographs of MOSP reveal cylindrical structures with different diameters. These surface (physical) characteristics would result in high metal removal due to available binding cavities for the metal ions. The efficiency of a sorbent depends on available number of pores, pore size and the surface area. The particles with higher surface area and have many pores is expected to be more efficient for metal removal.

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B. Fourier Transform Infrared (FTIR) spectroscopy

The IR spectra of MOSP as shown on Fig. 2a show broad bands around 3333 cm^{-1} attributed to the surface hydroxyl group. The bands at 2917 and 2849 cm^{-1} are due to C-H group of the alkenes, at 1741cm^{-1} are the C=O from esters, at 1593 cm^{-1} are the C=C aromatics and C-O from carboxylic acids at 1104 to 1027 cm^{-1}. Decrease in intensity and shift of the above mentioned peaks as shown in Fig. 2b could be due to interaction of the metal with the specific functional groups. The metal adsorption capacity is influenced strongly by the surface structures of carbon [13]. Studies done with other biomass sorbents have shown similar functional groups responsible for metal removal [14]–[17]. The functional groups responsible for metal removal in MOSP are therefore hydroxyl (OH), C-H of the alkenes, C=C alkenes and C-O from the carboxylic acids. The success of heavy metal uptake by agricultural products is believed to be dependent on a number of factors, one of which is chemical composition. One compositional characteristic of successful heavy-metal adsorption products is the presence of lignocellulosic biomass. Lignocellulosic biomass refers to plant biomass that contains cellulose, hemicellulose, and lignin [18], [19]. Another characteristic of successful agricultural products is the presence of acidic groups such as carboxylic and phenolic groups. Carboxylic acids are the most common type of organic acids and are characterized by the presence of at least one carboxyl group

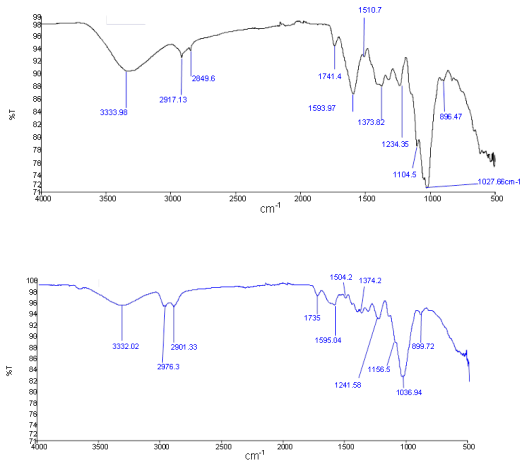

Fig. 2: Spectra of MOSP (a) before metal ion removal (b) after metal ion removal.

It can be speculated that combination of the following could be the principal mechanism for metal removal [44]. i) electrostatic interactions between the conjugate base of either carboxyl group or amine group (at pH 8) reacting with metal ions, (ii) Coordination or complex formation (using empty d-orbitals of metal ions) to interact with the electron pairs from the oxygen in the carboxyl, hydroxyl and nitrogen of the amine groups, (iii) Ion exchange processes in which the ionisable hydrogen on the carboxyl and amine groups exchange with metal cations, (iv) Microprecipitation (especially at higher pH) where the OH- ions forms insoluble hydroxides with the metal ions and the sorbent here then acts as a filter, (v) Acid-base interactions. Most of these metal ions are hard acids and the interact with atoms on the functional groups such as oxygen on the carboxyl and hydroxyl group and nitrogen on the amine groups (vi) Adsorption for example with the presence of alkenes, the concentration of electron density on them actually creates dipole moments with negative dipole moment concentrated on the center of the double bond and the positively charged metal ions will sit on these areas with high electron density [20].

C. Parameters

Effect of contact time

Contact time is an important parameter for determining the equilibrium time required for the sorption of metal ions on a sorbent as it is directly proportional to amount of metal ions removed from aqueous solution. It was observed that the percentage efficiency of the MOSP increased with time and subsequently reached a constant value at the optimal time where no more ions were adsorbed from the solution. At then constant value, the amount of ions being adsorbed by the MOSP was concluded to be in a state of dynamic equilibrium. The time required to attain this state of equilibrium is referred to as the equilibrium (optimal) time [21]. The amount of ion adsorbed at the equilibrium time reflects the maximum adsorption capacity of the adsorbent under optimal conditions. The result showed that the adsorption of ion increases with time up to the optimal time of 60 minutes as reflected on Fig. 3.

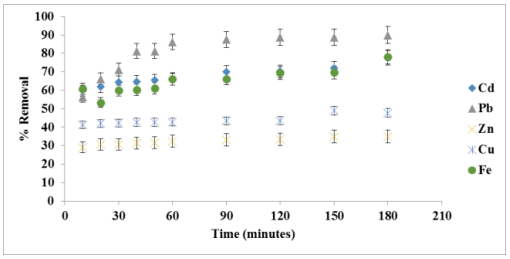

Fig. 3: Effect of contact time on metal removal using MOSP (all other variables kept constant)

Effect of biomass dosage

It is expected that as the sorbent amount increases, the number of sorbent particles surrounding the metal ion or ratio of sorbent particle to metal ion increases. Increases the surface area on which the metal ions binds to the surface of the sorbents and hence increasing the removal efficiency. The adsorption of ions increased with the MOSP dosage as shown in Fig. 4. At MOSP dosage above the optimal dosage, adsorption equilibrium was reached. The percentage of ions removal increased with the increasing amount of MOSP upto 1g of the sorbent. This may be attributed to the availability of

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more binding sites for complexation of ions [22]. Further increment in MOSP dose did not cause significant improvement in adsorption for Cd, Pb and Fe. This seems to be due to the binding of almost all ions to the MOSP leading to equilibrium between the ions bound to the adsorbent and those remaining unadsorbed in the solution. However, removal of Zn and Cu decreased when more than 1g of the sorbent was used. This is attributed to possibility of metal bleeding from the material and also the fact that there is possibility of the particle overlapping and overcrowding resulting in a reduction of the total adsorbent surface area and hence decreases the percentage removal [20]. ANOVA showed no significant difference when 1g was used as the optimal dosage for all the selected metal ions.

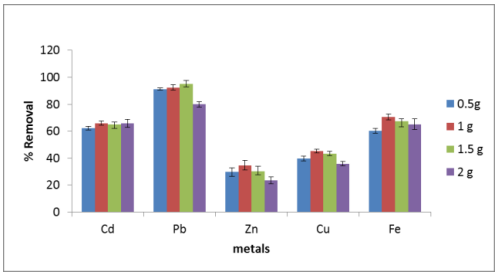

Fig. 4: Effect of biomass dosage on metal removal using MOSP (all other variables kept constant)

Effect of pH

The pH of the solution has a significant impact on the uptake of heavy metals since it determines the surface charge of the adsorbent and the degree of ionization and speciation of the adsorbate [21]. An increase in pH of solution while keeping all other factors (time, temperature, metal concentration, sorbent dose and particle size) constant increased the percentage removal (rise of curves) of the selected metal ions using the MOSP as shown in Fig. 5. This could be due to the surface charge on the sorbent. The functional group such as amines, carboxylic and hydroxyl, form anionic sites as pH is raised from acidic to basic conditions. The anionic sites could be responsible for binding with the metal cations. At low pH, the cations compete with the hydrogen ion in the solution for the active sites and therefore lower adsorption. But at higher pH, the surface of the adsorbent has a higher negative charge which atracts more cations. At pH>8, precipitation occurred. Therefore pH 8 was taken as the optimum pH.

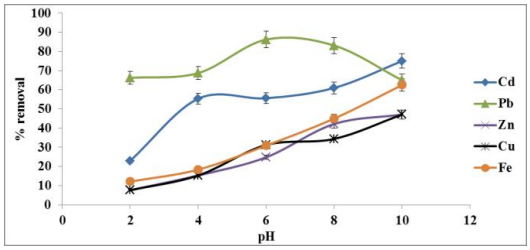

Fig. 5: Effect of pH on metal removal using MOSP (all other variables kept constant)

Effect of Metal Ion concentration

The rate of adsorption is a function of initial concentration of ions. The initial concentration provides essential driving force to overcome all mass transfer resistance of metal ions between the aqueous and the solid sorbent [23]. It was observed that at higher adsorption was found to take place at lower concentrations as shown in Fig. 6. This is due to the interaction of all the ions present in the solution with binding sites on the MOSP surface. At higher concentrations, more ions are left unadsorbed in the solution due to saturation of adsorption sites. The number of ions adsorbed from a solution of higher concentrations is more than that removed from less concentrated solutions. At lower ions concentration, the percentage removal was higher due to larger surface area of adsorbent being available for adsorption. When the concentration of ions increases, the percentage removal decreased due to decrease in available sites for adsorption which is as the result of saturation of adsorption sites. At a higher concentration of ions, the ratio of initial number of moles of ions to the adsorption sites available was higher, resulting in lower adsorption percentage [24]–[26].

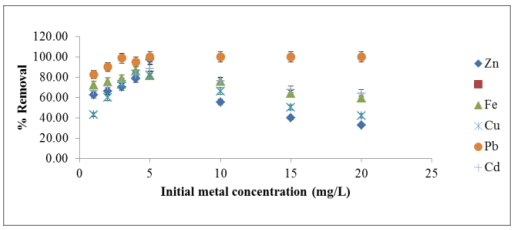

Fig. 6: Effect of metal ion concentration on metal removal using MOSP (all other variables kept constant)

Effect of particle size

The particle size varies with surface area, and with the number of micropores. Since sorption is particle diffusion controlled, the increase in micropore increases the number of accessible sites, hence increases the amount adsorbed. Smaller particle sizes gave higher adsorption capacities [18], [27]. This

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may be attributed to the higher external surface available with smaller particles at a constant total mass. This was observed when the particle size were varied from 100 to 500 µm. Higher efficiencies was recorded with 100 µm particles as shown in Fig. 7. Besides adsorption at the outer surface of the adsorbent, there is also the possibility of intraparticle diffusion from the outer surface into mass transfer, which is greater for large particles [28], [29]. As a result of various factors, such as diffusion part length or mass transfer resistance, contact time and blocked sections of the particle may not be utilized for adsorption, therefore, the adsorption capacity of large particles may be low [11]. Therefore 100 µm was taken as optimal particle size.

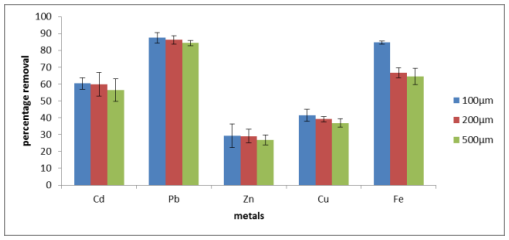

Fig. 7: Effect of particle size on metal removal using MOSP (all other variables kept constant)

Effect of Temperature

Increase of removal efficiency with increase in temperature has been attributed to two factors. An increasing number of molecules could also acquire sufficient energy to undergo an interaction with active sites at the surface and increasing temperature may produce a swelling effect within the internal structure of sorbent enabling large metal ions to penetrate further [30]. Temperature effect on metal removal by the sorbents was investigated using batch experiments conducted in water bath with temperature range from 25°C to 60°C. There was no significant change in percentage removal for other metals except for lead where there was increase as shown in Fig. 8. . It was also observed that there was no significant change when higher temperatures up to 60°C were used; hence 35°C was used as optimum temperature. Similar results have been reported [31], [32].

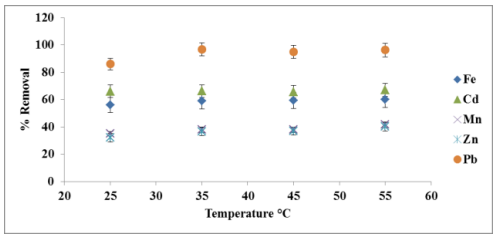

Fig. 8: Effect of temperature on metal removal using MOSP (all other variables kept constant)

D. Removal of metal ions from aqueous solution using optimized conditions

After determining the optimum parameters as shown in Table 1, the parameters were applied in a 50 mL aqueous solution in similar procedure as section II (E). The percentage removal of metal ions was as shown in the Fig. 9

Table 1: Optimized extraction parameters using 20 ppm standard mixture solution.

Material	Contact time (min)	pH	Temp (ºC)	Biomass dose (g)	Particle size (µm)
MOSP	60	8	35	1.0	100

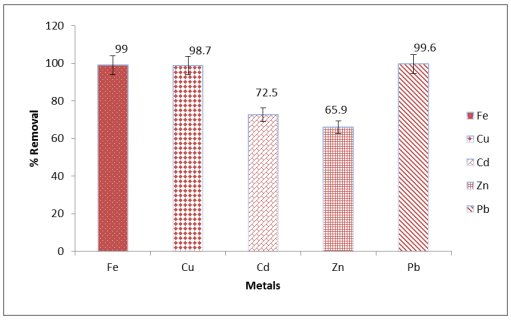

Fig. 9: Percentage removal of the selected ions from aqueous water using the optimized conditions

The removal efficiency trend was Pb> Fe>Cu>Cd>Zn. Higher percentage removal using MOSP could be attributed to a number of factors like (i) possibility of more binding sites on the surface of MOSP ; (ii) there was interaction of the metal to the functional groups in represented in FTIR spectra. The ionic sizes trend of the metals is Pb>Cd>Zn>Cu >Fe for divalent cations. The larger ions are expected to be removed first and the order of removal should decrease from Pb to Cu, but in some cases it will be different depending on the environment of the interacting sites. This trend was not observed completely and this could be attributed to the fact that the metals were interacting differently MOSP adsorbing sites.

E. Conclusion

In this study, an attempt to add value to waste material by developing an ecofriendly method for removing Pb, Cu, Cd, Zn, and Fe ions from aqueous water was conducted. These studies demonstrated that pH, particle size, sorbent dose, contact time, temperature and concentration are significant factors in adsorption. The percentage removal efficiency of Fe, Cu, Cd, Zn and Pb ions using treated MOSP was found to be 99.0 ± 4.27, 98.7 ± 3.89, 72.5± 2.14, 65.9± 1.64 and 99.6± 6.69 respectively. The developed method was found to be a cheap

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and effective method therefore can be implemented on decontaminating polluted water samples.

F. REFERENCES

[1] M. Tüzen, "Determination of heavy metals in fish samples of the middle Black Sea (Turkey) by graphite furnace atomic absorption spectrometry," Food Chem., vol. 80, no. 1, pp. 119–123, Jan. 2003.

[2] A. M. Mathew, "Phytoremediation of heavy metal contaminated soils," vol. VI, pp. 95–97, 2005.

[3] G. Abbasse, B. Ouddane, and J. C. Fischer, "Determination of total and labile fraction of metals in seawater using solid phase extraction and inductively coupled plasma atomic emission spectrometry (ICP-AES)," J. Anal. At. Spectrom., vol. 17, no. 10, pp. 1354–1358, Sep. 2002.

[4] M. V Balarama Krishna, K. Chandrasekaran, S. V Rao, D. Karunasagar, and J. Arunachalam, "Speciation of Cr(III) and Cr(VI) in waters using immobilized moss and determination by ICP-MS and FAAS.," Talanta, vol. 65, no. 1, pp. 135–43, Jan. 2005.

[5] R. J. . Fourest E Serre, "Contribution of carboxy group to heavy metal binding sites in fungal wall," Toxicol. Environ. Chem., vol. 54, pp. 1–10, 1992.

[6] P. Sharma, P. Kumari, M. M. Srivastava, and S. Srivastava, "Ternary biosorption studies of Cd(II), Cr(III) and Ni(II) on shelled Moringa oleifera seeds," Bioresour. Technol., vol. 98, pp. 474–477, 2007.

[7] S. Barua, I. M. M. Rahman, M. Nazimuddin, and H. Hasegawa, "Evaluation of Moringa oleifera Carbon for the As (III) Removal from Contaminated Groundwater," vol. 8, no. 3, pp. 1390–1399, 2014.

[8] Jimoh, T. O., "Utilization of Blighia sapida (Akee apple) pod in the removal of lead, cadmium and cobalt ions from aqueous solution," J. Environ. Chem. Ecotoxicol., vol. 4, no. July, pp. 178–187, 2012.

[9] M. Nasiruddin Khan and M. Farooq Wahab, "Characterization of chemically modified corncobs and its application in the removal of metal ions from aqueous solution," J. Hazard. Mater., vol. 141, no. 1, pp. 237–244, 2007.

[10] N. Foidl, H. P. S. Makkar, K. Becker, N. Foild, and S. Km, "the Potential of Moringa Oleifera for Agricultural and Industrial Uses," What Dev. potential Moringa Prod., pp. 1–20, 2001.

[11] A. Shukla, Y. H. Zhang, P. Dubey, J. L. Margrave, and S. S. Shukla, "The role of sawdust in the removal of unwanted materials from water," J. Hazard. Mater., vol. 95, no. 1–2, pp. 137–152, 2002.

[12] G. Annadural, R. S. Juang, and D. J. Lee, "Adsorption of heavy metals from water using banana and orange peels.," Water Sci. Technol., vol. 47, no. 1, pp. 185–190, 2003.

[13] M. Taha, M. Hassan, S. Essa, and Y. Tartor, "Use of Fourier transform infrared spectroscopy (FTIR) spectroscopy for rapid and accurate identification of yeasts isolated from human and animals.," Int. J. Vet. Sci. Med., vol. 1, no. 1, pp. 15–20, 2013.

[14] P. Sikiti, T. A. Msagati, B. B. Mamba, and A. K. Mishra, "Synthesis and characterization of molecularly imprinted polymers for the remediation of PCBs and dioxins in aqueous environments.," J. Environ. Heal. Sci. Eng., vol. 12, no. 1, p. 82, 2014.

[15] M. A. Abdullah, A. U. Rahmah, and Z. Man, "Physicochemical and sorption characteristics of Malaysian Ceiba pentandra (L.) Gaertn. as a natural oil sorbent.," J. Hazard. Mater., vol. 177, no. 1–3, pp. 683–91, May 2010.

[16] M. Rajiv Gandhi, G. N. Kousalya, N. Viswanathan, and S. Meenakshi, "Sorption behaviour of copper on chemically modified chitosan beads from aqueous solution," Carbohydr. Polym., vol. 83, no. 3, pp. 1082–1087, 2011.

[17] S. Hashemian and J. Shayegan, "A comparative studyof cellulose agricultural wastes (almond shell, pistachio shell, walnut shell, tea waste and orange peel) for adsorption of violet B dye from aqueous solutions," Orient. J. Chem., vol. 30, no. 4, pp. 2091–2098, 2014.

[18] M. Helen Kalavathy and L. R. Miranda, "Moringa oleifera-A solid phase extractant for the removal of copper, nickel and zinc from aqueous solutions," Chem. Eng. J., vol. 158, no. 2, pp. 188–199, 2010.

[19] E. Pehlivan, T. Altun, S. Cetin, and M. Iqbal Bhanger, "Lead sorption by waste biomass of hazelnut and almond shell," J. Hazard. Mater., vol. 167, no. 1–3, pp. 1203–1208, Aug. 2009.

[20] I. W. Maina, V. Obuseng, and F. Nareetsile, "Use of Moringa oleifera (moringa) seed pods and Sclerocarya birrea (morula) nut shells for removal of heavy metals from wastewater and borehole water," pp. 1–33, 2016.

[21] W. S. Wan Ngah and M. a K. M. Hanafiah, "Removal of heavy metal ions from wastewater by chemically modified plant wastes as adsorbents: A review," Bioresour. Technol., vol. 99, no. 10, pp. 3935–3948, 2008.

[22] B. H. Hameed, "Grass waste: a novel sorbent for the removal of basic dye from aqueous solution.," J. Hazard. Mater., vol. 166, no. 1, pp. 233–8, Jul. 2009.

[23] S. V. Dimitrova, "Metal sorption on blast-furnace slag," Water Res., vol. 30, no. 1, pp. 228–232, 1996.

[24] L. V. A. Gurgel and L. F. Gil, "Adsorption of Cu(II), Cd(II) and Pb(II) from aqueous single metal solutions by succinylated twice-mercerized sugarcane bagasse functionalized with triethylenetetramine," Water Res., vol. 43, pp. 4479–4488, 2009.

[25] O. S. Amuda, a. a. Giwa, and I. a. Bello, "Removal of heavy metal from industrial wastewater using modified activated coconut shell carbon," Biochem. Eng. J., vol. 36, pp. 174–181, 2007.

[26] N. Unlü and M. Ersoz, "Adsorption characteristics of heavy metal ions onto a low cost biopolymeric sorbent from aqueous solutions.," J. Hazard. Mater., vol. 136, no. 2, pp. 272–80, Aug. 2006.

[27] E. Demirbas, M. Kobya, E. Senturk, and T. Ozkan, "Adsorption kinetics for the removal of chromium (VI) from aqueous solutions on the activated carbons prepared from agricultural wastes," Water SA, vol. 30, no. 4, pp. 533–539, 2004.

[28] S. Communication, "Sorption kinetics and intraparticulate diffusivities of Cd , Pb and Zn ions on maize cob," vol. 4, no. June, pp. 509–512, 2005.

[29] D. H. K. Reddy, K. Seshaiah, a. V. R. Reddy, M. M. Rao, and M. C. Wang, "Biosorption of Pb2+ from aqueous solutions by Moringa oleifera bark: Equilibrium and kinetic studies," J. Hazard. Mater., vol. 174, pp. 831–838, 2010.

[30] [E. I. El-Shafey, "Removal of Zn(II) and Hg(II) from aqueous solution on a carbonaceous sorbent chemically prepared from rice husk," J. Hazard. Mater., vol. 175, no. 1–3, pp. 319–327, Mar. 2010.

[31] S. Qaiser, A. R. Saleemi, and M. Umar, "Biosorption of lead(II) and chromium(VI) on groundnut hull: Equilibrium, kinetics and thermodynamics study," Electron. J. Biotechnol., vol. 12, no. 4, 2009.

[32] C. M. Zvinowanda, J. O. Okonkwo, M. M. Sekhula, N. M. Agyei, and R. Sadiku, "Application of maize tassel for the removal of Pb, Se, Sr, U and V from borehole water contaminated with mine wastewater in the presence of alkaline metals," J. Hazard. Mater., vol. 164, pp. 884–891, 2009.

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Potential for solar dryer application for food processing in Botswana

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***Abstract*—**Solar drying is a process of utilizing energy from the sun to remove moisture from products, especially food. It is a process that prolongs the shelf life of the harvested products, reduces post-harvest losses and lowers transportation costs since the products become portable and can be easily packaged subsequent to drying. Additionally, solar drying improves the quality and quantity of food. Food preservation by use of solar dryers holds immense potential in the food processing industry in Botswana due to abundant solar irradiance. Solar drying methods that can be applied in Botswana include direct, indirect and the mixed type. The traditional open to sun drying or the direct method is the primary technique currently being applied. Of note is that traditional open sun drying has some disadvantages. More efficient and effective drying techniques such as indirect and mixed type are necessary to guarantee high quality and a constant supply of foods. This paper reviews the traditional drying technologies used in Botswana and explores potential modern solar drying technologies that can be used to substitute and or complement them.

Keywords—Solar dryer; solar irradiance; open sun drying; food preservation

I. INTRODUCTION

Economies of most developing countries are largely depended on agriculture [1]. The agricultural sector produces food so as to meet one of the most basic needs of citizens. People grow crops and rear animals for subsistence and commercial reasons hence contributing to the economic status of their countries. Most developing countries are not self-sufficient when it comes to food provisions to their entire populations because of unprecedented increases in the number of people within their respective boarders [2]. A lack of knowledge and use of inappropriate preservation techniques and a shortage of storage amenities causes deterioration of the quality and quantity of produce. Most crops are seasonal as are other sources of food e.g. mopani worms and fruits, as such appropriate preservation during and immediate post-harvesting time is vital in maintaining the relevant balance between food supply and population growth. In the case of mopane worms, the preservation process involves use of firewood which is suspected to cause deterioration in final product quality as well as contributing to deforestation. Not only will some of the worms get burnt to beyond consumption state but the method results with a soil grains contaminated product.

Drying food in the open using energy from the sun in order to preserve it is one of the main processing techniques used in sunny areas. Botswana is endowed with relatively high solar insolation levels of 21 MJ/m^2/day, and on average records 280-330 clear sunny days per year [3]. It is therefore not surprising that in Botswana, open sun drying is the most widely method for food preservation taking advantage of the abundant solar irradiance. Consequently, it is logical that efforts be directed at utilizing the sun for food drying but using improved techniques. The traditional open sun drying method involves scattering the products to be dried in thin layers on flat and open surfaces therefore exposing them to the sun and wind. In the case of mopane worms, after cooking them, they are laid for drying on a swept piece of ground [4]. Drying meat and other related products involve cutting them into thin strips and suspending on a wire for the sun to dry. Drying generally prolongs the shelf life of the harvested products, improves the quality and quantity of products, reduces post-harvest losses and lowers transportation costs since the products are portable and easily packaged after the drying process [5].

There are a number of disadvantages associated with traditional open sun drying. It requires a large open space area, is highly depended on the presence of insolation, is prone to contamination by dust and food being processed is vulnerable to attack by insects, birds, rodents and infections from micro-organisms [4]. Furthermore, open sun drying happens to be labour and time intensive. This is because the food under processing needs to be covered, not only at night but also during harsh weather conditions, and must be protected from animals [1]. Additionally, non-uniform and insufficient drying leads to deterioration of the food grain quality during storage [1]. In order for countries to meet the basic requirement of high quality and constant supply of food for their growing populations, efficient and effective solar dryers are a necessary requirement. Solar dryer designs that use cheap and locally

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available materials are the best alternative to improving the quality and quantity of the food and minimizing of post-harvest losses.

II. CLASSIFICATION OF SOLAR DRYING SYSTEMS

Various kinds of solar dryers have been developed for agricultural products and work is continuously being done to improve on these dryers in other countries. Literature shows that basically, there are four types of solar dryers [8]. These are namely direct, indirect, mixed mode and hybrid solar dryers.

Further classification of dryers is based on their operating temperature range hence high temperature and low temperature dryers. They may also be categorized broadly into fossil fuel dryers (conventional dryers) and solar energy dryers depending on their heating sources. High temperature dryers are powered by fossil fuels, while low temperature dryers are either fossil. The heating modes and the manner the solar heat is utilized by solar dryers can also be used for dryer classification [9]. Other factors that may be used in categorizing solar dryers include: mode of air movement, exposure of insulation, direction of air flow, architecture of the dryer and the status of solar contribution.This leads to classification into two broad groups which are, active solar-energy drying systems (hybrid solar dryers) and passive solar energy drying systems(natural-circulation solar drying systems).

Fig. 1, is an illustration of the main features of different designs of various classes of solar dryers.

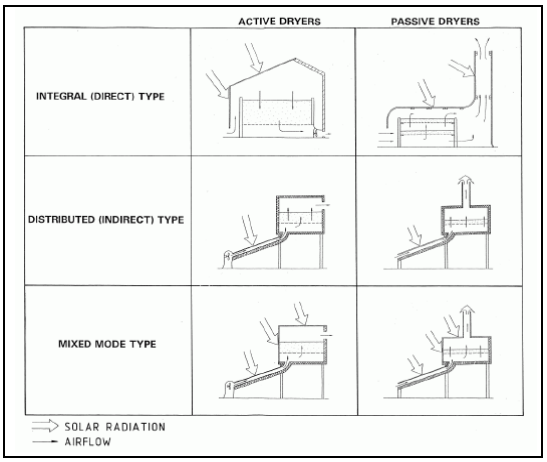

Fig. 1. Different designs of various classes of solar dryers [1].

III. COMPARING OPEN SUN DRYING AND THE SOLAR DRYER

The sun has been used for drying for as long as humans have inhabited the planet [10]. The application of a solar dryer (also known as solar drying) for dehydration process is a possible alternative to open sun drying [1]. Solar drying is the process of using an enclosed unit to remove moisture from the products (foods) using energy from the sun in a cleaner and healthier way [11]. On the other hand, open sun drying involves simply laying or hanging the products in the sun on mats, roofs or drying floors. Both methods utilize thermal energy from the sun; however the modes of operation are different. The advantages and disadvantages of solar dryers are summarized in *table I* while *table II* lists the disadvantages and disadvantages associated with open sun drying.

TABLE II. ADVANTAGES AND DISADVANTAGES OF SOLAR DRYERS.

Advantages	Disadvantages
Food is of better quality and quantity. It reduces post-harvest losses. Reduces the risk of contamination from micro-organisms. Low labor requirements. Higher drying rate hence reduced drying time. Protects food from dust, rains, insects, birds and animals as solar dryers are enclosed.	Solar dryers are expensive; they have high initial investment capital. Solar dryers have often been too complicated to local farmers due to inadequate training. A backup system such as a heater is necessary for products that require continuous drying. Can only be used during day time when it is sunny.

TABLE III. ADVANTAGES AND DISADVANTAGES OF OPEN SUN DRYING.

Advantages	Disadvantages
Prevent the usage of fossil fuels that lead to environmental pollution. It is very cheap, no cost are incurred in buying materials.	Food is exposed to insects, dusts, rain, birds and animals. Food contaminations, as the idle time in between drying sessions allow the growth of unwanted microorganisms. Sudden rains and strong winds may totally ruin the all food being dried. Deterioration of food quality due to direct exposure to the sun. Non-uniform and insufficient drying. Labor and time intensive, as products need to be covered at night and during harsh weather conditions, and also must be protected from domestic animals.

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IV. FOOD DRYING IN BOTSWANA

A. Common practices of drying food products.

Traditional open to sun drying is the main method of preserving food that has been used in Botswana since far back in time. In rural areas agricultural products such as ground nuts, jugo beans, bean leaf stew (morogo wa dinawa), seeds, meat (segwapa) and wild spinach are seasonal and are normally produced in high quantities hence cannot all be consumed in-season. As a way of preserving these produces for future usage during drought times or out of season, Batswana resort to drying using the sun [6]. Some produce must be pre-processed prior to exposure to the sun. Examples are the mopane worms which go through a fire-based treatment and salting before drying and meat which is usually salted before drying (see *Fig. 2*). Other products such as maize are normally dried without undergoing any pre-processing.

Traditionally open drying surfaces consist of paved grounds, mats, trays, boards, wires or strings supported by poles. Sun-drying of fish is done on racks made either of chicken wire or woven reed mats mounted on poles erected on the ground [6]. Some configurations of which are shown in *Fig. 3*. The racks are installed where there is enough shading, such as under trees so as to avoid direct heat from the sun. The fish is exposed to ambient temperature for about 7 days before packaging [6]. The fish being dried should be covered at night, during harsh weather conditions, and must also be protected from domestic animals throughout the drying process. On the other hand, sun drying of mopane worms is done on a swept piece of ground as shown in *Fig. 4*, a process that apparently allows easy access for insects [4]. The mopane worm is directly exposed to the heat from the sun for 2-4 days depending on weather. A visit to a mopane processing site in the bush has also revealed that sometimes a large fire is made on the ground and mopane worms are then directly spread on that piece of ground after extinguishing the fire upon removal of amber and ash.

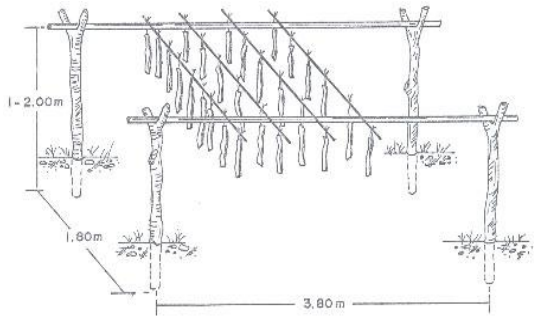

Fig. 2. Set up for meat drying [8].

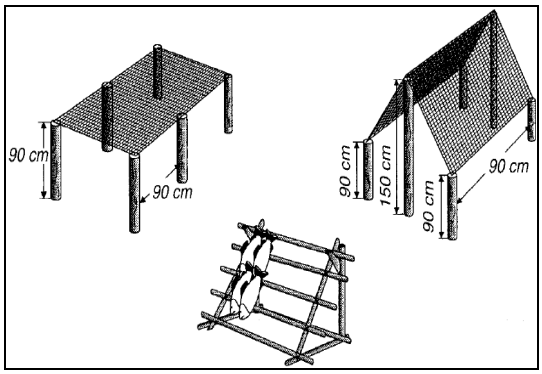

Fig. 3. Fish drying racks [7]

Fig. 4. Drying mophane worm on an open ground [4].

B. Government iniatives on promotion of food drying using solar energy in Botswana.

The Government of Botswana has contributed in food preservation by introducing the dried salted fish technology after the country suffered from severe droughts [6]. Open sun drying technology of salted fish was successfully promoted for long term preservation of seasonal catches in remote areas. The success of dried salted technology was primarily due to a Government programme of buying the salted-dried fish for subsequent distribution to the most disadvantaged [6]. Regardless of the Government contributions towards fish drying using the sun, there are some major problems with the system. The quality of the dried salted fish is poor, due to insufficient and ineffective drying [5]. It is therefore necessary to apply solar dryer technology for food processing in Botswana to eliminate the disadvantages associated with open sun drying. However, in Botswana less or limited research and innovations have been done on solar dryers. It is quite difficult

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to come across published work that deals with solar drying technology that is specific to Botswana.

V. Conclusion

Traditional open sun drying of agricultural products or food has long been used in Botswana in rural areas due to abundant solar irradiation. However, there are problems associated with open sun drying hence there is a need for adoption of other solar drying technologies. Solar dryer application for food processing as a solar drying technology has a large potential in Botswana but to our knowledge, it is not being widely researched on, utilized or promoted. Raising awareness is crucial in sensitizing the public, institutions, researchers and relevant stakeholders of Botswana on the advantages of adapting environmentally friendly methods of food processing.

REFERENCES

[1] W. Weiss and J. Buchinger, Solar Drying, Austria: AEE Intec, 2002.

[2] A. Mustayen, S. Mekhilefa and R. Saidur, "Performance study of different solar dryers: A review," Renewable and Sustainable Energy Reviews, vol. 34, p. 463–470, March 2014.

[3] EA, "Energy Statistical Bulletin," Ministry of Minerals, Energy and Water Resources, Gaborone, 2008.

[4] A. N. Manoharan and M. Praseedakumari, "Spatial analysis of Mopani worms distribution in Botswana, Africa: A preliminary study using GIS," GCK Science Letters, vol. 3, no. 1, pp. 34-43, 2014 .

[5] A. Fudholi, K. Sopian, M. Ruslan, M. Alghoul and M. Sulaiman, "Review of solar dryers for agricultural and marine products," Renewable and Sustainable Energy Reviews, vol. 14, p. 1–30, 2009.

[6] T. C. Mmopelwa, "Sun-dried salted fish as a means of reducing post-harvest losses in botswana," in Proceedings of the symposium on post-harvest fish technology, Cairo, 1990.

[7] B. M. Berkel, B. V. Boogaard and C. Heijnen, Preservation of fish and meat, Wageningen: Agromisa Foundation, 2004.

[8] Regional Office for Asia and the Pacific, "FAO Corporate Document Repository," [Online]. Available: http://www.fao.org/docrep/010/ai407e/AI407E18.htm. [Accessed 2 June 2017].

[9] K. Ong, "Solar dryers in Asia-Pacific region," Renewable Energy, vol. 16, p. 779–784, 1999.

[10] O. Ekechukwu and B. Norton, "Review of solar-energy drying systems II: an overview of solar drying technology.," Energy Conversion & Management, vol. 49, no. 6, pp. 615-655, 1999.

[11] R. J. Fuller, "Solar drying - A technology for sustainable agriculture and food production," Solar energy conversion and photoenergy systems , vol. III, pp. 3-9, 2002.

[12] B. Rwubatse, I. P. Akubor and E. Mugabo, "Traditional drying techniques for fruits and vegetables losses alleviation in Sub-Saharan Africa, " Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), vol. 8, no. 9, pp. 52-56, 2014.

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***Abstract*—Even though Research and Development (R&D) is a key driver of economic growth and development, the contribution to R&D as a proportion of Gross National Income (GNI) is less than 1% in developing countries, including Botswana. This suggests that there is limited internally sourced funding for research, making external donors the major source of research funding in most developing economies. This study assessed dynamics in external research funding at the Okavango Research Institute (ORI) since the last 15 years. Data were sourced from project contracts from the institute's archives. Results revealed that external research funding has had a significant contribution to Botswana's research strategy. The key research area that received most funding was ecological research, while the International Development Research Centre and the EU were the most dominant research funding organizations at ORI. Donor agencies from only four continents contributed to research funding at ORI while there were none from South America and Australia. Furthermore, there was minimal research funding from multi-lateral and bi-lateral donors of which the Botswana government is a signatory. One key recommendation from this study is that government and academics should forge close partnerships to optimize leveraging of external research funding. This will ultimately drive R&D initiatives in the country, which is pivotal to economic growth and development**

***Keywords*—Natural resources management, Okavango Delta, Research and development; Research funding**

I. BACKGROUND

Expenditure on research and development (R & D) is a key indicator of a country's effort to engender innovation [1] which is a major driver of economic development [2]. Subsequently, rich nations spend more on R & D [1] and higher education than poorer countries [3] Invariably R & D, driven by expenditure on higher education, drives economic growth in rich nations compared to developing countries [3, 2]. As a consequence, developing countries depend on (external) development aid to drive their growth [4] Development aid to developing countries by 2007 reached US$100 billion, while sub-Saharan Africa (SSA) received only US$12.1 billion of this as country programmable aid, which is only 12.1% of development aid reaching Africa [5] Generally, this has resulted in little aid reaching the developing world, which has created shortfalls in key development sectors such as research. To compound this, low-income countries and most SSA countries do not have research budgets [6], which is a major impediment towards sustainable development [7]. Most developing countries spend less than 0.25% of their Gross National Income (GNI) on R & D [8]. Therefore, some of the key challenges facing research in developing countries include limited material and financial resources, and poor physical and communication infrastructure [9].One of the key drivers to economic competitiveness is university education that promotes research and innovation [2], which is one of Botswana's development policies [10].

Botswana is a middle-income country that has escaped most of the deep socio-economic challenges faced by other African countries [11]. However, despite its economic status, characterized by a relatively high per capita income [12], (internal) funding for research and development remains a challenge. The global ranking of Botswana in 2012 indicates that the country's contribution to R & D as a proportion of its GNI was 0.25%, placing it in the 86th position [8]. This poor and erratic funding has engendered lack of a comprehensive research activity in the country [13]. Nonetheless, because of its appreciation of the value of R & D towards economic development, Botswana has developed an innovation policy to "strategically focus on research and development" [10]. Although there are valuable natural resources in Botswana (as found in the Okavango Delta) serving as a major source of socio-economic livelihoods, there have been limited internally generated funds ear-marked for environmental research. Subsequently, there is an urgent need to ensure that the ecological integrity of the Okavango Delta is safeguarded to ensure sustainable development. This is consistent with the Sustainable Development Goals (SDG's) as outlined in the [12] report. The aim of this paper is to highlight this externally funded research and ascertain its relevance to Botswana's research strategy.

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The Okavango Research Institute is the main (government) research institute (of the University of Botswana) mandated to conduct research on the Okavango Delta. This study, therefore, assesses the level of external research funding, which the institute has received over the years, sources of its funding, and the research areas that have been funded.

II. MATERIALS AND METHODS

A. *Study Area*

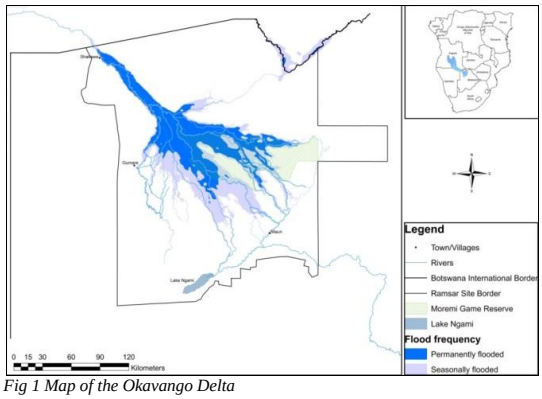

Fig 1 Map of the Okavango Delta

The Okavango Delta is one of the largest inland deltas in the world [14], and the largest source of surface water in Botswana [15].It is located in semi-arid North-western Botswana (Fig 1), which enhances its value significantly, both as a source of water and livelihoods. The delta is the world's largest Ramsar site [16] and is also a World Heritage site. Current population statistics estimate the Ngamiland population at 152 284 [17], and the majority of these people depend on the Delta as a major source of their livelihoods [18]

B. *Data Collection*

Primary data on donor funding from 2001 to 2015 were sourced from archival records located in the Finance Office at the Okavango Research Institute (ORI). These data were mostly in the form of contracts signed between different donors and the University of Botswana.

III. DATA ANALYSIS

Donor funding data were captured using Microsoft Excel database for easy analysis. Donor data were summarized into frequencies which were then used to generate charts, line graphs and multi-graphs.

IV. RESULTS

Ten identified research areas were funded over a 15 year period in the Okavango Delta (Fig 2), in which the total funding was just over P120 million from four continents (Fig 3). Ecology, which received funding from three continents except Asia, was the most funded research area, while cultural heritage, which received funding only from North America, was the least funded area (Fig 2). North America had the biggest contribution (approximately 57%) over the study period, while Asia contributed the lowest proportion (<1%) to research funding in the Okavango Delta. Funding agencies from other continents like South America and Australia have not provided any research funding in the delta during the study period. The EU was the main research donor at ORI over the study period (Table 1). While Africa provided the highest level of funding to Health, Europe provided the highest level of funding to energy and North America provided the highest level of funding to ecology (Fig 2). Qualitatively, research funding from Africa and Europe has increased steadily over the past 15 years while funding from North America decreased within the same period (Fig 4).

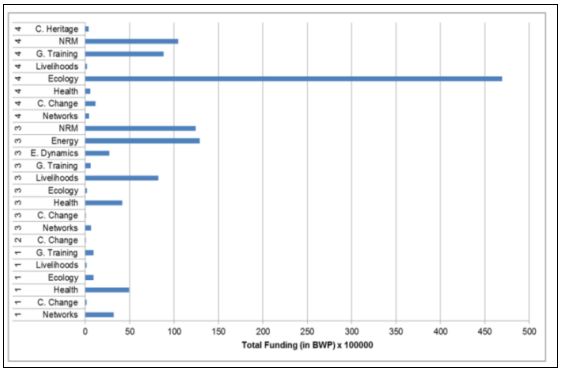

Fig 2 Comparison in funding among the four continents in each research area over the entire study period.

(Note: 1 = Africa; 2 = Asia; 3 = Europe; 4 = North America; C. Heritage = Cultural Heritage; G. Training = Graduate Training; C. Change = Climate Change; NRM= Natural Resources Management; E. Dynamics = Ecosystem Dynamics)

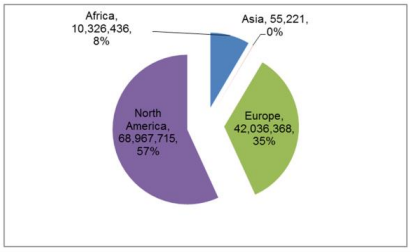

Fig 3 Relative proportion of research funding in the Delta from different continents between 2001 and 2015 where values indicate the total funding (in BWP) over the period

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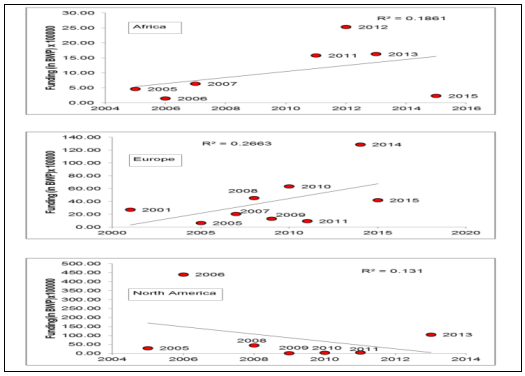

Fig 4 Trends in total research funding from each continent over the study period

TABLE 1 RELATIVE PROPORTION OF THE DIFFERENT FUNDING AGENCIES THAT HAVE FUNDED RESEARCH AT THE OKAVANGO RESEARCH INSTITUTE DURING THE STUDY PERIOD

Percentage (%)	Donor
3	ACP Group, Apina Project, Association of American Geographers, RISE[1], CDKN[2], FAO[3], FCB[4], Germany, Inqua Project, IUQR[5], IUCN, NEA[6], RP-PCP, DRFN[7], UNESCO[8], WARFSA, WaterNet, Wenner-Gren foundation for anthropological research, WHO[9]
6	NASA, UNDP
8	START[10]
11	IDRC[11]
14	EU

Note: 1 = Regional Initiative in Science and Education; 2 =Knowledge Management Team; 3= The Food and Agriculture Organisation; 4=Forest Conservation Botswana; 5=International Union for Quaternary Research; 6=National Executing Agency; 7=The Desert Research Foundation of Namibia; 8=United Nations Education and Scientific Organisation; 9= World Health Organisation; 10=International START Secretariat; 11=International Development Research Centre

V. DISCUSSION

This study has revealed that research funding from North America, which once constituted the highest proportion of total research in the Okavango Delta, has decreased gradually between 2001 and 2015. Conversely, research funding from the rest of Africa and Europe has increased steadily during the same period. These local dynamics in research funding might reflect international macro-economic relationships between Africa and North America. According to the World Bank (2016) report, net official development assistance as percentage of GNI in 2014 exceeded the 0.7% of GNI limit set by the UN for several European countries (it exceeded 1% GNI for Sweden and Luxembourg), and was relatively low for the US (<0.25% of GNI). However, while the US was the largest donor by volume [12] to the developing world at US$ 32 Billion in 2014, international development aid to Botswana has decreased substantially over time after it was declared an upper middle income country [11]. Hence, it can be argued that the gradual decrease in North American funding for research in Botswana could be based on the perception that Botswana is now capable of funding its own R & D initiatives.

Results (Table 1) reveal that most research on the Okavango Delta was funded by the EU, or EU based donors, while the second most common donors were based in North America (IDRC and START). However, none of the donors came from any of the key agencies through which government has bi-lateral and multi-lateral agreements on natural resource or biodiversity conservation. This implies that ORI academics may not have taken advantage of funding from these international agencies like Ramsar, IUCN, the world Heritage Council, the CBD, or these funding agencies were not accessible to ORI. This notwithstanding, ORI should take advantage of the Ramsar status of the Okavango Delta, and its listing as a world Heritage Site to leverage funds from multi-lateral and bi-lateral donors for management and monitoring of the Delta's natural resources. It is noteworthy that IDRC is one of the dominant contributors to external research fusing at ORI (Table 1). This is consistent with one of its key tenets of IDRC to "foster research activity" in developing countries [19].

Based on the results (Fig 2), ecological research received the highest funding between 2001 and 2015 in the Delta, while the second most funded area was Natural Resources Management (NRM). This finding buttresses the key mandate of ORI, which is natural resources management [20], and which makes the funding relevant to its mandate. Also, external funding at ORI falls within the research framework circumscribed by the Okavango Delta Management Plan (ODMP) through its research strategy [16], making the external funded research at ORI relevant to the Okavango Delta information gaps. The University of Botswana (UB) strategic plan [21] emphasizes the need to increase graduate student enrolment at the university as an effort to intensify research activity and competitiveness globally. The results show that some of the projects at ORI focused primarily on graduate training, which also fulfils the aims of the UB strategic plan. One of the key focus areas of the Botswana Tertiary Education Council (TEC) [10] is to develop a curriculum that equips students with "specialist knowledge" and "critical skills". Hence, the graduate training provided through external funded research at ORI contributes to this key area of the Tertiary Education Council. Therefore, externally funded research at ORI contributes to key government policies. However, there is need to create a broad based approach to leverage more funding from external sources. These will contribute to the limited internal funds available for R & D, which is a key component of economic growth and development.

There is concern that externally funded research in the SADC region might drive the research agenda of international funding agencies and not necessarily of the recipient governments [22]. However, this study has shown that this concern has not affected externally funded research at ORI. External research funding at ORI has contributed primarily to ecological and natural resources management research and graduate training in research. Nationally, ORI is, therefore, contributing to the twin goals of economic growth and development that Botswana needs. Knowledge generated from research in ecology and NRM will contribute towards monitoring and measurements of the country's efforts to achieve the SDG's [12] by 2030. Moreover, the current research at ORI is responding directly to the ODMP's research strategy, highlighting research gaps in the delta which will ultimately ensure sustainable use of its natural resources. Furthermore, despite the limited research activity in Botswana

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due to limited research funding, Botswana is the second most productive country in SADC after South Africa [22]. Therefore, optimizing externally sourced research funding will certainly contribute significantly to R & D in Botswana.

VI. SYNTHESIS

Government has access to multi-lateral and bi-lateral donors for research funding, but has limited skilled manpower resources to conduct research. There is need for academic institutions and government ministries to forge research partnerships to access these funds. There are two clear pathways for Botswana academic institutions (like ORI) to leverage funds for research. (i) The local private sector (industry) can provide some of the funding needed for research in natural resources management. (ii) Multi and bi-lateral donors are another source of funding for R & D in Botswana. However, these can be achieved through a deliberate effort by government to create an enabling environment.

[2] Argues that there is need for enhanced cooperation between industry and universities to facilitate R & D (in the South African context). The same argument can be made for Botswana where government should create a favourable environment for the private sector (industry) to invest in R & D. Some of this can be through a tax credit system where companies investing in R & D receive tax exemptions/ breaks [13] subsequently, part of this investment should then be made available for research in natural resources management, which would contribute to the country's efforts to achieve the 2030 SDGs. According to the [23], achieving the SDGs will "end poverty and enhance social and economic development".

As highlighted by the [12] report, governments and developmental partners need to invest resources in data collection to monitor and measure progress against SDGs. Investing resources in R & D remains a challenge for a middle income country like Botswana suggesting that a measure of external funding for research is still necessary for generating relevant data meant for advancing development. Therefore, it is incumbent upon academic institutions like ORI and government to forge closer partnerships and collaborations to leverage funding from multi-lateral and bi-lateral development partners. Academic institutions have the human resources to undertake R & D while government has the political connections to access global financial resources. Therefore, SDGs can be achieved for the Okavango Delta communities through a close collaborative effort between ORI and government, to leverage funding for R & D from international actors. The current situation, where ORI seeks funding on its own, while government does not optimize utilisation of R & D funds available from its developmental partners, is unsustainable.

VII.CONCLUSION

This study has shown that external research funds can contribute to R & D in developing countries. Arising from the limited internal research funds in Botswana, donor funding sourced by academics at ORI has consistently contributed to the country's research strategies and other policies related to R & D. However, there is evidence that ORI has not been able to utilise funding from multi-lateral and bi-lateral donors to which Botswana is signatory. This implies that external funding opportunities are yet to be optimized by ORI in intensifying research in the Okavango Delta. There is need for development of strategies to ensure that academics can access these funds. One strategic objective would be for government and UB to forge close collaboration to leverage external funding from multi and bi-lateral donors. In order to elevate its economic growth and development trajectory, a close partnership between the government of Botswana and both multi and bi - lateral donors will result in increased funding, leading to an enhanced R & D activity in the country.

VIII. REFERENCE

[1] OECD, 2014, OECD Fact book 2014: Economic, Environmental and Social Statistics, OECD Publishing. http://dx.doi.org/10.1787/factbook-2014-en

[2] A. Nicolaides, "Research and innovation-the drivers of economic development",African Journal of Hospitality, Tourism and Leisure, 3(2). 2014.

[3] P. Aghion, M.Dewatripont, C. Hoxby, A. Mas-collell, A. Sapir.,Why Reform Europe's University? Bruegel Policy Brief, September 2007.

[4] DFID, What is the evidence on the impact of research on international development? Department for International Development, UK, 2014.

[5] H. Kharas, Trends and issues in developing aid, The Brookings Institution,November 2007.

[6] E. Harris, "Building scientific capacity in developing countries", European molecular Biology Organisation. Vol 5, No 1, 2004.

[7] C.S. Wagner, I. Brahmakulam, B. Jackson, A. Wong, T. Yoda, Science and technology collaboration: Building capacity in developing countries? Rand Publications, Santa Monica,California, USA, 2001.

[8] UNESCO, Research and development expenditure (% of GDP) - Country Ranking, viewed Accessed 7 May, 2017 http://www.indexmundi.com/facts/indicators/GB.XPD.RSDV.GD.ZS /rankings

[9] A.G. Bruner, R.E. Gullison., A. Balmoford, financial costs and shortfalls of managing and expanding protected area systems in developing countries. 54(1) Bio science, December 2004.

[10] TEC, A Proposal for a Tertiary Education Policy for Botswana. Tertiary Education Council, Gaborone, October 2006.

[11] Bertelsmann Stiftung (BTI), Botswana Country Report. Gütersloh: Bertelsmann Stiftung, 2014.

[12] World Bank,World development indicators, The World Bank, Washington DC, 2016.

[13] University World News,Botswana, bleak outlook for research despite government funding. 17 January 2014 Issue No: 30320

[14] B. R. Allanson, R. C. Hart, J. H. O'Keeffe, and R. D. Robarts, , Inland Waters of Southern Africa; An Ecological Perspective, The Netherlands, Kluiwer Academic Publishers, 1990.

[15] G. S. Merron,"Pack-hunting in two species of catfish, Clarias gariepinus and C. ngamensis, in the Okavango Delta, Botswana" ,Journal of Fish Biology, (43):575-584, 1993.

[16] P.J. Ashton, S.D. Turner., K.H. Jensen., P.J. Mundy., and B.B Neergaard, , Development of a Five-Year Research Strategy for the Okavango Delta Management Plan (ODMP), Contract Report for the Okavango Delta Management Plan (ODMP) Secretariat, Maun, Botswana, by Scanagri A/S, Copenhagen, Denmark. Xiv + 101 pages, 2005

[17] Statistics Botswana, 2016, Selected Statistical Indicators 1966 -2016, Statistics Botswana, Gaborone.

[18] J.M. Mendelsohn, C. vanderPost, L. Ramberg, M. Murray-Hudson, P. Wolski, and K. Mosepele,Okavango Delta: floods of life, RAISON - Windhoek, Namibia, 2010.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

[19] A.S. Metcalfe, S.Esseh, and J. Willinsky, "International development and research capacities", Increasing access to African Scholarly Publishing. Canadian Journal of Higher Education, 39(3); 89-109, 2009.

[20] UB, 2010. A strategy for excellence (2010-2016). Maun, Botswana.

[21] UB, 2008. University research strategy, Gaborone, Botswana.

[22] J Mouton, N. Boshoff, L. de Waal, S. Esau, B Imbayarwo, M. Ritter, D van Niekerk, The state of public science in the SADC Region, Chapter 4, p 199 – 301. undated

[23] World Bank., 2015, Annual Report 2015, The World Bank, Washington DC.

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Diversity and population structure of some woodland species in communal areas of north western Botswana.

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***Abstract*— Plants in arid areas are widely used for timber, food, fire wood and livestock fodder. As a result they could be threatened by over-exploitation from overgrazing and overharvesting. These threats are exacerbated by lack of knowledge on the composition and population structure of woodland species. The aim of this study was to classify woodland species and determine their population structure. Sampling was conducted in 20 × 50m plots. In total 75 plots were sampled where canopy cover was estimated and diameter at breast height measured. Hierarchical cluster analysis was used to derive different communities. Indicator species analysis was utilized to determine the indicator value for different species in a given community. Plant species richness and diversity were determined for each plant community. Multi Response Permutation Procedures (MRPP) was used to determine the level of separation between the plant communities. Kruskal-Wallis test was exercised to compare species diversity and richness between woodland communities. Plant species were classified into four communities of *Acacia erioloba-Grewia bicolor*, *Terminalia sericea-Burkea africana*, *Acacia mellifera-Boscia albitrunca* and *Combretum collinum-Baphia massaiensis*. Results of MRPP showed that the communities were significantly ($p<0.05$) different from each other. Species richness and diversity were significantly lower in *Acacia mellifera-Boscia albitrunca* community. Populations of *Acacia erioloba*, *Philenoptera nelsii* and *A. nigrescens* showed bell-shaped structure while those of *Burkea africana*, *Boscia albitrunca* and *Combretum collinum* had reverse J-shaped pattern. *Terminalia sericea*, *Ziziphus mucronata* and *Colophospermum mopane* had only 2 or 3 classes skewed towards juveniles.**

Keywords*— *Classification, Cluster analysis, Indicator value, Plant community and Population structure

I. Introduction

In semi-arid regions, plant community composition, distribution and population structure may be influenced by climate change, water and nutrient availability [1]. Water availability influences moisture dependent processes such as germination and nutrient cycling [2]. Water stress mostly has negative influence on the establishment and growth of perennial species in arid and semi-arid regions [2]. Other environmental factors that may influence plant community composition, distribution and population structure include grazing, browsing, seed dispersal by herbivores and wood harvesting for subsistence use. Grazing may result in the establishment of opportunistic woody species leading to bush encroachment while over browsing results in tree and shrub destruction [3]. Plant species show differential response to livestock grazing. Other species increase in abundance while others reduce in response to livestock grazing [2]. This is as a result of herbivores actively selecting for or against a given plant species [4]. Livestock grazing also disrupts nutrient cycling, plant succession, vegetation stratification which contributes to soil erosion and a decrease in water availability to biotic communities [5].

Plants in arid habitats are widely used for timber, food, fire wood and cattle fodder by the human population [6]. They also contribute significantly to the overall ecosystem functioning through nutrient cycling, evapo-transpiration which influences the water cycle, soil erosion prevention and habitat provision [7]. In Botswana, woodland species also provide services and goods to humanity. Fruits of *Grewia* spp. are used for food, *Colophospermum mopane* provides habitat to the mopane worm (*Gonimbrasia belina*) which is used as relish and for monetary exchange [8], *Sclerocarya birrea* fruits are eaten and also used for production of beer to generate income and *Acacia* spp are mostly used for creating fences for livestock kraals [9]. Despite their importance, little is known about the composition, distribution and population structure of dryland woodland

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species in northern Botswana. This is despite the fact that these resources are threatened by over-exploitation from overgrazing and over-harvesting. Woodland resources are also threatened by climate change which is projected to result in low rainfall amount and increased temperatures in Botswana [10]. Already Botswana is experiencing high temperatures, unreliable and low rainfall amounts [11] which climate change will exacerbate. Drought conditions and low temperatures may upset the current ecological functioning of ecosystems in Botswana by excluding the intolerant species. This may reduce biodiversity [12], nutrient cycling [13] and primary production [14]. As a result the changes in primary production, nutrient cycling and biodiversity may affect the economic status of the human communities who depend on the woodland resources. In order to conserve these resources there is need to generate information on their species composition and population structure. This can help in designing management policies and conservation strategies which can promote their sustainable use. It can also help in designing long term monitoring program. The current study aims at classifying dryland woodland communities and establishing the population structure of the constituent species in north western Botswana.

II. MATERIALS AND METHODS

A. Study Area

This study was conducted in sites along transect from Sehitwa to Gudigwa. The study sites were around the villages of Ngarange, Samochema, Seronga, Gudigwa, Gumare and Sehitwa (Fig. 1). The livelihood of the people in this region is mainly cattle farming, crop production and tourism.

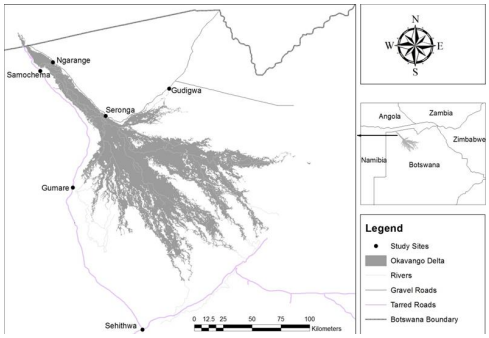

Fig. 1. Study sites in north western Botswana.

The climatic conditions in north western Botswana are semi-arid characterized by seasonal and variable rainfall. Rainfall occurs in one distinct season between November and March with a maximum of less than 400mm/yr. The daily temperatures range between a minimum of 22˚C and maximum of 34˚C [11]. The north western Botswana region is generally characterized by soils that are sandy, nutrient poor with low water holding capacity. Common woodland species in this region include *Terminalia sericea*, *Acacia erioloba*, *Acacia tortilis*, *Acacia hebeclada*, *Acacia tortilis*, *Combretum collinum* and *Acacia mellifera*.

B. Vegetation Sampling

Plant species were sampled from randomly selected 20 × 50m plots placed 200m away from the main road. The plots were located at 50km intervals (using the GPS) away from each other along the road. In each plot plant floristic composition analysis was carried out. Species were identified and assigned estimated cover values. Unknown species were collected for further identification in the Peter Smith University of Botswana (PSUB) herbarium at the Okavango Research Institute (ORI) in Maun. For population structure, in each plot circumference was measured using a measuring tape for individuals with circumference of >=15cm. In multi-stemmed plants, circumference was measured for each stem.

III. DATA ANALYSIS

A. Classification of Plant Communities

Plant communities were determined using Hierarchical cluster analysis (Flexible β linkage, β = -0.25, Sorensen distance, data relativized by maximum) and indicator species analysis in PC-ORD [15]. Indicator species was used to determine the characteristic species of each plant community [16]. Monte Carlo test was performed to test for significance of the indicator value for each species. The analysis started with determining the ideal number of classes. This was determined where mean *p* is minimized and the number of ecologically significant species maximized [16]. The ideal number of woodland communities was found to be four clusters. Multi-Response Permutation Procedures (MRPP) was used for pair-wise comparisons of species composition between communities [16]. The test statistic T was calculated as: $T=(\delta_{observed}-\delta_{expected})/s.dev\delta_{expected}$) to determine the extent of separation between communities. More negative values indicate stronger separation while less negative values show weak separation. Within group homogeneity was calculated as: $A=1-(\delta_{observed}/\delta_{expected})$. $A_{maximum}$ =1 when all items are identical within a group (δ=0), A=0 when heterogeneity within groups equals expectation by chance, A<0 with more heterogeneity within groups than expected by chance. The Kruskal-Wallis test was used to test for the statistical significant difference in diversity, richness and density between different plant communities.

B. Linear Regression Analysis for Inferring Recruitment Status

Diameter at breast height (dbh) was calculated from circumference measurements as; Diameter (d) = Circumference (C)/π, where π = 3.14. Individuals of different plant species were grouped into 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70 and >70cm dbh size classes. Population structure of different tree species was assessed through linear regression analysis between ln (*Ni* + 1) and ln (mi) [17, 18], where *Ni* is the number of individuals in the *i*th size class, and

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mi is the mid-point of the size-class. The dbh class midpoint (mi) and the mean number of individuals (*Ni* + 1) in each class were used as independent and dependent variables respectively. Positive slopes of regression indicate no recruitment while negative ones show ongoing recruitment. The correlation coefficient r^2 shows the "goodness of fit" of the regression model, and thus gives some indication of the strength of the conclusion about recruitment status.

IV. RESULTS

The number of plant communities was determined to be four. Four communities that were identified in this study are; *Acacia erioloba-Grewia bicolor*, *Terminalia sericea-Burkea africana*, *Acacia mellifera-Boscia albitrunca* and *Combretum collinum-Baphia massaiensis*. Pairwise MRPP comparisons between vegetation communities showed that they were significantly (p<0.05) different from each other (Table I).

A. *Description of Plant Communities*

Acacia erioloba-Grewia bicolor plant community

This plant community was co-dominated by *Acacia erioloba* and *Grewia bicolor*. Other species found in the *Acacia erioloba-Grewia bicolor* plant community include *Acacia erubscens*, *Ziziphus mucronata*, *Searsia tenuinervis*, *Acacia nigrescens* and *Acacia tortilis* (Table II). The mean species diversity and richness in this community were 1.21 and 7.62 respectively. The evenness was 0.45 while dominance was 0.42 (Table III). This plant community is found in dry sandy soils.

Terminalia sericea-Burkea africana plant community

The co-dominant species in this plant community were *Terminalia sericea* and *Burkea africana*. This plant community was found in sandy soils and mostly comprises of deciduous plant species such as *Dichrostachys cinerea*, *Ximenia americana* and *Combretum engleri* (Table IV). The mean species diversity was 1.17 while richness was 7.70. The evenness and dominance indices were 0.48 and 0.44 respectively in this community (Table III).

Acacia mellifera-Boscia albitrunca plant community

This plant community was relatively characterized by few species that included *Acacia hebeclada* with an IV close to one of the dominant species (*B. albitrunca*) and *Peltophorum africanum* with a much lower IV. The dominant species in this community were *Acacia mellifera* and *Boscia albitrunca* (Table V). The species diversity and richness in this plant community were 0.87 and 4.56 respectively. Evenness and dominance were 0.59 and 0.55 respectively (Table III).

Combretum collinum-Baphia massaiensis plant community

The *Combretum collinum-Baphia massaiensis* plant community was found in deep sandy soils. Other species found in this community were *Grewia retinervis*, *Philenoptera nelsii*, *Colophospermum mopane*, *A. fleckii* and *Bauhinia petersiana* (Table VI). Mean species diversity and richness were 1.10 and 7.29 respectively; mean evenness and dominance were 0.45 and 0.46 respectively (Table III).

TABLE I. MULTI-RESPONSE PERMUTATION PROCEDURES PAIRWISE COMPARISONS OF VEGETATION CLUSTERS

Classes	T	A	*p*
AE-GB[1] vs AM-BA[2]	-11.46883586	0.09929001	0.00000001
AE-GB vs CC-BM[3]	-17.83214480	0.12307366	0.00000000
AE-GB vs TS-BA[4]	-29.38757454	0.23821170	0.00000000
AM-BA vs CC-BM	-12.24795536	0.21384820	0.00000018
AM-BM vs TS-BA	-19.17013207	0.33718632	0.00000000
CC-BM vs TS-BA	-20.06260176	0.23461113	0.00000000

[1]AE-GB (*Acacia erioloba-Grewia bicolor*), [2]AM-BA (*Acacia mellifera-Boscia albitrunca*), [3]CC-BM (*Combretum collinum-Baphia massaiensis*), and [4]TS-BA (*Terminalia sericea-Burkea africana*).

B. *Population Structure of Different Plant Species*

Analysis of population structure yielded three diameter size classes patterns. *Acacia erioloba*, *Philenoptera nelsii* and *Acacia nigrescens* had bell-shaped structure with more individuals at 10-20cm size class (Fig. 2). *Burkea africana*, *Combretum collinum* and *Boscia albitrunca* were characterized by a reverse J-shaped population structure. For *B. africana*, there were missing individuals in 30-40cm, 50-60cm, 60-70cm and >70cm size classes while *Combretum collinum* was characterized by missing individuals at 50-60cm, 60-70cm and >70cm. There were also missing individuals at 30-40cm, 40-50cm, 50-60cm, 60-70cm and >70cm size classes in *Boscia albitrunca* (Fig. 3). *Terminalia sericea*, *Ziziphus mucronata* and *Colophospermum mopane* were characterized by small size classes of 0-10cm and 10-20cm (Fig. 4). All the species had negative regression size class distribution indicating on-going recruitment (Table VII).

TABLE VII. REGRESSION ANALYSIS SLOPE COEFFICIENTS FOR DIFFERENT WOODLAND SPECIES IN THE COMMUNAL AREAS OF NORTHERN BOTSWANA.

Woodland species	Slope coefficient	R^2
Combretum collinum	-2.67	0.81
Acacia erioloba	-1.60	0.47
Terminalia sericea	-2.25	0.81
Burkea africana	-1.99	0.74
Philenoptera nelsii	-1.97	0.69
Acacia nigrescens	-1.54	0.58
Ziziphus mucronata	-1.87	0.78
Boscia albitrunca	-2.32	0.88
Colophospermum mopane	-2.56	0.76

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TABLE II. SPECIES COMPOSITION IN *ACACIA ERIOLOBA-GREWIA BICOLOR* COMMUNITY

Species	IV	*p*-Value	Growth form	Family
Acacia erioloba	56.6	0.0002	Tree/Shrub	Fabaceae
Grewia bicolor	32.5	0.0388	Shrub	Tiliaceae
Acacia luederitzii	18.5	0.0236	Shrub	Fabaceae
Acacia nigrescens	22.9	0.0412	Tree	Fabaceae
Combretum hereroense	19.6	0.0394	Shrub	Combretaceae
Terminalia prunioides	11.1	0.1130	Tree	Combretaceae
Combretum imberbe	18.0	0.0848	Tree	Combretaceae
Acacia erubescens	27.0	0.0354	Tree	Fabaceae
Ziziphus mucronata	26.2	0.0238	Tree	Rhamnaceae
Searsia tenuinervis	24.0	0.1104	Shrub	Anacardiaceae
Gymnosporia senegalensis	10.9	0.2226	Shrub	Ebenaceae
Diospyros lycioides	9.4	0.2432	Shrub	Ebenaceae
Acacia tortilis	21.8	0.0994	Shrub	Fabaceae
Acacia ataxacantha	3.7	1.0000	Shrub	Fabaceae

TABLE III. SPECIES DIVERSITY (±SD), RICHNESS (±SD), EVENNESS (±SD) AND DOMINANCE (±SD) IN DIFFERENT PLANT COMMUNITIES.

Vegetation community	Shannon diversity index	Mean species richness	Evenness	Dominance
Acacia erioloba-Grewia bicolor	1.21±0.08	7.62±0.54	0.45±0.03	0.42±0.04
Terminalia sericea-Burkea africana	1.16±0.10	7.70±0.77	0.48±0.03	0.44±0.04
Acacia mellifera-Boscia albitrunca	0.87±0.16	4.56±0.69	0.59±0.03	0.55±0.08
Combretum collinum-Baphia massaiensis	1.10±0.09	7.29±0.61	0.45±0.02	0.46±0.04

TABLE IV. SPECIES COMPOSITION IN *TERMINALIA SERICEA-BURKEA AFRICANA* PLANT COMMUNITY

Species	IV	*p*-Value	Growth form	Family
Terminalia sericea	91.6	0.0002	Shrub/Tree	Combretaceae
Commiphora africana	6.8	0.6457	Shrub	Burseraceae
Dichrostachys cinerea	25.3	0.2432	Shrub	Fabaceae
Euclea divinorum	3.9	0.7856	Shrub	Ebenaceae
Ximenia americana	14.0	0.3079	Shrub	Olacaceae
Burkea africana	26.8	0.0118	Tree	Fabaceae
Pterocarpus angolensis	4.3	0.6459	Tree	Fabaceae
Combretum engleri	12.7	0.1670	Shrub	Combretaceae
Combretum mossambicense	3.1	0.8906	Shrub	Combretaceae
Ximenia caffra	4.3	0.6431	Shrub	Olacaceae

TABLE V. SPECIES COMPOSITION IN *ACACIA MELLIFERA-BOSCIA ALBITRUNCA* PLANT COMMUNITY

Species	IV	*p*-value	Growth form	Family
Acacia mellifera	61.6	0.0002	Shrub	Fabaceae
Boscia albitrunca	56.0	0.0004	Tree	Capparaceae
Acacia hebeclada	53.1	0.0002	Shrub	Fabaceae

TABLE VI. SPECIES COMPOSITION IN *COMBRETUM COLLINUM-BAPHIA MASSAIENSIS* PLANT COMMUNITY

Species	IV	*p*-Value	Growth form	Family
Combretum collinum	56.0	0.0002	Tree	Combretaceae
Grewia retinervis	44.3	0.0084	Shrub	Tiliaceae
Acacia fleckii	16.6	0.1128	Shrub	Fabaceae
Philenoptera nelsii	25.3	0.1134	Tree	Fabaceae
Bauhinia petersiana	13.8	0.6109	Shrub	Fabaceae
Baphia massaiensis	55.1	0.0004	Shrub	Fabaceae
Colophospermum mopane	27.5	0.0128	Tree	Fabaceae
Albizia versicolor	4.6	0.7514	Tree	Fabaceae

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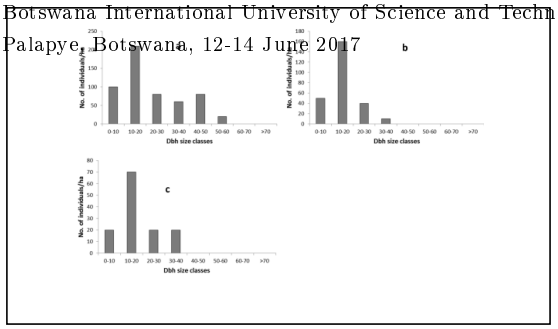

Fig. 2. The population structure of *Acacia erioloba* (a), *Philenoptera nelsii* (b) and *Acacia nigrescens* (c).

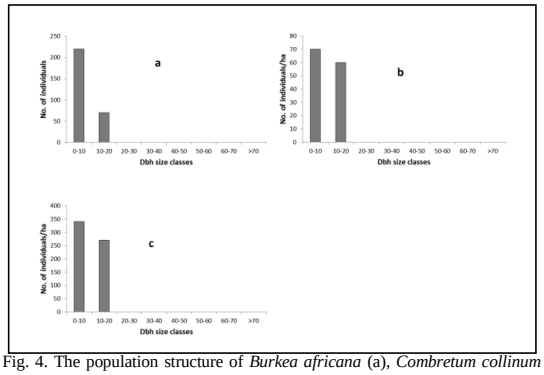

Fig. 4. The population structure of *Burkea africana* (a), *Combretum collinum* (b) and *Boscia albitrunca* (c).

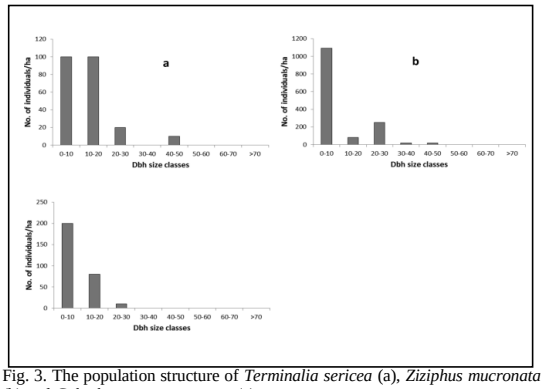

Fig. 3. The population structure of *Terminalia sericea* (a), *Ziziphus mucronata* (b) and *Colophospermum mopane* (c).

V. DISCUSSION

A. Plant Communities

This study revealed that there were four major plant communities in north western Botswana being; *Acacia erioloba-Grewia bicolor, Terminalia sericea-Burkea africana, Acacia mellifera-Boscia albitrunca* and *Combretum collinum-Baphia massaiensis*. The species composition and distribution of these plant communities may be influenced by climatic stress, availability of nutrients and water, grazing, browsing, seed dispersal and cutting of wood for subsistence use [3]. Grazing opens up new spaces for colonization by woody species [3] by removing the grass layer and reducing the competition for water [19]. Grazing may also affect the composition and distribution of plant species in dry land plant communities through selection by herbivores for or against a given species, trampling on vegetation which damages seedlings [5].

In north western Botswana, livestock farming is based on communal grazing where stocking rate is not controlled and consequently rangelands are prone to overgrazing. The influence of grazing on plant community composition and distribution can be inferred from the dominance of *A. mellifera*. This species is mostly associated with overgrazed habitats and has an invasive behavior [20]. The encroachment of *A. mellifera* in overgrazed areas was also found in the Kwazulu Natal region in South Africa [21] and Kalahari area, northern Botswana [19]. *Acacia mellifera* is able to succeed in colonizing overgrazed areas because of its shallow lateral root system [20] which enables it to use water from the surface of the soil [19]. This means that it stands a better advantage of surviving from little rain water as compared to other woodland species with deep root systems [19]. In Botswana rainfall is generally a limiting factor for plant growth [22] due to its low levels and unpredictability [23]. With the seasonal rains in northern Botswana being generally low (ca. 400mm) and the area being semi-arid [11] *A. mellifera* may have a competitive advantage over other species to use the little rainwater and be dominant in the grazed areas because of its shallow roots. Its roots extend to about 8cm-15cm from the stem, running parallel to the surface and can reach a maximum depth of 25cm [24]. In this study its invasive behavior was evident in that its community was the most species poor. This implies that other species were unable to compete with it the little water that is available. *Boscia albitrunca* which is the co-dominant species in *Acacia mellifera-Boscia albitrunca* plant community is a long drought tolerant species [25]. This suggests that it is an indicator of prevailing dry conditions in north western Botswana. In this case, dry conditions eliminate the grass layer and reduce its competition for water, nutrients and sunlight. As a result the seedlings of species such as *A. mellifera* which have shallow roots establish [19]. If this occurs in a sequence of years, it may result in the encroachment of woodland species. Fire may also play a crucial role in promoting bush encroachment of species such as *A. mellifera* through its role in removing the grass layer [26]. In our study evidence of the occurrence of fire was observed. However, this was not

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quantified in terms of frequency, spatial extent and the last time it occurred as it was not within the scope of our study.

Another plant community identified in north western Botswana was *Terminalia sericea-Burkea africana*. The co-occurrence of *Terminalia sericea* and *Burkea africana* has also been reported in Savanna ecosystems such as Nylsvley Provincial Nature Reserve, northern Transvaal, South Africa [27], Miombo forest in Lupa forest reserve in Tanzania [28] and Hwange National park in Zimbabwe [29]. Both *Terminalia sericea* and *Burkea africana* have shallow root systems which enable them to recover water from little rains that prevail in north western Botswana [30]. The shallow rooting system in *T. sericea* and *Burkea africana* enables them to successfully compete with grasses for available water and nutrients with grass species which are also shallow rooted [31]. These species are also fast growers which enables them to out-compete other species that such as *Baikiaea plurijuga* that are slow growers [27]. This also implies that their fast growth allows them to escape the dry season. Once the dry season sets in they will be at a stage where they can tolerate it following the development of tap roots for accessing deep groundwater sources. *Burkea africana* and *T. sericea* are also able to photosynthesize at lower soil moisture content [30] which again explains their dominance in the dry region of north western Botswana. *Terminalia sericea* could also be an indicator of disturbance and it is one of the early colonizers of a disturbed site [28]. In our case this could be an indication that the communal areas are disturbed by grazing which seems to be the main source of disturbance.

The other two plant communities identified in this study were *Acacia erioloba-Grewia bicolor* and *Combretum collinum-Baphia massaiensis*. The distribution of these communities is also linked to the availability of water. They are found in sandy soils with low water holding capacity. In order to survive this, they should be adapted to dry conditions. *Baphia massaiensis* is able to tolerate short periods of drought and flowers from October to March, with leaves growing mainly from October to June [32]. This life cycle suits the semi-arid conditions of Botswana which are generally characterized by rains from October to March, and dry conditions during the winter season from around May to August. The shedding of leaves after June is a response to dry conditions and it is meant to reduce the loss of water through evaporation. *Baphia massaiensis* is also important for providing forage for livestock and game [32]. Therefore, browsing from game and livestock may influence its performance and growth. Its abundance could suggest that it is not heavily relied on for browsing in northern Botswana. This implies that the grass is the main source of forage for the livestock in this area hence the dominance of *A. mellifera* which suggests grass over-grazing. *Acacia erioloba*, *Grewia bicolor* and *Combretum collinum* were also found in sandy soils. These species are also adapted to growing in semi-arid conditions prevailing in north western Botswana. As previously stated, annual rainfall in north western Botswana is low. As a result plant species that establish in this region should be adapted to low water availability and seasonal rainfall. These species are adapted to low water content through development of tap roots and shedding of leaves during the winter season when it is dry.

In addition to grazing and climatic conditions, plant community composition in north western Botswana may also be influenced by human use. Human use of woodland species include gathering of firewood, cutting poles for fencing homes, fields and kraals, felling for road making and human settlement [33]. Historically, acacia species in Tsao, Nokaneng, Gumare and Sepopa were cut to prevent the spread of tsetsefly [33]. Furthermore, human communities in north western Botswana harvest woody species for fire wood [34]. In addition to this our field observations showed that woodland species are also used for building of traditional huts, fencing kraals and homesteads. Woodland plants may also be affected by land clearing for cultivation [35]. These uses may also have an impact on the abundance and distribution of the preferred species. Human induced fire could be one of the factors that influence species composition and distribution of woodland plants in northern Botswana [35]. During our study we observed scars of fire. Fire may exclude intolerant species and promote the establishment of tolerant ones. Its influence may be a function of season, frequency, areal extent and height. For instance in northern Botswana high fire frequency reduced tree densities of *Baikiaea plurijunga*, but increased densities of shrubs and seedlings [36].

B. Population Structure of Different Plant Species

The population structure of tree species in north western Botswana can be grouped into three categories of bell, reverse J shaped and two class pattern dominated by more individuals in the 0-10cm and 10-20cm size classes. In the bell-shaped pattern, the species were characterized by more individuals skewed towards the 10-20cm size class. Tree species with the bell-shaped population structure were *Acacia erioloba*, *Philenoptera nelsii* and *Acacia nigrescens*. The bell-shaped population structure could indicate that there was a massive recruitment of individuals in the middle size classes when the conditions were favourable [37, 38]. In our case, this massive recruitment may have taken place recently as all the species with the bell-shaped structure had more individuals in the relatively young size class of 10-20cm suggesting that over the years there was suppression of growth of individuals from the smaller size classes into the larger ones.

The environmental bottlenecks which may suppress rejuvenation of tree species include fire, logging and grazing [39, 37]. Fire may suppress recruitment of individuals by killing them before they grow into the next size class [39]. In terms of logging, our results suggest that the individuals were cut for poles used for construction of human settlement in our study area. Big individuals in the larger size classes such as 40-50cm, 50-60cm and 60-70cm are likely to be preferred since they are strong and durable which is suitable for the construction of a strong structure. Other studies have also showed that logging of woodland species resulted in bell-

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shaped population structure. This was found in *Prosopis africana* in Burkina Faso [40] and Senegal [39]. Logging also had negative impact on the population structures of woodland species with species such as *Cordyla pinnata*, *Pterocarpus erinaceus* and *Terminalia macroptera* affected in Fathala Forest in Senegal [39]. The impact of this is exacerbated by increasing human population in the area which results in increased demand of the building materials [40]. Less grazing may result in more grass cover which competes with the seedlings for sunlight, water and nutrients resulting in suppression of their recruitment [39]. Conversely, grazing of the seedlings may also inhibit their recruitment into the next growth stage [38]. This suggests that there could be interplay between fire, logging and grazing influencing recruitment of tree species in north western Botswana. However, until further research is conducted on the environmental factors that drive the population structure dynamics in northern Botswana it will difficult to know their role in recruitment of tree species.

Combretum collinum, *Burkea africana* and *Boscia albitrunca* had a reverse J-shaped population with more individuals in the smaller size classes than in the larger ones. All these species did not have any individuals in the larger size classes. *Burkea africana* and *C. collinum* only had individuals up to the 40-50cm size class while *Boscia albitrunca* had individuals up to 20-30cm size class. Generally, the reverse J-shaped population structure is regarded as being healthy as the individuals in the lower size classes are recruited to replace the aging and dying older ones [39, 41, 37, 38]. The strong negative regression slopes in these species seemed to prove this correct. However, as can be expected some of the individuals die before maturity hence a decline in their number in the larger size classes. The death of the individuals between the different growth stages could be attributed to the factors such as fire, herbivory and logging already discussed for the bell-shaped pattern in the previous section.

The last group of species was those that had only two size classes of 0-10m and 10-20m which were *Terminalia sericea*, *Ziziphus mucronata* and *Colophospermum mopane*. While this is a once off study seeking to understand population structure patterns which may be a product of environmental controls, the result here suggest that the individuals of these species could be unable to be recruited beyond the 10-20cm size class. This could result from unfavorable growth conditions, poor dispersal mechanisms and slow growth [39]. It may also imply that individuals of these species are selectively removed before reaching the other growth stages [38]. In the communal setting like our study area the removal of individuals of these species could mainly be a product of human logging for construction materials [40]. However, these results should be interpreted with caution as there could be some individuals missed during our sampling campaign. This could especially be more applicable to *C. mopane* in which we missed some of its patches which fell outside our selected sampling plots.

C. Implications for Management

The results of this study point to the conservation need of *Colophospermum mopane*, *Terminalia sericea* and *Ziziphus mucronata* to facilitate the recruitment of their individuals beyond the 10-20cm size class. This could be achieved through enclosures to exclude the impact of both humans and their livestock. The enclosures have been successful in rehabilitation of tree species in woodland habitats in Ethiopia [42, 43]. Species with the bell shaped recruitment pattern should also be considered for protection especially that the recruitment of their individuals appears to stall at the 10-20cm size class. There should also be efforts towards raising education awareness for the sustainable use of the woodland resources in the human communities in northern Botswana. However, this should be preceded by studies on the extent to which the communities rely on the woodland species. There is also need to determine the correct livestock stocking capacity in the area so the farmers can be advised on the correct number of cattle to keep.

VI. CONCLUSION

Four plant communities of *Acacia erioloba-Grewia bicolor*, *Terminalia sericea-Burkea africana*, *Acacia mellifera-Boscia albitrunca* and *Combretum collinum-Baphia massaiensis* occur in north western Botswana. Species composition in these communities may be a product of a suite of environmental factors including fire, rainfall and grazing. The presence of *A. mellifera* could be an indication of an overgrazed rangeland in northern Botswana which may imply overstocking in the area. Tree species in north western Botswana had different patterns of population structure which could be a result of human use and livestock grazing/browsing. *Acacia erioloba*, *Philenoptera nelsii* and *A. nigrescens* showed bell-shaped structure while *Burkea africana*, *Boscia albitrunca* and *Combretum collinum* had reverse J-shaped pattern. *Terminalia sericea*, *Ziziphus mucronata*, and *Colophospermum mopane* had only 2 or 3 classes skewed towards juveniles.

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VIII. REFERENCES

[1] M. B. Coughenour, and E. E. James, "Landscape and climatic control of woody vegetation in a dry tropical ecosystem: Turkana District, Kenya," J. Biogeogr. Vol. 20 (4), pp. 383-398, July 1993.

[2] C. J. Yates, D. A. Norton, and R. J. Hobbs, R. J, "Grazing effects on plant cover, soil and microclimate in fragmented woodlands in south-western Australia: implications for restoration," Austral Ecol. Vol. 25, pp.36-47, February 2000.

[3] J. R. Brown, and S. Archer, "Woody plant invasion of grasslands: establishment of honey mesquite (*Prosopis glandulosa* var. *glandulosa*) on sites differing in herbaceous biomass and grazing history," Oecologia, Vol. 80, pp. 19-26, 1989.

[4] R. C. Szaro, R. C, "Riparian forest and scrubland community types of Arizona and New Mexico," Desert Plants, Vol. 9, pp. 1- 138, 1989.

[5] T. L. Fleischner, "Ecological costs of livestock grazing in western North America," Conserv. Biol, Vol. 8 pp. 629-644, September 1994.

[6] V. Carter, "Wetland hydrology, water quality, and associated functions," in National Water Summary on Wetland Resources, J. D. Fretwell, Fretwell, J.S. Williams, and P. J. Redman, Eds. U.S Geological Survey, 1996, pp.35-48.

[7] H. Brix, and H. H. Schierup, "The use of aquatic macrophytes in water-pollution control," Ambio, Vol. 18, pp. 100-107, 1989.

[8] A. Heath, A, R. Heath, R, Field guide to the plants of Northern Botswana including the Okavango Delta, United Kingdom, Royal Botanical Gardens, 2009, pp. 1-593.

[9] K. Ellery, and W. N. Ellery, Plants of the Okavango Delta: A field guide, Durban, Tsaro Publishers, 1997, pp. 1-39.

[10] P. K. Kenabatho, B. P. Parida, and D.B. Moalafhi, "The value of large-scale climate variables in climate change assessment: The case of Botswana's rainfall," Phys. Chem. Earth, Parts A/B/C, Vol. 50, pp. 64-71, August, 2012.

[11] T. Scudder, R. E. Manley, R. W. Coley, R. K. Davis, J. Green, G. W. Howard, S. W. Lawry, D. Martz, P. P. Rogers, A. R. D. Taylor, S. D. Turner, G. F. White, and E. P. Wright, The IUCN review of the southern Okavango integrated water development project, Gland, IUCN, 1993, pp. 1-544.

[12] C. D. Thomas, A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, and L. Hughes, "Extinction risk from climate change," Nature, Vol. 427, pp. 145-148, January 2004.

[13] D. Wang, S. A. Heckathorn, K. Mainali, and E. W. Hamilton, "Effects of N on Plant Response to Heat-wave: A Field Study with Prairie Vegetation," J. Integrative Plant Biol, Vol. 50, pp. 1416-1425, October 2008.

[14] P. Ciais, M. Reichstein, N. Viovy, A. Granier, J. Ogée, V. Allard, and F. Chevallier, "Europe-wide reduction in primary productivity caused by the heat and drought in 2003," Nature, Vol. 437, pp. 529-533, September 2005.

[15] M. Dufrêne, and P. Legendre, "Species assemblages and indicator species: the need for a flexible asymmetrical approach," Ecol. Monogr, Vol. 67, pp. 53–73, August 1997.

[16] B. McCune, J. B. Grace, Analysis of ecological communities, 2nd ed., Gleneden Beach, Oregon, U.S.A, MjM software, 2000, pp. 1-307.

[17] C. M. Shackleton, "Demography and dynamics of the dominant woody species in a communal and protected area of the eastern Transvaal Lowveld," S. Afr. J. Bot, Vol. 59, pp. 569-574, December 1993.

[18] R. Condit, R. Sukumar, S.P. Hubbell, and R. B. Foster, "Predicting population trends from size distributions: a direct test in a tropical tree community," The Amer. Natur, Vol. 152, pp. 495-509, October, 1998.

[19] C. Skarpe, "Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana," J. App. Ecol, Vol. 27, pp. 873-885, December 1990.

[20] D. J. Tolsma, W. H. O. Ernst, and R. A. Verwey, "Nutrients in soil and vegetation around two artificial water points in eastern Botswana," J. App. Ecol, Vol. 24, pp. 991-1000, December 1987.

[21] M. T. Hottman, and T. G. O'Connor, "Vegetation change over 40 years in the Weenen/Muden area, KwaZulu-Natal: evidence from photo-panoramas," Afr. J. Range For. Sci, Vol. 16, pp. 71-88, November 1999.

[22] G. K. Ramothwa, "A review of agro-meteorological activities in Botswana," Meteorological Services, Gaborone, Botswana, 1986

[23] A. C. Chipanshi, and S. Ringrose, "Reflections on the 1997/98 El Niño phenomenon in Botswana," Weather, Vol. 56, pp. 11-24, January 2001.

[24] M. E. Adams, "A study of the ecology of *Acacia mellifera*, *A. seyal* and *Balanites aegyptiaca* in relation to land-clearing," J.Appl. Ecol, Vol. 4, pp. 221-237, May 1967.

[25] A. Burke, "Savanna trees in Namibia—Factors controlling their distribution at the arid end of the spectrum," Flora, Vol. 201, pp. 189-201, January 2006.

[26] G. Oba, E. Post, P. O. Syvertsen, and N. C. Stenseth, "Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia," Landscape Ecol, Vol. 15 , pp. 535-546, August 2000.

[27] T. M. Smith, and K. Grant, "The role of competition in the spacing of trees in a *Burkea africana-Terminalia sericea* savanna," Biotropica, Vol. 18, pp. 219-223, September 1986.

[28] S. B. Boaler, and K. C. Sciwale, "Ecology of a Miombo site, Lupa North Forest Reserve, Tanzania: III. Effects on the vegetation of local cultivation practices," J. Ecol, Vol. 54, pp. 577-587, November 1966.

[29] S. L. Childes, and B. H. Walker, "Ecology and dynamics of the woody vegetation on the Kalahari sands in Hwange National Park, Zimbabwe," Plant Ecol, Vol. 72, pp. 111-128, October 1987.

[30] M. C. Rutherford, "Woody plant biomass distribution in Burkea africana savannas," in Ecology of tropical savannas. Ecological studies (analysis and synthesis), B. J. Huntley and B. H. Walker, eds. Springer, Berlin, Heidelberg.

[31] M. H. T. Hipondoka, and W. D. Versfeld, "Root system of *Terminalia sericea* shrubs across rainfall gradient in a semi-arid environment of Etosha National Park, Namibia," Ecol. Indic, Vol. 6, pp. 516-524, August 2006.

[32] http://treeatlas.biodiversity.org.na/viewspec.php?nr=75. Tree atlas of Namibia. Accessed: 4/24/2017.

[33] Snowy Mountains Engineering Corporation, "Ecological Zoning Okavango Delta," Ministry of Local Government and Lands, Gaborone, Botswana, 1989.

[34] G. Mmopelwa, J. N. Blignaut, and R. Hassan, "Direct use values of selected vegetation resources in the Okavango Delta Wetland," S. Afr. J. Econ. Manag. Sci, Vol. 12, pp. 242-255, June 2009.

[35] S. Ringrose, A. C. Chipanshi,W. Matheson,R. Chanda, L. Motoma,I. Magole, and A. Jellema, "Climate-and human-induced woody vegetation changes in Botswana and their implications for human adaptation," Environ. Manag, Vol. 30, pp. 98-109, July 2002.

[36] R. Ben-Shahar, "Changes in structure of savanna woodlands in northern Botswana following the impacts of elephants and fire," Plant Ecol, Vol. 136 (2), pp. 189-194, June 1998.

[37] C. V. Helm, and E. T. F. Witkowski, "Characterizing wide spatial variation in population size structure of a keystone savanna tree," For. Ecol. Manage, Vol. 263, pp. 175-188, January 2012.

[38] F. Gurmessa, T. Soromessa, and E. Kelbessa, "Structure and regeneration status of Komto Afromontane moist forest, East Wollega Zone, west Ethiopia," J. Forest. Resear, Vol. 23, pp. 205-216, June, 2012.

[39] A. M. Lykke, "Assessment of species composition change in savanna vegetation by means of woody plants' size class distributions and local information," Biodiver. Conserv, Vol. 7, pp. 1261-1275, October 1998.

[40] L. Traoré, T. K. Sop, S.D. Dayamba, S. Traoré,K. Hahn,A. Thiombiano, "Do protected areas really work to conserve species? A case study of three vulnerable woody species in the Sudanian zone of Burkina Faso," Environ. Dev. Sustain, Vol. 15, pp. 663-686, June 2013.

ISSN: 2521-229X
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[41] T. K. Sop, J. Oldeland, U. Schmiedel, I. Ouedraogo, A. Thiombiano, "Population structure of three woody species in four ethnic domains of the sub-sahel of Burkina Faso," Land Degrad. Dev, Vol. 22, pp. 519-529, July 2010.

[42] T. Mengistu, D. Teketay, H. Hulten, Y. Yemshaw, Y, "The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia," J. Arid Environ. Vol. 60, pp.259-281, January 2005.

[43] G. Mulugeta, "Vegetation Dynamics of Area Enclosure Practices: A Case of Gonder Zuria District, Amhara Region, Ethiopia," J. Nat. Sci. Res, Vol. 4, pp. 2224-3186, 2014.

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Company-Wide Data Integration Model for the Water Utility Sector

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***Abstract*— Data in the water utility sector are generated by different tools of different types in different formats and stored in different systems that run in different platforms and located in different places. This limits the value-adding potential of data thus posing a need for company-wide integrative approaches to data management. Though data warehousing proves to be the best solution in this regard, prior models reviewed in this paper offer limited integrative capabilities with focus on unique operational functions. Therefore, this paper advances a data integration model designed according to Kimball's Business Dimensional Lifecycle methodology and comprising of the processes of water abstraction, production, storage, distribution, consumption, and the revenue and cost functions as well. The paper aims at establishing the integration capabilities of data integration across the value chain with a specific application to Water Utilities Corporation Botswana (WUC).**

Keywords*— *Data Integration; Data Warehousing; Data Model; Data Mart; Dimensional Modeling; Schema Integration; Water Utility; Water Sector; Value Chain; Data Management

I. INTRODUCTION

Data in organizations are produced and used by all business and or operational functions, hence must be allowed to flow freely across the entire ecosystem [1]. Conversely, most organizations have vast amounts of data but find it difficult to access and use it as it is in diverse formats, reside in diverse files and database structures developed by different vendors, and run on diverse platforms [2]. Studies show that due to data disintegration, the water utility sector is limited in deriving optimal value from their data [3], [4], [5], [6]. Thus, this sector needs company-wide data management platforms capable of meeting information needs at all managerial levels and that can be achieved through data integration. Data integration pertains to the exchange of information between systems regardless of whether they are designed to work together and this involves the collection, processing, and clearing of data from different sources to generate a unified vision of those data [7]. Even though data warehousing proves to be the best solution to data disintegration, its adoption and use are limited across enterprises [8]. Above that, data warehousing solutions with focus on unique operational functions proves to be ineffective in resolving problems spread across the value chain. Therefore, this work is motivated by the current data integration needs, coupled with the minimal adoption and application of data warehousing and the minimal existence of formal researches on the application of data warehousing in the water utility sector. The objective of this paper is to explore the integration potentials that can be leveraged in a data warehouse that models water utility value chain with reference to WUC. The development of the model followed Kimball's Business Dimensional Lifecycle in which data marts were created first [9], modelled one at a time [10] and combined at the end to create a single repository [9]. We present model requirements in the form of value chain processes and corresponding data views. We then integrate the business processes and data views into a single repository model for company-wide data management, viewing and analysis. Finally, we discuss findings on the integration capabilities of the model. The rest of the paper is organized as follows: section II overviews data disintegration in the water utility sector from the global, continental (Africa), and country (Botswana) perspectives. Section III gives insights on the data integration platform advanced in this paper, data warehousing. Section IV discusses the proposed model in terms of methodology, conceptual designs and model evaluation. Section V presents discussions on findings. Finally, section VI draws conclusion on research findings.

II. DATA DISINTEGRATION IN THE WATER UTILITY SECTOR

Data disintegration is one of the major challenges facing Botswana, Africa and the global water utility sector. In the global water utility sector, data are generated and or stored in diverse operational systems spread across the value chain such as Hydraulic Modelling tools, Flow and Pressure meters, Geographical Information Systems (GIS) and Schematic tools, Acoustic sensors, Water Quality sensors, Pump Optimization tools, Data Loggers, Supervisory Control and Data Acquisition (SCADA) systems, Asset Management tools, Automatic Meter Reading (AMR) and Advanced Metering Infrastructure (AMI) tools, Leak Detection software, Alert Systems and Workforce tools [11]. The water utility sector also make use of support systems such as Human Resource Management systems, Finance Management systems, Accounting Packages and other back office applications that support daily operations [12]. These operational systems operate as silos, thus making it difficult to summarize activities across business processes [10]. For instance, the strategic approach to data management and modelling of raw surface water and drinking water systems differ significantly as they are considered distinct operational functions, thus making it difficult to integrate them for comprehensive watershed decisions [13]. Also, although water quantity and quality are inseparable, they are managed by different authorities, thus creating numerous obstacles between

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water users and managers [14]. In addition, this sector uses Enterprise Applications such as Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and Supply Chain Management (SCM) systems [15] that integrate an organization' business processes with those of its suppliers and customers [16]. Though Enterprise Applications achieve data integration, they are optimized for data input and transaction processing rather than for reporting and analytics [15], hence susceptible to the weaknesses of operational systems. Moreover, the level of disintegration increases as data grow 'old' and are archived for operational efficiency [17]. The global water utility sector has come to realize that data integration is crucial to its operations and sustenance and this has given birth to global initiatives such as the United Nations' Integrated Water Resources Management (IWRM) [18]. In its deliberation on the current state of affairs, IWRM initiative poses a need for processes' integration across the entire water utility value chain:

> The traditional fragmented approach is no longer viable and a more holistic approach to water management is essential. This is the rationale for the Integrated Water Resources Management (IWRM) approach that has now been accepted internationally as the way forward for efficient, equitable and sustainable development and management of the world's limited water resources … [4].

The continent of Africa is hard-hit by the global data disintegration crisis. For instance, the Southern African Development Committee (SADC) reports challenges such as incompatible water resources data and information systems, limited coverage and poor operation and maintenance of hydro-meteorological networks between riparian states. Also, sharing information and hydro-meteorological data between shared watercourse states is constrained by technological diversity among member states, diversity in terms of data and information systems, and inaccessibility of relevant data and information to stakeholders [6]. In particular, one of the main stakeholders in the provision of water services in Botswana (SADC member state), WUC, generates, stores and manages a wide diversity of data currently distributed across various manual and electronic systems, formats, platforms and physical places. It is running on SAP ERP system for most of its operational needs: Billing, Human Resource Management (HRM), Material Management, Plant Maintenance, Customer Relationship Management (CRM), Financial Management, and Sales and Distribution. Instrumentation data and data on water abstraction, production, storage and distribution is extracted from source systems (SCADA, in most cases) into spreadsheets for analysis and reporting. While data on production quantity is generated mostly by telemetry systems, production quality data is produced manually as a product of laboratory tests and stored in a repository different and separate from that which holds quantity data. Records of incidents such as pipe bursts are recorded in SAP ERP system but most of the service data are kept in paper forms. Water consumption data are collected on monthly basis, in most cases manually and in some few cases, electronically, through the use of Automatic Meter Reading tools. Consumption data are stored in the Meter Reading Management System, RouteMaster, which is built on Microsoft.Net technology and runs on the Microsoft SQL Server platform [19]. Routemaster is in turn interfaced with the Billing module which runs on the SAP platform. Some data such as hydro-meteorological, socio-economic, and demographic data are with external stakeholders and service providers, and in social media platforms such as Facebook. Moreover, WUC continuously archives 'old' data, meaning that most of its historical data remain inactive. With this diversity of disintegrated data, it becomes difficult to have a holistic view of value chain operations. It is also difficult to maximize value from the data asset. Therefore, a unifying approach is needed in this sector to efficiently manage, validate and present past and current data collected both internally and externally from various devices in useful formats. This would improve data access and usage and also optimize on the value-adding potentials of data in this sector.

III. WHY DATA WAREHOUSING?

Data warehousing offers tremendous data integration capabilities. This process involves data extraction from internal and external source systems that represent diverse data structures and technical platforms [20]. Thereafter, it undergoes transformations and then loaded into a single repository for ease of understanding, access, and use [2], [20]. Data warehousing separates Online Analytical Processing (OLAP) functions from Online Transactional Processing (OLTP) functions [17] for optimal operational and analytic performance. It also provides a platform for easy integration and maintenance of current and historical data [17]. Despite these potentials, previous reviewed models offer limited capabilities due to specific focus on unique operational functions. The Intelligent Asset Management system enables effective management of asset criticality, asset identification and hierarchy, cost assignment, general ledger reconciliation, and reliability engineering [21]. On the basis of consumption, revenue and cost data, the system built on a data warehouse by Valor Waters (VW) initially addressed financial issues of conservation, revenue risks and affordability. Valor Waters analytic capabilities have evolved with time to support new service offerings such as water cut off analyzer, handles water cut-offs for non-paying customers; water rate simulator, simulates water usage; hidden revenue locator, eliminates water meter discrepancies; water energy nexus calculator, calculates water energy usage, and hot water heater leak detector which detects water heater leaks [22]. Data warehousing has also been applied to help water utility organizations maintain their immense water infrastructure system by aiding in information analysis about water works systems and determining the best ways to maximize maintenance budget [23]. There is also an innovation where a data warehouse serves as the foundation for District Meter Area (DMA) flow meter data analysis system for detection of bursts at the DMA level and generation of automated alerts in response to abnormal flows [24]. To address the integration limitations of process-specific data models, this paper proposes data warehousing across the water utility value chain for company-wide integration platform.

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IV. THE PROPOSED DATA INTEGRATION MODEL

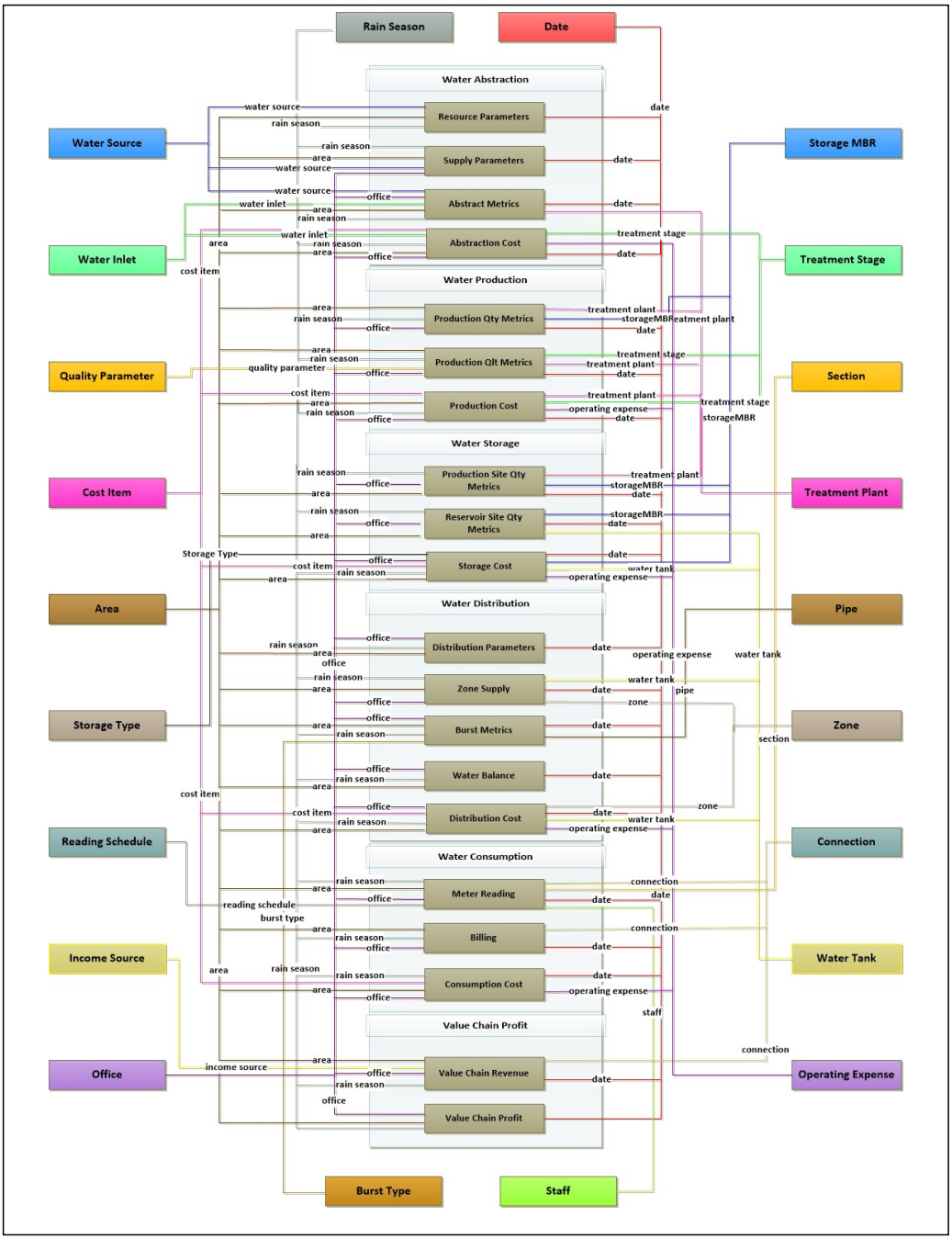

Figure 1: Proposed data warehouse model for WUC

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A. *Methodology*

The proposed data warehousing model was constructed on the basis of the water utility value chain processes of water abstraction, production, storage, distribution and consumption. Kimball's Business Dimensional Lifecycle methodology was adopted in the design of the model. The first activity in this approach is the identification of information requirements and associated business processes. The deliverable at the end of this activity is a document called Data Warehouse Bus Matrix (see figure 2), listing key business processes and some insights on how they are to be analyzed. Then data marts, data models representing individual operational functions, are built based on the matrix, one at a time and integrated with the addition of each data mart, with the last one completing the development of the data warehouse [9]. This approach uses dimensionality modelling; a logical design technique that maps aspects of business/operational processes [25] and presents data in a standard, intuitive form for high-performance access [9]. In this research, information requirements and associated business processes were identified through literature reviews, unstructured interviews and observations, and deducted for requirements specification, outlined in the data warehouse bus matrix in figure 2.

B. *Model Designs*

The first data mart, water abstraction integrates water abstraction quantity metrics with water resource parameter metrics (i.e. dam level), supply parameter metrics (contractual supply volumes) and water abstraction costs. The second data mart, water production integrates production quantity with quality and costs. The third data mart, water storage unifies production site metrics with distribution/reservoir site metrics and storage costs. The fourth data mart, water distribution combines distribution parameters with the different distribution functions (zone supply, pipe bursts, water balance), and distribution costs. The fifth data mart, consumption integrates meter reading metrics with billing and consumption costs while the sixth data mart, value chain profit integrates revenues and costs across the value chain. Finally, all data marts are integrated into a single repository illustrated in figure 1 which demonstrates logical relationships that spans through the entire value chain. Relationship links represent data marts' consolidation through shared dimensions and this involves defining a similar level of granularity for linking together schemas per data mart and the related measures and dimensions. Integrating abstraction metrics with production, storage, consumption, distribution and profitability metrics creates a single view of the value chain represented by the cube

Data Warehouse Bus Architecture

Water Utility Data Warehouse Value Chain Matrix

Value Chain Process	COMMON DIMENSIONS																						
	date	rain season	reading schedule	income source	area	zone	office	section	staff	operating expense	connection	water source	water inlet	water tank	burst type	pipe	treatment plant	treatment stage	storage MBR	storage type	quality parameter	cost item
water abstraction	x	x			x		x			x		x	x				x	x					x
water production	x	x			x		x			x							x	x	x		x	x
water storage	x	x			x		x			x				x			x		x	x			x
water distribution	x	x			x	x	x			x				x	x	x							x
water consumption	x	x	x		x		x	x	x	x	x												x
value chain profit	x	x		x	x		x				x												

Figure 2: Proposed Bus Matrix for WUC

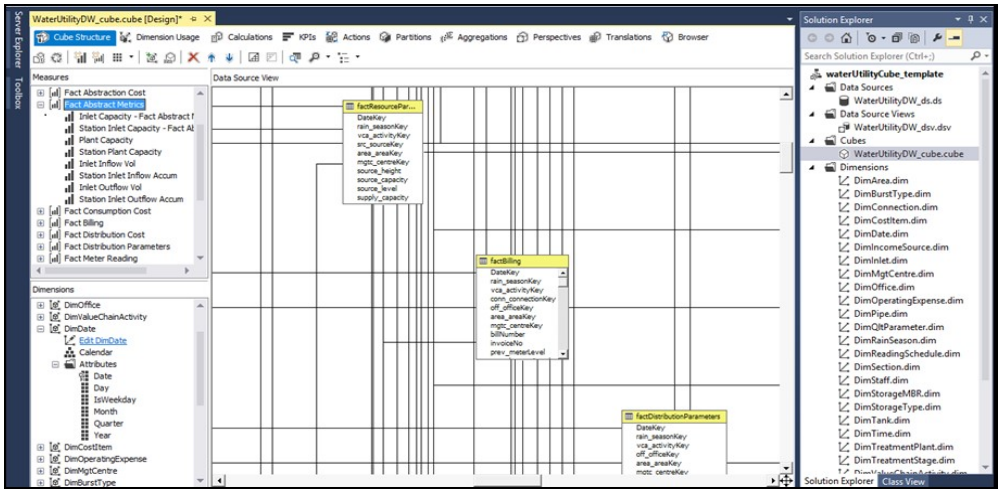

Figure 3: Proposed Integration Cube for WUC

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in figure 3 in which measures and dimensions across the value chain are contained in one cube. This data architecture enables water performance to be viewed holistically across the value chain.

C. *Model Evaluation*

The model was evaluated according to the software testing process encompassing process verification and validation. Verification determines that a system meets the specified requirements while validation evaluates that a system attains its intended use when placed in the intended environment [26]. In process verification, the logical designs were interpreted to WUC participants for evaluation of their correctness in representing water utility value chain and necessary adjustments were made. In process validation, a test case in the form of multidimensional query was developed and run on the integration cube in figure 3. This test case which represents monthly abstraction, production, storage, distribution and consumption costs in a given rain season, screened by cost item, operating expense, office (customer service center/water works station/reservoir site), area, and management center is illustrated in figure 4.

Filtering Dimensions	
RainSeason	All
MgtCentreByRegion	All
areaByCluster	All
OfficeByType	All

Row Dimensions	AbstractExpenseQty	AbstractExpenseAmnt	PdctnExpenseQty	PdctnExpenseAmnt	StorageExpenseQty	StorageExpenseAmnt	DistributnExpenseQty	DistributnExpenseAmnt	ConsumptnExpenseQty	ConsumptnExpenseAmnt
2015	52670545920	22690488320	1.03512E+11	38247907328	33579298816	21353484288	94128291840	34610921472	53310554112	22129786880
1	12856344576	6237569024	26103242752	10569842688	7872053248	4738588672	25144688640	9834938368	12662013952	5889212416
January	4222205952	2092843008	8395931648	3579658240	2741059584	2184323072	7564312576	3267133440	3803709440	1938669568
Treatment & Distribution	4222205952	2092843008	8395931648	3579658240	2741059584	2184323072	7564312576	3267133440	3803709440	1938669568
Electricity Use	4222107648	562888704	2098982912	894914560	685264896	546080768	1891078144	816783360	950927360	484667392
production	4222107648	562888704	2098982912	894914560	685264896	546080768	1891078144	816783360	950927360	484667392
Power	4222107648	562888704	2098982912	894914560	685264896	546080768	1891078144	816783360	950927360	484667392
Labor Use	98304	1529954304	6296948736	2684743680	2055794688	1638242304	5673234432	2450350080	2852782080	1454002176
staff	98304	1529954304	6296948736	2684743680	2055794688	1638242304	5673234432	2450350080	2852782080	1454002176
Salaries & Wages Ind.	81920	973291520	4197965824	1789829120	1370529792	1092161536	3782156288	1633566720	1901854720	969334784
Salaries & Wages P&P	16384	556662784	2098982912	894914560	685264896	546080768	1891078144	816783360	950927360	484667392
February	4572987392	2110816256	9153486848	3575300096	2553905152	1159405568	9033416704	3281616896	4511760384	2043117568
Treatment & Distribution	4572987392	2110816256	9153486848	3575300096	2553905152	1159405568	9033416704	3281616896	4511760384	2043117568
Electricity Use	4572889088	548831232	2288371712	893825024	638476288	289851392	2258354176	820404224	1127940096	510779392
production	4572889088	548831232	2288371712	893825024	638476288	289851392	2258354176	820404224	1127940096	510779392
Power	4572889088	548831232	2288371712	893825024	638476288	289851392	2258354176	820404224	1127940096	510779392
Labor Use	98304	1561985024	6865115136	2681475072	1915428864	869554176	6775062528	2461212672	3383820288	1532338176
staff	98304	1561985024	6865115136	2681475072	1915428864	869554176	6775062528	2461212672	3383820288	1532338176
Salaries & Wages Ind.	81920	1005322240	4576743424	1787650048	1276952576	579702784	4516708352	1640808448	2255880192	1021558784
Salaries & Wages P&P	16384	556662784	2288371712	893825024	638476288	289851392	2258354176	820404224	1127940096	510779392
March	4061151232	2033909760	8553824256	3414884352	2577088512	1394860032	8546959360	3286188032	4346544128	1907425280
Treatment & Distribution	4061151232	2033909760	8553824256	3414884352	2577088512	1394860032	8546959360	3286188032	4346544128	1907425280
Electricity Use	4061052928	571211776	2138456064	853721088	644272128	348715008	2136739840	821547008	1086636032	476856320
production	4061052928	571211776	2138456064	853721088	644272128	348715008	2136739840	821547008	1086636032	476856320
Power	4061052928	571211776	2138456064	853721088	644272128	348715008	2136739840	821547008	1086636032	476856320
Labor Use	98304	1462697984	6415368192	2561163264	1932816384	1046145024	6410219520	2464641024	3259908096	1430568960
staff	98304	1462697984	6415368192	2561163264	1932816384	1046145024	6410219520	2464641024	3259908096	1430568960
Salaries & Wages Ind.	81920	985993600	4276912128	1707442176	1288544256	697430016	4273479680	1643094016	2173272064	953712640
Salaries & Wages P&P	16384	473104384	2138456064	853721088	644272128	348715008	2136739840	821547008	1086636032	476856320

Figure 4: Integration Test Case Illustration

V. FINDINGS AND DISCUSSIONS

We found out that the proposed model provides a platform for maximal integration of data at individual operational functions (represented by data mart models) and at the corporate level (represented by the data warehouse model). Each data mart has one or more schemas (individual schemas represent integration of individual sub-functional operations within an operational function) connected through shared dimensions for holistic integration of operational processes modelled by the data mart. Water abstraction integration model enables tracking of relationships between water abstraction metrics, supply parameter metrics, water resource parameter metrics and resultant costs at a diversity of 10 analytic views. Water production integration model provides a platform for tracking and analyzing production quantity in relation to quality and costs at a dynamicity of 10 data views also. Water storage integration enables the flow of water to be tracked between the production site and distribution/reservoir site as well as the resulting costs at 10 multi-angle views. With water distribution integration, zone supply metrics may be viewed in relation to the set distribution parameters, pipe bursts and distribution costs metrics at a diversity of 11 analytic angles. Integrating the water consumption function enables meter reading, billing and resulting costs to be analyzed at a diversity of 10 analytic angles. Finally, the integration of value chain revenues and costs provides a platform for profitability analysis at 6 various angles. In overall, the data warehouse model represents a company-wide integration model with 22 dimensional views. For instance, figure 4 demonstrates costs across the value chain under a diversity of data views. Water quantity may also be traced from the beginning process of water abstraction to the end process of consumption, thus giving a complete picture of what happens to water as it traverses the network. Tracing water volumes from the beginning to the end of the value chain may aid in addressing the issue of water loss/non-revenue water. Water loss may be tracked along the value chain to identify processes with high or ow water losses in relation to diverse dimensional attributes. The differences in those losses may also be accounted for in terms of the dimensional variations represented by the model. Tracing water quantity flows along the value chain may also aid in computing the water balance statement to account for

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water usage given the system input volume at a given time and other dimensional variations. Moreover, this model enables water quality to be traced alongside water quantity from water inlet (pre-treatment stage) through the different water processing stages and distribution networks to identify specific places of high or low infection risks.

VI. CONCLUSION

The data warehouse that models the value chain has the capability to turn the water utility sector aspirations of water management efficiency from being an abstract concept to reality. This model provides a platform for optimal data integration at both the data mart and warehouse levels to create a single version of truth that spans the water utility value chain. This model enables data in social media platforms and that with external stakeholders and service providers to be combined with internal data in operational systems, archival storages and physical files, thus, ensuring that all data across the value chain remain active and contribute its value to the information needs of the organization. This process-based data model guarantees stability in dynamism as it is more adaptive to constant adjustments to information needs compared to a data warehouse model designed to address specific information needs at a specific time. The unstable information needs may then be plugged into the model which offers flexibility to easily adjust to the constantly changing information requirements without having to rebuild the data warehouse structure or with minor alterations to existing architecture. Therefore, the model provides a better foundation for company-wide implementations such as balanced score cards. However, for a complete view of water utility operational performance, waste water processes also need to be integrated into the model.

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REFERENCES

[1] H. Heyns, "Becoming an analytics-driven organisation to create value," Ernst & Young, United Kingdom, Technical document 2015.

[2] C. Ballard et al., "Data modeling techniques for data warehousing," IBM, California, Technical documentation 1998. [Online]. http://www.redbooks.ibm.com/redbooks/pdfs/sg242238.pdf

[3] J. S. Horsburgh, D. G. Tarboton, D. R. Maidment, and I Zaslavsky, "A relational model for environmental and water resources data," Water Resour. Res., vol. 44, no. W05406, pp. 1-12, May 2008.

[4] United Nations. (2014, November) Integrated water resource management. [Online]. http://www.un.org/waterforlifedecade/iwrm.shtml

[5] Accenture Consulting, "Unlocking the value of analytics: accenture's digitally enabled grid program," Accenture Consulting, Technical document 2013. [Online]. https://www.accenture.com/us-en/insight-digitally-enabled-grid-unlocking-value-analytics.aspx

[6] SADC, "sadc regional water strategy," SADC, Gaborone, Strategy document 2006.

[7] A. H. Mousa, N. Shiratuddin, and M. S. A. Bakar, "Generic framework for better choosing between data integration types (GFCBDIT) during build business intelligence applications," International Journal of Digital Content Technology and its Applications(JDCTA), vol. 8, no. 5, pp. 27-35, October 2014.

[8] J. McKendrick. (2011, September) A new dimension to data warehousing: 2011 ioug data warehousing survey. [Online]. http://www.dbta.com/research

[9] T. M. Connoly and C. E. Begg, "Business intelligence," in Database systems: a practical approach to design, implementation, and management, 5th ed. London, England: Pearson Education, 2010, ch. 32-35, pp. 1145-1229.

[10] M. V. Mannino, Data warehouse technology and management, 2nd ed. New York, America: McGraw-Hill, 2004.

[11] S. Callahan and J. M. Miller, "Data integration solutions for effective utility management: progression towards smart city implementation," in One Water Technical Conference. & Expo, Ohio WEA-AWWA, 2014.

[12] P. Ponniah, Data warehousing fundamentals: a comprehensive guide for IT professionals. New York: John Wiley & Sons, Inc, 2001.

[13] S. C. Karcher, J. M. VanBriesen, C. T. Nietch, and M. T. Heberling, "Assessing the challenges associated with developing an integrated modeling approach for predicting and managing water quality and quantity from the watershed through the drinking water treatment system," EPA, Cincinnati, Technical document 2012.

[14] T. Dai and J. Labadie, "River basin network model for integrated water quantity/quality management," Journal of Water Resources Planning and Management, vol. 127, no. 5, pp. 295-305, October 2001.

[15] R. Sherman, "Don't stop at how, learn why," DM Review, p. 26, June 2008.

[16] J. L. Whitten, L. D. Bentley, and K. C. Dittman, "Enterprise applications," in Systems analysis and design methods. New York: McGraw-Hill, 2004, pp. 32-35.

[17] J. M. A. Navamani, A. Kannammal, and P. R. J. Thangaiah, "Building multi-dimensional cube to analyze public examination results: a business intelligence approach," Applied Mechanics and Materials, vol. 622, no. 11, pp. 11-22, August 2014.

[18] Department of Water Affairs- Ministry of Minerals, Energy & Water Resources, "Botswana integrated water resources management & water efficiency plan," Botswana Government, Gaborone, Strategy document 2013.

[19] Consolidated African Technologies, "rma.net - meter management simplified," Consolidated African Technologies, Randburg, Technical document 2016. [Online]. http://www.cats.co.za/resources/RMA.Net%20Brochure.pdf

[20] H. J. Wixom and B. H. Watson, "The current state of business intelligence," IT Systems Perspectives, pp. 96-99, September 2007.

[21] R. V. Buskirk, "Performance management best practises: data management practises for intelligent asset management in a public water utility," September 2011. [Online]. http://www.we-inc.com

[22] Valor Water. (2016) Valor Water website. [Online]. http://www.valorwater.com

[23] Informatica. (2016) Informatica website. [Online]. http://www.informatica.com/us/customers/thames-water-utilities-ltd.aspx

[24] S. R. Mounce and J. B. Boxall, "Implementation of an on-line artificial intelligence district meter area flow meter data analysis system for abnormality detection: a case study," 2010.

[25] IBM Corporation. IBM Knowledge Centre. [Online]. http://pic.dhe.ibm.com/infocenter/dataarch/v9r1/index.jsp?topic=%2Fcom.ibm.datatools.dimensional.ui.doc%2Ftopics%2Fc_dm_design_cycle_1_idbusprocreqs.html

[26] Pan, J. (1999) Carnegie Mellon University. [Online]. https://users.ece.cmu.edu/~koopman/des_s99/sw_testing/

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Enhancement of the Pyrolysis Process Using Ultrasound

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***Abstract*— It has been estimated that Botswana has more than 200 billion tons of coal locked up in its underground reserves. The logistics for export purposes simply do not exist to get these vast resources to the markets. There has been huge efforts prove feasibility of develop plans to establish these logistics but to date there is still nothing forthcoming. On the other end of the spectrum there has been interest to develop and commercialize processes in which coal is converted into valuable products (e.g. via coal pyrolysis) which either have local markets or for which the export logistics already exist (or can easily be created).**

Sonochemistry can be utilized to enhance the coal pyrolysis process. In sonochemistry, ultrasound waves are applied to a liquid or liquid mixture to such an intensity that cavitation takes place. Cavity formation and collapse cause extreme local temperatures (>5000K) and pressures (>100bar) at extreme heating and cooling rates (109K/s). The hot spot theory is widely used to describe this phenomenon. Since chemical kinetics are directly influenced by pressure, temperature and heating/cooling rates, it follows that sonochemistry can be used enhance chemical processes and this has been shown to be true in many other industries (especially the medical industry). It is therefore reasonable to expect increased oil production yields and rates during the pyrolysis of coal as well and this would result in a better return on investment (ROI) for projects.

This project, which is still in its incipient stage, aims to determine the sonochemical parameters which will be conducive to the pyrolysis of coal. The kinetics of sonochemical pyrolysis reactions have been studied and these sonochemical principles have been used to establish a framework in which the project objectives can be met. These objectives include the formulation of a mathematical model for sonochemical pyrolysis, the design and construction of sonochemical pilot reactor and the subsequent testing and analysis using the pilot facility.

The experimental work will entail attachment of an ultrasonic transducer to a small desktop adiabatic batch reactor (able to contain 1000ml of raw material). The pressure and temperature of this reactor will be set to predetermined values before the experiment starts. The changes in pressure and temperature will be measured accurately and recorded together with product yields for various ultrasonic frequencies and intensities. Gas and vapour products will be sampled during the experiment and analysed while the liquid and solid products will be analysed after completion of the experiment. The experiment will be repeated for a range of operating conditions. The effect of ultrasonic frequency, intensity, temperature and pressure will be analysed, documented together with conclusions and recommendations.

Keywords—sonochemistry, sonolysis, pyrolysis, ultrasonic, cavitation, acoustic irradiaton, bubble dynamics, energy, fuel, oil

I. INTRODUCTION

It has long been a known fact that Botswana has more than 200 billion tons of coal. However, this vast amount of coal lies dormant underground since there is no way to transport significant amounts of it to a port for export purposes. The amount of coal consumed internally to generate power warrants only one coal mine in the whole of Botswana. It has therefore been the goal of many organisations to find alternative ways in which to utilise this coal economically. Many attempts have been made to prove feasibility of a new dedicated long haul railway line to both the Indian and Atlantic Oceans, but with no success to date. Others have ventured along power generation opportunities while yet others are looking into coal to liquid (CTL) projects. However, on a relatively small scale of implementation, such as is relevant to Botswana, there has been little success in proving feasibility to date.

Pyrolysis has been applied to coal and other forms of carbonaceous materials for many centuries to obtain high value energy products. Thermal decomposition of the raw material is achieved by applying heat in an oxygen free environment. Various regimes of pyrolysis have been developed over time and these cover applied temperature (below 400 °C, up to 600 °C and above 600 °C), heating rate (slow, medium, fast and flash pyrolysis), pressure (vacuum up to several atmospheres) and a wide range of catalytic processes.

Ultrasonic energy has been used successfully is other industries to enhance chemical reactions. Since pyrolysis also requires significant energy for the decomposition to take place, it can hypothesised that acoustic energy could equally be applied to achieve the same through sonolysis.

Sonochemistry is a mild, safe, and particularly green technology [13]. It accelerates chemical reactions and permits the use of less forcing conditions. It make a process more economical by the use of standard reagents and solvents and often reduces the number of synthetic steps required. It reduces any induction period with unwilling synthetic partners and initiates stubborn reactions while enhancing catalyst efficiency and radical reactions at the expenses of polar ones.

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II. SONOCHEMISTRY

A. Chemical Kinetics

Although we are concerned about amounts of material that react, amount of products that form and the rate at which they form (i.e. at a macroscopic level), this is driven by what happens on a molecular level. Collision of atoms with each other, energy levels to initiate reactions and even orientation of the molecules during collisions play a role and have to be considered in the application of sonochemistry (i.e. the chemical reaction mechanisms) [8].

Generally, the more collisions, the higher the probability of a reaction taking place. Various parameters affect the collision rate, of which the most common are temperature, pressure, concentration, surface areas and catalysts.

Secondly the energy levels of the reactants need to be high enough to facilitate bond breaking.

Chemical reaction rates are influenced by thermodynamics and kinetics. While thermodynamic data tell us how much energy is gained or released if the reaction takes place, the kinetic factor is more important when considering reaction rates and many factors influence them, including (a) the nature of the reactants, (b) the phase of the reactants, (c) temperature, (d) pressure, (e) concentration, (f) surface area and (g) catalysts.

Kinetics for pyrolysis reactions are often based on the following equations for the reaction rate (r) as a function of concentrations (C) and activation energy (E_a):

$$r = \frac{\delta C_{tar\ compound}}{\delta t} = k(T)\cdot(C_{tar\ compound})^{m}\cdot(C_{CO2})^{n}\cdot(C_{H2O})^{o}\cdot(C_{H2})^{p} \quad (1)$$

$$k(T) = k_0 \cdot \exp\left(\frac{-E_a}{R \cdot T}\right) \quad (2)$$

B. Bubble Dynamics and the Hot Spot Theory

The creation, oscillation and implosion of bubbles play a vital role in the sonochemical reactor.

The ultrasonic energy is absorbed into the cavitation bubbles thereby inducing the sonochemical reactions. This also corresponds with the observation that the sound absorption coefficient (α) increases dramatically in the sonochemical reactor [5]. The absorption coefficient is therefore a very important parameter in sonochemistry and is affected by the frequency (f), the density (ρ), the speed of sound in the medium (c), the viscosity (η_s), thermal conductivity (k) and the heat capacities (c_p and c_v) of the fluid [6]:

$$\alpha = \frac{2\pi^2 f^2}{\rho c^3}\left[\frac{4\eta_s}{3} + \frac{(C_p/C_v - 1)k}{C_p}\right] \quad (3)$$

It has been shown that mathematical modelling of bubble dynamics shows good correlation with experimental observation [7].

Dissolved gas in the fluid and/or vaporization of the liquid forms a micro bubble during ultrasonic irradiation. This bubble increases in size as the acoustic pressure decreases. The subsequent compression phase causes the cavity to contract and for specific conditions the cavity collapses in a much shorter time as the expansion phase. Since the collapse time is much shorter than required for mass and heat transfer, the cavity compression leads to high pressure and almost adiabatic temperature rise of its contents.

This explanation of how the extreme pressures (> 100 bar), temperatures (> 5000 K) as well as associated heating and cooling rates (> 10^9 K/s) are caused is referred to as the "hot spot theory". The collapse is followed by an oscillation (the after bounce) until the next rarefaction phase and the start of a new cycle [1].

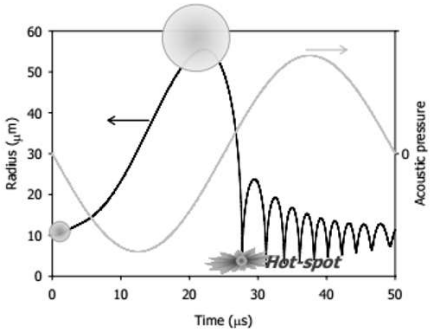

Fig. 1. Cavity formation and collapse [1]

C. Acoustics

Sound waves travel through a gas, liquids or solid medium as a longitudinal wave and their characteristics are related by frequency (f), wavelength (γ), speed (ν), bulk modulus of the fluid (K) and the density of the fluid (ρ) as shown in equations (4) and (5).

$$\gamma = \nu/f \quad (4)$$

$$\nu = \mathrm{sqrt}(K/\rho) \quad (5)$$

Ultrasonic waves in a closed environment (such as a reactor) reflect from surfaces in the constraining geometry (boundary conditions) and are thus superimposed onto other wave cycles within the system. When the wavelength (or a submultiple thereof) of the acoustic wave corresponds to the distance between two parallel features of the reactor, then standing waves will form. These standing waves appear at very discrete frequencies and have characteristic patterns (also

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referred to as acoustic modes). Numerous acoustic modes typically exist for any given reactor geometry.

When an ultrasonic excitation frequency coincides with an acoustic mode of a reactor geometry, then that acoustic mode will start to resonate and form a standing wave in the system. The amplitude of the standing wave will depend on the damping in the acoustic system and could in some cases even become destructive to the equipment.

Acoustics are therefore of paramount importance in the field of sonochemistry. Not only will it dictate the locations where sonochemistry will take place, but also what the intensity of the ultrasound will be at those locations. In developing an efficient reactor, it is necessary to carefully consider the acoustic properties thereof.

D. *Factors influencing sonochemical reactions*

Many efforts have been made by many researchers to enhance ultrasonic irradiation efficiency and the influence of various parameters have been studied.

1) Frequency

The rarefaction phase shortens with increasing frequency and higher power is required to cause cavitation at higher frequencies [2].

On the other hand higher frequencies produce smaller bubbles and higher amounts of radicals. There is also a relationship between resonant frequency and bubble radius and tuning to the appropriate frequency will drive the sonochemical reaction to its maximum yield [9][10].

2) Intensity

A minimum intensity is required to reach the cavitation threshold [2]. The amount of electrical energy which is needed in order to attain the desired ultrasonic intensity depends on many other conditions including the reactor design.

In general sonochemical effects will be increase with an increase in in intensity. While in some cases drastic improvements have been observed with increased intensity [12] it does not necessarily improve the desired outcome [11].

3) Solvents

Bubble collapse produces shear forces in the bulk liquid and viscosity increases the resistance to shear [2].

It has been observed that sonochemical reactions of hydrocarbons are more rapid in polar than non-polar solvents [14].

More volatile solvents support cavitation at lower acoustic energy. Cavitation is difficult in solvents that have low vapour pressure [2].

The vapour pressure has an impact on the yield of radicals during sonochemical reactions [4]. The effective value of polytropic ratio ($\gamma=c_p/c_v$) in the cavitation bubble is a major factor in the radicals yield and in volatile organic solutes the effect of vapour pressure on gamma plays an important role. In aqueous mixtures, different behaviours are observed with organic solvents having vapour pressures higher than water that with organic solvents having vapour pressures lower than water. Therefore organic liquids greatly diminish the intensity of cavitational collapse [3].

4) Dissolved gases

Dissolved gas in the liquid medium has been used to aid in the formation of cavitation bubbles [4]. The energy on collapse increases for gases with large polytropic ratio. Monoatomic gases are preferred [2]. Argon, nitrogen, hydrogen, carbon monoxide and air are some of the common gases used. Saturation of various gases in water enhances the production of the radical H_2O_2 [3]. Polyatomic gases like hydrocarbons reduce the maximum temperatures attained in the bubble since they provide vibrational and rotational modes that will absorb much of the kinetic energy [4][16][17].

5) Surface tension

Liquid-gas interfaces are generated during cavitation. The addition of a surfactant facilitates cavitation [2].

6) Temperature

Higher temperatures cause the vapour pressure to raise and cavitation will be easier. However, this also result in less violent bubble collapse [2].

7) Reactor Pressure

Raising the reactor pressure will produce a larger intensity of cavitational bubble collapse [2].

8) Chemical dosing

The addition of chemicals (e.g. NaCl and $FeCl_3$) has been shown to enhance cavitation in certain cases due to hydrophobic interactions [14].

9) Presence of solid particles

When solid particles exist in the heterogeneous reactant mixture, then bubble collapse becomes asymmetric causing high jets of fluid to shoot into the collapsing bubble space. This jet causes extremely violent fluid dynamic conditions and causes impingement into the solid particle with increased reactivity.

10) Standing waves

Reaction rates depend significantly on the presence of standing waves since cavitation bubbles gather at the anti-nodes of the standing waves by the primary Bjerkes forces [13].

11) Liquid flow

Liquid flow prevents the cavitation bubbles from agglomerating and reaction rates are thereby enhanced. However, little research has been done on sonochemistry under turbulent flow.

III. Reactor Development

In order to conducts experiments that are useful, the results need to enable one to scale up later to commercial versions. It is therefore necessary to consider some aspects of large scale implementation as well when designing the experimental reactor.

The selection of ultrasonic parameters such as ultrasonic mode (continuous or pulse), frequency, power, processing temperature, solvent, aeration together with the geometric

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design of the reactor determines the level and distribution of energy intensity in the system. With these aspects taken into consideration and proper geometric construction it is possible to optimise the efficiency and reliability of the reactor performance [15].

A. Design considerations

When designing sonochemical reactors it is important to consider:

- Position of ultrasonic horn in the sonochemical reactor.
- Surface and shape of the tip of the transducer or horn.
- Replacement of a single high-output transducer with an array of transducers having lower power output.
- Superposition of ultrasonic field by changing reactor geometries.

B. Reactor types

Various reactor types exist with their own advantages and limitations [15]. In this scenario a reactor type is sought after that easily scalable and has potential to be implemented economically. The following types of reactors are in this category:

1) Liquid whistle

Ultrasound is generated by mechanical oscillation. It has the advantages of low cost and is suitable for continuous flow reactions. However, it is limited in frequency and power output.

2) Probe reactor

This reactor type delivers ultrasonic energy directly to the liquid reactant through an immersed horn. It has the advantage of high power output and concentrated energy delivery. Although it is already commercialized, its limitations are that the horn tip is easily eroded and that its acoustic intensity distribution is poor. It is also difficult to control the reaction temperature and has low cavitational efficiency.

3) Resonating tubular reactor

Ultrasound in this reactor is generated by vibration of resonating stainless steel tubes which contain the reactant which flows through them. It avoids possible contamination of reactants and is capable for handling large-scale feedstock. It has been successful in Phenol oxidation.

4) Reverberative flow reactor

Intensified acoustic intensity is achieved by reflection and reverberation techniques. Energy is delivered in concentrated and intensified manner and it produces a uniform ultrasonic field.

5) Polygonal Reactor Transducer

An array of transducers surround the polygonal vessel containing liquid reactant. It delivers a concentrated, intensified and uniform ultrasonic field. Due to the polygonal shape of the vessel, it is limited to low reactor pressure applications.

C. Experimental setup

The reactor geometry has a great influence on the formation of *standing waves* and small features in the reactor geometry can have a huge impact on the efficiency of achieving this. On the other hand, the structural response of the reactor itself could be used to assist in the creation and amplification of such standing waves (acoustic resonance). In normal circumstances it is good practice to specifically steer away from any such situations since they could easily lead to equipment failure [18]. However, if the system is designed to withstand acoustic induced resonance, huge amounts of energy can be harnessed to assist in sonochemical reactions. It will therefore be one of the aims of this design to create the conditions where fluid-structural interaction is promoted by having acoustic and structural modes coincide. It follows then that it will also be necessary to apply frequency tuning to ensure that the structural and acoustic modes are excited.

The first set of experiments will focus on a batch process in a simple geometry, i.e. a cylindrical vessel. Thereafter the pilot reactor (fig. 2) will be fitted with ultrasonic equipment to study characteristics and performance in a continuous process.

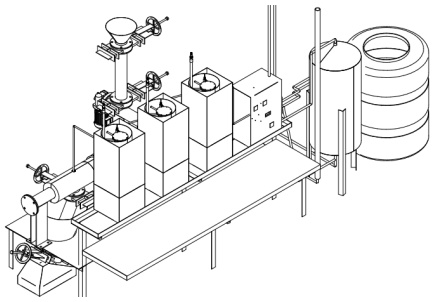

Fig. 2. Pilot Plant at Chemical, Materials and Metallurgical Department

. Both macroscopic and microscopic characteristics in the sonochemical field contribute to the efficiency of the sonochemical reactor. The macroscopic characteristics define what the acoustic field looks like and they are influenced primarily by the geometry of the reactor, but also parameters like fluid density and the frequency and orientation of the ultrasonic excitation source. This acoustic field defines the localised conditions on a microscopic level and together with other conditions e.g. ultrasonic frequency and the physical properties of the fluid, these local conditions affect the local reactions. It is therefore necessary to model on both a macroscopic as well as a microscopic level in order to accurately predict pyrolysis enhancement.

D. Macroscoping modelling

The first step in determining the properties of the acoustic field, is to create a 3D model of the reactor. Thereafter, the acoustic modes of the fluid are determined by means of the Finite Element Method (FEM). In addition to determining the acoustic modes, the structural modes will also be determined using the FEM. A study of the acoustic field and structural behaviour will lead to the choice of (a) the location of the

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ultrasonic transducer and (b) the frequency of the ultrasonic excitation.

E. Microscopic modelling

The hot spot theory will be combined with the principles of bubble dynamics to develop a mathematical model which will aim to predict the localised conditions on a microscopic level. The chemical reactions which take place during pyrolysis will then be added into this model to predict reaction rates. The localised conditions which are determined in the macroscopic analysis will be applied to the microscopic mathematical model.

IV. Conclusion

Literature has shown great potential for the promotion of chemical kinetics by the use of ultrasound. However, scalability has always been a challenge and commercial application in the industrial sector is still very limited and it has not yet been applied commercially in the pyrolysis field. This study aims to perform experimental and analytical work where ultrasound is applied to influence pyrolysis reactions and the ultimate goal is to unlock sonochemistry as a commercially viable technique to convert coal and biomass into valuable products.

References

[1] Van Iersel, Maikel Maria. Sensible Sonochemistry. Eindhoven : Technische Universiteit Eindhoven, 2008.

[2] Chen, Dong, Sharma, Sanjay K. and Mudhoo, Ackmez. Handbook on Applications of Ultrasound Sonochemistry for Sustainability. Boca Raton, FL 33487-2742 : Taylor & Francis Group, LLC, 2012.

[3] Yang, Chia-Yu (Iris). The Feasibility Studies on Sonochemical Processes for Treating Used Oil: Toxin Reduction for Eliminating Recycle Interference. s.l. : Faculty of the Graduate School University of Southern California, 2008.

[4] Riesz, Peter and Misik, Vladimir. Sonochemistry of aqueous solutions: EPR and spin trapping studies of radical intermediates. Radiation Biology Branch, National Cancer Institute. Bethesda, MD 20892-1002 : s.n., 1998.

[5] X. Zheng, Y. Keiji and L. Xiao-Jun, "Quantitative calculation of reaction performance in sonochemical reactor by bubble dynamics," Chin. Phys. B Vol. 24, No. 10, 2015.

[6] M. Lupacchini, A. Mascitti, G. Giachi, L. Tonucci, N. d'Alessandro, J. Martinez and E. Colacino, "Sonochemistry in non-conventional, green solvents or solvent-free reactions," Tetrahedron 73, pp. 609-653, 2016.

[7] C. Gong and D. P. Hart, "Ultasound Induced Cavitation and Sonochemical Yields," *Journal of the Acoustical Society of America, Vol. 104,* 1998.

[8] Wikiversity, "Chemical Kinetics," 4 October 2016. [Online]. Available: https://en.wikiversity.org/wiki/Chemical_kinetics. [Accessed 18 Jan 2017].

[9] M. Horowitz, "Method for electrically cracking petroleum crude". USA Patent 4077870, 1978.

[10] M. Penconi, F. Rossi, F. Ortica, F. Elisei and L. P. Gentili, "Hydrogen Production from Water by Photolysis, Sonolysis and Sonophotolysis with Solid Solutions of Rare Earth, Gallium and Indium Oxides as Heterogeneous Catalysts," Sustainability, pp. 9310-9325, 2015.

[11] A. Praptijantoa, E. Agustiana, Y. Putrasaria, D. Sebayangd, A. Z. M. Rusa, S. Hasana and P. Untoroe, "Sonochemistry approach to reducing biodiesel reaction time from Jatropha Curcas oil by clamp on tubular reactor," in 2nd International Conference on Sustainable Energy Engineering and Application, 2014.

[12] M. Kunaver, E. Jasiukaityte and N. Cuk, "Ultrasonically assisted liquefaction of lignocellulosic materials," Bioresource Technology 103, pp. 360-366, 2012.

[13] X. Zheng, Y. Keiji and L. Xiao-Jun, "Quantitative calculation of reaction performance in sonochemical reactor by bubble dynamics," Chin. Phys. B Vol. 24, No. 10, 2015.

[14] Z. Wu, J. Lifka and B. Ondruschka, "Sonochemical reaction of selected cyclic C6Hx hydrocarbons in organic solvents," Ultrasonics Sonochemistry 12, p. 127–131, 2005.

[15] J. Luo, Z. Fang and R. L. S. Jr., "Ultrasound-enhanced conversion of biomass to biofuels," Progress in Energy and Combustion Science, pp. 1-38, 2103.

[16] K. M. Sadeghi, J.-R. Lin and T. Fu, "Sonochemical Treatment of Fuel Components," Los Angeles, CA 90089-2531.

[17] K. S. Suslick, Y. Didenko, M. M. Fang, T. Hyeon, K. J. Kolbeck, . W. B. Mcnamara III, M. M. Mdleleni and M. Wong, "Acoustic cavitation and its chemical consequences," Phil. Trans. Roy. Soc. A, Urbana, IL 61801, USA, 1999.

[18] D. E. Botha, G. N. Van Zyl and J. K. Roux, "The Role of Computational Technologies in Solving Fluid-induced Piping Vibration Problems," in Cape 2001 – Ageing of Material & Methods for the Assessment of Lifetimes of Engineering Plant, Cape Town, 2001.

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Cloud-based Wireless Monitoring System and Control of a Smart Solar-Powered Aquaponics Greenhouse to Promote Sustainable Agriculture and Fishery in an Arid Region

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***Abstract*— This paper presents the design and implementation of an aquaponics greenhouse cloud-based wireless monitoring system and control that allow plants and fish to co-exist in a synergetic and controlled ecology. Two controllers are designed based on threshold values for effective nitrification and mineralization processes, as well as to enhance the rate of photosynthesis. As compared to our previous work, Wi-Fi technology and cloud data storage are utilized instead of GSM to reduce the cost in monitoring and increase accessibility of the aquaponics greenhouse parameters to many users. Modification in the design of the solar energy conversion system is done with higher ratings on solar panels and batteries to ensure an uninterrupted power. The experimental data gathered during summer and winter days in an arid region show the performance of the designed aquaponics greenhouse system in promoting sustainability. Current developments in the design and implementation of an aquaponics greenhouse system as well as possible improvements for large-scale production set-up are also discussed in the paper.**

Keywords*— *agricultural engineering; aquaculture; hydroponics; automation; control design; electronic design, sustainable agriculture; sustainable fishery; renewable energy

I. Introduction

Countries in arid regions such as Middle East and African countries face several challenges in ensuring food security from agricultural sector due low fertility soil, limited irrigation water and adverse weather conditions in raising crops [1]-[4]. To promote growth in food production, improve quality of agricultural products, and increase in fish stock without over harvesting of marine food sources, scientific and technological researches on sustainable farming and fishing such as aquaponics, greenhouses and aquaculture are conducted and financially funded by government agencies and non-government institutions in arid regions [4]-[10].

An aquaponics greenhouse is a building structure for soil-less method of cultivating plants in hydroponic beds in conjunction with growing fish in aquaculture tanks. In a recirculating aquaponics system, fish excrete ammonia rich wastes directly into the water of the aquaculture tanks [11]. As the water is being pumped into the hydroponic beds, the dissolved waste nutrients are converted by living bacteria into organic fertilizers needed for plant growth. In return, the plant roots filters and clean the water for fish utilization as it is recycled back into the aquaculture tanks [12]. To guarantee growth and survival of living organisms in an aquaponics greenhouse system, water quality parameters on the recirculating aquaponics system such as water temperature, pH, dissolve oxygen (DO), electrical conductivity (EC), total dissolve solids (TDS), total suspended solids (TSS), salinity, nitrate (NO_3), ammonia (NH_3) levels, as well as the greenhouse environmental parameters such as air temperature, relative humidity (%RH), carbon dioxide (CO_2) and lighting, must be monitored in real-time and automatically controlled [7],[8],[13],[14]. With this process, aquaponics greenhouse allows plants and fish to exist together in a synergetic and controlled ecology that promotes sustainability in agriculture and fishery [8]-[10],[12].

With this aquaponics greenhouse system, farming techniques and engineering methods that protect the environment, benefit the public health and support the local economy in arid region are applied to produce fish and vegetables. This eco-friendly system utilizes renewable energy source in terms of solar energy, water recycling and waste management [7]-[9],[12]. The use of cheaper energy source, minimal water exchange, organic fertilizer from fish waste and natural biofilter reduce the operating cost of the aquaponics greenhouse system; hence, it is considered as a cost-effective system [11],[12]. The growth in sales of the aquaponics greenhouse products support the economy of local communities [12]. Moreover, the harvested products from this system are organic, healthy and safe for human consumption [7]-[9],[12].

In this paper, Section II cites the current developments in the design and implementation of an aquaponics greenhouse system. Section III describes the design, set-up and implementation of the aquaponics greenhouse cloud-based

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wireless monitoring system and control. In Section IV, the experimental data taken during a typical summer and winter seasons in an arid region show the performance of the designed aquaponics greenhouse system in promoting sustainability. Lastly, Section VI concludes the present paper and identifies the possible improvements in the design of aquaponics greenhouse system for large-scale production.

II. Current Developments in the Aquaponics Greenhouse Control and Monitoring System

The need to constantly monitor and automatically control the aquaponics and greenhouse parameters to achieve healthy fish and plant growth is extensively studied [7][8][15]-[20]. A.M Nagayo et al. [7],[8] designed and implemented a smart and energy-efficient aquaponics greenhouse system using Arduino microcontroller interfaced with various sensors, actuators, NI LabVIEW software and GSM shield to monitor and automatically control the necessary water quality parameters and greenhouse environmental conditions for Nile tilapia, water spinach and lettuce production with minimal operating cost and human intervention. The experimental data and analysis of results showed that the system was sustainable to be used in Oman and other arid regions. However, to reduce the cost in monitoring the system performance, the use of Wi-Fi technology and cloud data storage was recommended instead of GSM[8]. Also, the design of the solar power conversation module needs to be modified to ensure 24/7 operation of the whole system. M.F. Saaid et al [15] presented a design of automated indoor aquaponics using Arduino microcontroller that monitors and controls the temperatures in fish and plant areas, feeding of fish and water level in the aquaculture tank.

D. Karimanzira, et al. [16] demonstrated the use of dynamic modelling technique to analyse aquaponics system to produce Nile tilapia and tomatoes. The designed INAPRO system is a double recirculation system consisting of recirculating aquaculture system (RAS) and recirculating hydroponics unit within a greenhouse. For management and control of aquaponics system, it uses dynamic two player systems associating two controllers – RAS and greenhouse controllers [16]. This model was implemented in VBA Excel to simulate various aquaponics conditions for possible large-scale production in the future.

Ipanera, an Industry 4.0 based architecture for aquaponics system was published by P.C.P. De Silva and P.C.A. De Silva [17] to control water quality parameters using adaptive fuzzy controller. This Internet of Things (IoT) system requires two control operations: (a) control for the effective mineralization of fish waste to fertilizer and (b) a process control for supervisory monitoring [17]. Ipanera consists of the following modules: (a) endpoints which are responsible for gathering data and control all the operations of a soil-less food production system using fuzzy logic; (b) IoT cluster that provides a platform for registering and grouping endpoints, setting-up communication from one endpoint to another, generating alerts to endpoints and updating fuzzy configuration; (c) analytics server which conducts parameter optimization of the individual fuzzy controllers, analysis of data from all endpoints and predictions as well as machine learning operations; and (d) Hypertext Transfer Protocol (HTTP) server that stores the modified controller updates [17]. Another fuzzy logic controller for aquaponics system prototype was designed and implemented by F.J. Baldonado which automates the process of maintaining the temperature, pH and water levels to ensure for fish and plants growth [18]. However, this system monitors and controls only limited water quality parameters.

D. Wang et al. designed a smart monitoring and control for aquaponics system based on OpenWrt [19]. The system consists of the following modules: (a) sensor data acquisition module that gather real-time environmental parameters such as temperature, humidity, water level, oxygen in water, E-coli level and photos; (b) control and management center, consisting of Arduino and WRTnode, which stores the data collected, process data, upload data to the Web server and download the instruction information from the server to execute controlled operation; (c) Web server that stores and analyze the information from the sensor and camera [19]. With the designed system, the user or farm owner, can use mobile terminal to monitor and activate the actuators such as air pump, water pump and lamp remotely. On the other hand, a proposed system for an autonomous aquaponics system using 6LoWPAN based Wireless Sensor Network (WSN) and Next-Generation Telco was presented by N. Hari Kumar et al. [20]. The proposed system consists of WSN devices, temperature/pH/nitrate sensors, cloud data storage, trend analysis module for predicting the future values of Nitrate and PH, and image analysis module to classify healthy fish from disease- infected fish [20].

III. Aquaponic Greenhouse System Design Considerations

A. Block Diagram of the Aquaponics Greenhouse Control and Monitoring System

Fig. 1 shows the modified block diagram of the Aquaponics Greenhouse Control and Monitoring system based on the recommendations given by A. M. Nagayo et al. [8]. The modified system consists of two microcontrollers. Controller 1 (C1) is an Arduino microcontroller that controls water quality parameters of the aquaculture tank and hydroponic beds for effective nitrification and mineralization process. Controller 2 (C2) is a Particle Photon microcontroller which controls the greenhouse environmental parameters to improve the rate of photosynthesis in the hydroponic bed. Both microcontrollers perform the following tasks: (a) read and process data from various sensors through signal conditioning circuits; (b) verifies the data gathered with the defined threshold values, and (c) triggers the actuators when the sensor readings are not within the normal limits to perform a controlled operation. The actuators such as water pumps, aeration pumps, greenhouse lights, warmer lamps, exhaust fans, evaporative cooler and DC motor for fish feeder are turned on

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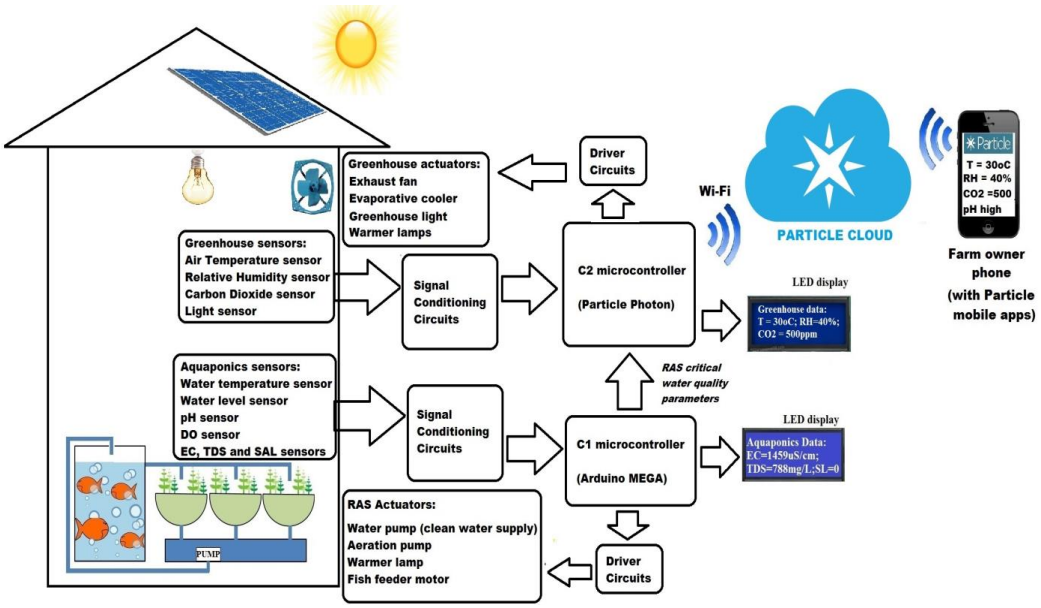

Fig. 1. Block diagram of the aquaponics greenhouse control and monitoring system.

by the microcontrollers through driver circuits. For monitoring purposes, the real-time data gathered by the Arduino and Particle Photon microcontrollers are displayed in LCDs. Also, greenhouse environmental parameters and critical water quality parameters in the Recirculating Aquaponics System (RAS) are published in the Particle Cloud, which can be accessed by farm owner anytime using the Particle mobile application software. The completed Aquaponics Greenhouse facility located at the grounds of Al Musanna College of Technology, Oman is shown in Fig 2 and the set-up inside it.

Fig. 2. The actual aquaponics greenhouse facility and the set-up inside it - aquaculture tank, hydroponic beds, control and monitoring system

B. Control and Monitoring of Greenhouse Environmental Parameters

To improve the rate of photosynthesis and other plant growth processes in the hydroponic beds, greenhouse environmental parameters such as air temperature (T_{air}), relative humidity (RH), carbon dioxide (CO_2) level and light intensity, are controlled and monitored automatically [7],[8]. The C2 controller was designed based on threshold values for each sensor specified by [7],[8].[21]-[28] that allow the optimal growth of water spinach (*Ipomoea aquatica*) in the hydroponic beds during summer season, with the addition of lettuce (*Lactuca sativa*) in winter season. Table I shows the set range of threshold values for the greenhouse environmental parameters, which are monitored remotely by the farm owner using the Particle Cloud mobile apps, and controlled operation to be done through actuators when the parameter values are out of range.

C. Control and Monitoring of Water Quality Parameters in the Recirculating Aquaponics System (RAS)

To allow the optimum growth of tilapia (*Oreochromis niloticus*) in the aquaculture tank and the water spinach (*Ipomoea aquatica*) in the hydroponic beds in summer time, with addition of lettuce (*Lactuca sativa)* during winter time, water quality parameters of the aquaponics system such as water temperature (T_{water}), pH level, dissolved oxygen (DO) level, electrical conductivity (EC), total dissolve solids (TDS) and salinity (SAL), are controlled and monitored automatically [7],[8]. The C1 controller was designed based on threshold values for each sensor specified by

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TABLE I. RANGE OF THRESHOLD VALUES FOR THE GREENHOUSE ENVIRONMENTAL PARAMETERS AND THE CORRESPONDING CONTROLLED OPERATIONS

Greenhouse Environmental Parameters	Sensor Used	Acceptable Range of Values	Set threshold values based on A.M Nagayo et al. [7],[8]	Controlled operation based on A.M.Nagayo et al. [7],[8]
Air Temperature (T_{air})	DHT22	17 °C to 30 °C [24]	17 °C to 30 °C	If Tair <= 16°C, warmer lamps (W) are turned ON.
				If Tair > 30°C, exhaust fan (F) is turned ON.
				If Tair > = 33°C, evaporative cooler (E) is turned ON.
				If Tair < 10°C or Tair > 40°C, publish critical parameters in Particle Cloud.
Relative humidity (RH)	DHT22	25% to 70% [22]	40% to 70%	If RH > 70%, exhaust fan (F) is turned ON.
				If RH < 40 %, evaporative cooler (E) is turned ON.
				If RH < 25% or RH > 85%, publish critical parameters in Particle Cloud.
Carbon Dioxide (CO_2)	MG811	340 ppm to 1300 ppm [25],[26]	340 ppm to 1300 ppm	If CO_2 > 1300ppm, exhaust fan (F) is turned ON.
				If CO_2 < 340ppm, warmer lamps (W) is turned ON since heating can increase the amount of carbon dioxide in the greenhouse [27].
				If CO_2 < 200 ppm or CO_2 > 1800 ppm, publish critical parameter in Particlae Cloud.
Light Intensity	Light Dependent Resistor (LDR)	LDR V_{out} < 4 V [7].[8]	V_{out} < 4 V	If the output voltage of the LDR circuit, V_{out} >= 4 V (dark room), greenhouse lights are turned ON. This greenhouse light (G) will act as an artificial light during nighttime to enhance plant growth and development [28].

[7],[8].[24],[29]-[34] to maintain good water conditions for plants and fish. Table II shows the set range of threshold values for the water quality parameters, which are monitored remotely by the farm owner using the Particle Cloud mobile apps, and controlled operation to be performed through actuators when the parameter values are not within the desired limits.

D. Cooling and Heating System of the Aquaponics Greenhouse

In regions with extremely dry climates, like Middle East and some African countries, evaporative cooling of air has the added benefit of conditioning the air with more moisture [8]. For the aquaponic greenhouse facility, a pad and fan type evaporative cooler shown in Fig. 3 is used to lower the air temperature and increase the relative humidity inside the greenhouse through the evaporation of water [7],[8]. Aside from evaporative cooler, exhaust fan is installed on the top wall of the greenhouse to vent out the accumulated hot air.

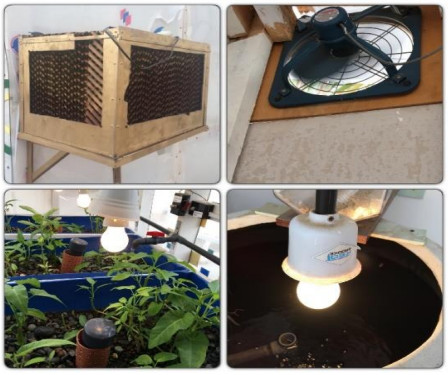

Fig. 3. Cooling and heating system of the aquaponics greenhouse [7],[8].

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TABLE II. RANGE OF THRESHOLD VALUES FOR THE RAS WATER QUALITY PARAMETERS AND THE CORRESPONDING CONTROLLED OPERATIONS

Water Quality Parameters	Sensor Used	Acceptable Range of Values	Set threshold values based on A.M Nagayo et al. [7],[8]	Controlled operation based on A.M.Nagayo et al. [7],[8]
Water Temperature (T_{water})	D18B20 temperature sensor	16 °C to 33°C [7],[8],[24]	16 °C to 33°C	If T_{water} > 33°C, water pump (WP) is turned ON for 25% partial water replacement.
				If T_{water} < 16°C, warmer lamps (W) are turned ON.
				T_{water} < 12°C and T_{water} > 35°C, the critical parameter is published in the Particle Cloud.
pH level	Atlas Scientific pH sensor	For plant, pH >= 5.5 to pH <=7.5 [24]	5.5 to 8.0 ppm	If pH < 5.5 or pH > 8.0, water pump (WP) is turned ON for 25% partial water replacement, and the critical parameter is published in the Particle Cloud.
		For fish, pH >=5.5 to pH <=10.0 [31]		
Dissolved Oxygen (DO) level	Atlas Scientific DO sensor	For fish, DO > 5.0 to DO <=11.5mg/L [30]	DO >= 5.0 to DO <=11.5 mg/L	If DO < 5.0, aeration pump (AP) is turned ON to increase the oxygen level.
		For plant, DO > 3.0 mg/L [24]		If DO < 5.0 or DO > 11.5, water pump (WP) is turned ON for 25% partial water replacement, and the critical parameter is published in the Particle Cloud.
Electrical Conductivity (EC) , Total Dissolved Solids (TDS) and Salinity (SAL) levels	Atlas Scientific Conductivity K 1.0 sensor	EC >= 30 to EC <= 5,000 uS/cm [31]	EC >= 30 to EC <= 5,000 uS/cm	If one of the parameters is not within the set range, the water pump (WP) is turned ON for 25% partial water replacement, and the critical parameter is published in the Particle Cloud.
		Acceptable TDS value is about half of EC [31].	TDS <= 2,500 mg/L	
		SAL >= 0 to SAL <= 2.0 ppt [34]	SAL >= 0 to SAL <= 2.0 ppt	

During daytime, the heat requirement of the greenhouse is provided by the sun. However, at cold winter nights, warmer lamps shown in Fig. 3 act as heat sources which increase the air temperature more than a few degrees above the outside air temperature [7],[8],[35].

E. Solar Energy Conversion System

Based on the recommendation of A.M. Nagayo et al. [8], solar panels and batteries with higher ratings are required to ensure that the aquaponic greenhouse system is powered-up reliably for 24 hours a day and 7 days a week. During peak summer season, the evaporative cooler, exhaust fan and water pumps are activated and operating most of the time. With these conditions, the AC power requirement of the aquaponics greenhouse system is computed as 370 Watts and the total energy requirement per day after correction factor is 7265.5 Watt-hours. Considering the calculated solar energy needed daily, four (4) 300 W, 28 V PV panels and eight (8) 12V, 200 Ah deep-cycle batteries are utilized, which are designed to be discharged at 25% to prolong the life of the batteries. A PWM solar charge controller with a rating of 60 A, 24 V is utilized, since it matches the ratings of the batteries in series-parallel connection. An inverter of 1000 W with 24 V DC input and 220 Vrms AC output, is used for the system, since the inverter power rating should be normally 25% to 30% greater than total watts (W) of appliances and DC input voltage should match the voltage of the battery bank. In providing DC regulated voltages of 12 V and 5 V to the sensors, signal conditioning circuits microcontrollers and driver circuits, switched mode power supplies are used.

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IV. Experimental Data and Analysis of Results for the Aquaponics Greenhouse System

A. Test Results of the Control and Monitoring System for the Greenhouse Environment

The sample greenhouse environmental parameters read by the sensors and status of the actuators taken on a typical winter time are shown in Fig. 4. The sample greenhouse data published in the Particle Cloud on a typical summer day are presented in Fig.5. Before performing the actual testing in the aquaponics greenhouse facility, the temperature readings of DHT22 were calibrated with digital and analog thermometers, and its relative humidity readings were calibrated with a psychrometer. As for the carbon dioxide (CO_2) sensor readings, the data were correlated with the MG811 sensitivity curve, temperature and relative humidity characteristics as specified on the manufacturer's data sheet [8]. Based on the experimental results, the greenhouse controller (C2) responded in well in accordance with the set threshold values.

As seen in Fig. 4, exhaust fan (F) was turned on since the relative humidity (RH) exceeded 70%. Fig. 5 shows that the air temperature inside the greenhouse increases while the relative humidity decreases during daytime in summer season, which matches with the typical weather condition in an arid region. Due to hot and dry weather during summer, the exhaust fan (F) and evaporative cooler (E) were activated most of the time to decrease the temperature in the greenhouse as compared to the outside temperature [8]. As seen in Fig. 6, the evaporative cooling system can lower the temperature inside the greenhouse by 2°C to 8°C and increase the relative humidity by 20% as compared to the outside environmental conditions. But, this cool air cannot be kept in the greenhouse due to effect of radiation and re-radiation of incident solar energy coming from the outside and diffused through the transparent walls [7],[8]. Referring to Fig.5, the carbon dioxide (CO_2) concentrations in the greenhouse during daytime decreases because the plants use carbon dioxide to carry on with the photosynthesis process [25]. At daytime, the LDR voltage readings are low due to exposure of greenhouse hydroponic beds to sunlight.

Fig. 4. Sample Aquaponics Greenhouse data and status of actuators taken on a typical winter day as displayed on an LCD

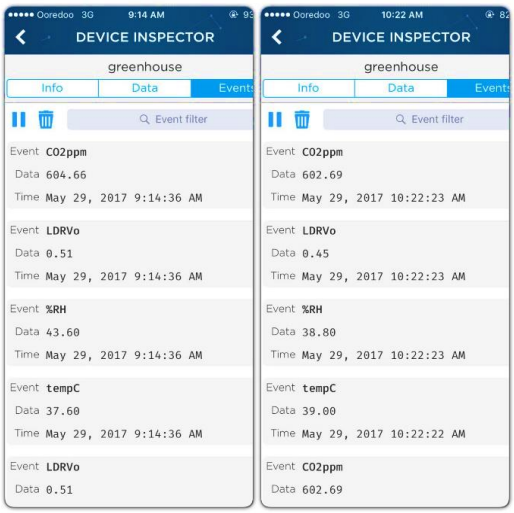
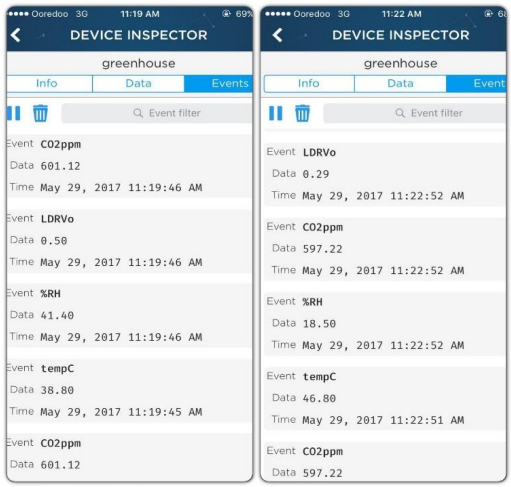


Fig. 5. Sample greenhouse data published in the Particle Cloud on a typical summer day



(a) Data taken inside the greenhouse *(b) Data taken outside the greenhouse*

Fig. 6. Environmental parameters inside and outside the greenhouse on a typical summer day

B. Test Results of the Control and Monitoring System for the Recirculating Aquaculture System

Fig.4 and Fig.7 show the RAS water quality parameters read from the sensors and status of the actuators taken a typical summer and winter days respectively. Before dipping the pH, DO and conductivity K1.0 sensors in the aquaculture tank, they were calibrated properly using the chemical solutions provided by the manufacturer. The pH sensor readings were also verified with the result of the pH test strip

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that was dipped into the aquaculture tank. Digital and analog thermometers were used to calibrate the D18B20 temperature sensor.

As seen in Fig. 4, water pump (WP) was turned on for 25% clean water replacement since the pH reading was below 5.5, and SMS = 1 means that critical alert message was published in the Particle Cloud. As seen in Fig. 7, the dissolved oxygen (DO) decreases as the water temperature increases due to the low solubility of oxygen when the temperature of water is high [8],[38]. As observed in Fig.7, the pH readings fluctuate due to photosynthesis and respiration by plants and vertebrates [39],[40]. During day time, CO_2 is absorbed by the plants from the water. With this condition, pH levels increased since there was less carbonic acid produced from chemical reaction of CO_2 and water [39],[40]. Moreover, significant changes in pH, electrical conductivity (EC), total dissolve solids (TDS) and salinity (SL) readings happened 2 hours after feeding the fish due to uneaten fish feed and production of fish waste [8],[37],[41]. These changes caused microcontroller C1 to enable the water pump (WP) for 25% clean water replacement and critical parameter alert was published in the Particle Cloud. Based on the experimental results, the RAS controller (C1) operated well in accordance with the set threshold values. Controller C1 activates the fish feeder system (FF) every 12 hours for a period of 30 seconds to release approximately 40 grams of commercial feed to the 14 Nile tilapia fish of 150g each in the aquaculture tank with a feeding rate of 4%.

With the modified solar energy conversion system design, the greenhouse aquaponics facility continuously operates for 24 hours even during summer season when evaporative cooler, exhaust fan and water pump are active all throughout the day.

IV. Conclusion

The current developments in the design and implementation of an aquaponics greenhouse system are presented in this paper with one common goal which is to ensure optimal growth and survival of plant and aquatic species in a synergetic and controlled ecosystem. This paper also discussed the design and implementation of a cloud-based wireless monitoring system and control for a solar-powered aquaponics greenhouse based on the recommendation by A.M Nagayo et.al [8]. Wi-Fi technology and cloud data storage are employed instead of GSM to lessen the cost in monitoring and increase accessibility of the aquaponics greenhouse parameters to farm owners and administrators. The design of the solar power conversion set-up that supplies electricity to the aquaponics greenhouse system was modified to ensure uninterrupted power for 24 hours a day and 7 days a week even when majority of the actuators are turned on. The experimental results obtained during summer and winter days showed that the designed aquaponics greenhouse system is suitable for implementation in arid regions to promote sustainability in agriculture and fishery.

For a large-scale production set-up of the designed aquaponic greenhouse in arid regions, the following may be done as future directives: (a) use of mechanical shading mechanism and increase number of evaporative cooler and exhaust fan units to address the problem of high temperature and low relative humidity [8]; (b) utilization of nitrate sensor and ammonia sensor for detailed analysis of water quality parameters [8]; (c) use of fuzzy logic to optimize the control response [18], nitrification process [17] as well as power requirement; (d) employ image processing techniques for evaluating disease infected fish [20] and plants; (e) statistical modelling to predict the environmental and water quality parameters to enable farm owners and administrators to perform system maintenance before critical condition arises, and (f) business plan for implementing this project as a possible source of income for local communities [8].

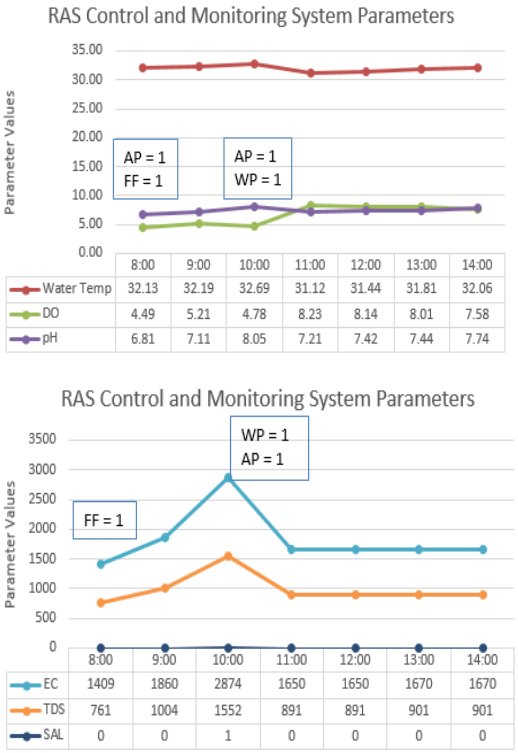

Fig. 7. Recirculating Aquaponic System data taken on a typical summer day

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REFERENCES

[1] H. Al Oufi, A. Palfreman and E. Mc Lean, "Observations upon the Al-Batinah Artisinal Fisheries, the Sultanate of Oman," *Marine Policy*, vol. 24, no. 5, pp. 423-429, September 2000.

[2] M.D. Mbaga, "Alternative Mechanism for Achieving Food Security in Oman," *Agriculture and Food Security 2013* 2:3, February 2013.

[3] A. Sasson, "Food Security for Africa: an Urgent Global Challenge," *Agriculture & Food Security* 2012 1:2, April 2012.

[4] S. Fiaz, M.A. Noor and F.O. Aldosri, "Achieving food security in the Kingdom of Saudi Arabia through innovation: Potential role of agricultural extension," *Journal of the Saudi Society of Agricultural Sciences*, 18 September 2016.

[5] S. Goddard, A.S. Al Busaidi and U.K. Al Kendi, "Fish Culture and Hydroponics at Low Salinities," *A Monograph on Management of Salt-affected Soil and Water for Sustainable Agriculture*, pp.89-94, January 2010.

[6] A.M. Al Ismaili and H. Jayasuriya, "Seawater Greenhouse in Oman: A Sustainable Technique for Freshwater Conservation and Production," *Renewable and Sustainable Energy Reviews* 54, pp. 653-664, February 2016.

[7] A.M. Nagayo, R.S.R Al Yahmadi, R.K.S Al Izki, et al., "Smart and Energy-Efficient Aquaponics Greenhouse for Sustainable Agriculture in the Sultanate of Oman," presented at the National Research Forum, TRC, Sultanate of Oman, October 2016, unpublished.

[8] A.M. Nagayo, E. Vega, Jamisola, R. et al., An Automated Solar-Powered Aquaponics System towards Agricultural Sustainability in the Sultanate of Oman, *2017 IEEE International Conference on Smart Grid and Smart Cities*, Singapore, July 23-26, 2017, submitted for publication.

[9] A.M. Nagayo, R. S. R. Al Yahmadi and E.A.Gonzalez, "Work in Progress: A Smart Solar-Powered Aquaponics Greenhouse System to Promote Sustainable Agriculture to Engineering Students," *The 47th Frontier in Educ. Conf.*, Indianapolis, Indiana, USA, October 18-21, 2017, submitted for publication.

[10] S. Al Qaydi, "Small Scale Sustainable Farming Activities in the United Arab Emirates: the Case of the East Coast of the UAE," *in Proc. of 2014 2nd International Conference on Food and Agricultural Sciences (IPCBEE)*, vol.77, Singapore, 2014.

[11] J. E. Rakocy, M. P. Masser and T.M. Losordo, "Recirculating Aquaculture Tank Production Systems: Aquaponics—Integrating Fish and Plant Culture," SRAC Publication no. 454, November 2006.

[12] S. Diver and L. Rinehart, "Aquaphonics – Integration of Hydrophonics with Aquaculture," NCAT, 2010.

[13] J. K. Buttner, R. W. Soderberg and D. E. Terlizzi, "An Introduction to Water Chemistry in Freshwater Aquaculture," NRAC Fact Sheet No. 170-1993, pp.1-4, 1993.

[14] D.C. Love, M.S. Uhl and L. Genello, "Energy and Water Use of a Small Scale Raft Aquaponics System in Baltimore, Maryland. United States," *Aquacultural Engineering* 68, pp.19-27, July 2015.

[15] M.F. Saaid, et al., "Automated Indoor Aquaponic Cultivation Technique," *in Proc. of 2013 IEEE 3rd International Conference on System Engineering and Technology (ICSET), August 19-20, 2013, Shah Alam*, IEEE, 2013 pp.285-289.

[16] D. Karimanzira, et al., "Dynamic Modeling of the INAPRO aquaponic system," *Aquacultural Engineering* 75, pp. 29-45, October 2016.

[17] P.C.P. De Silva and P.C.A. De Silva, "Ipanera: An industry 4.0 based Architecture for Distributed Soil-less Food Production Systems," in *Proc. of the 1st Manufacturing and Industrial Engineering Symposium (MIES), October 22, 2016, Colombo, Sri Lanka*, IEEE, 2016, pp.1 – 5.

[18] Balinado, F. J., "Fuzzy-Conroller Implementation to an Arduino-Based Solar Powered Aquaponic System Prototype," *LPU-Laguna Journal of Engineering and Computer Studies*, vol. 3,no. 2, March 2016

[19] D. Wang et al., "Design of A Smart Monitoring and Control System for Aquaponics Based on OpenWrt" in Proc. of 5th International Conference on Information Engineering for Mechanics and Materials (ICIMM), Altantis Press, 2015, pp. 937 – 942.

[20] N. Hari Kumar et al., "An Autonomous Aquaponics System Using 6LoWPAN Based WSN" in *Proc. of 2016 4th International Conference on Future Internet of Things and Cloud Workshop (FiCloudW), Austria*, IEEE, 2016, pp. 125 – 132.

[21] J. Kitsteiner (2014). *Permaculture Plants: Water Spinach, Kangkong, Ong Choy* [Online]. Available: http://tcpermaculture.com/site/2014/01/29/permaculture-plants-water-spinach-kangkong [Accessed: September 15, 2015]

[22] B. Eshenaur and R. Anderson. "Managing the Greenhouse Environment to Control Plant Diseases," Plant Pathology Fact Sheet, University of Kentucky – College of Agriculture, 2004.

[23] Advance Solar LLC Greenhouses (2002). *Planning and Building a Greenhouse (How to Build a Greenhouse)* [Online]. Available: http://www.advancegreenhouses.com/planning-and-building-a-greenhouse [Accessed: October 1, 2015]

[24] C. Somerville et al. "Small-scale Aquaponic food production: Integrated fish and plant farming," FAO technical technical paper no. 589. FAO, Rome, 2014.

[25] T.J. Blom, et al. "Carbon Dioxide In Greenhouses," OMAF Factsheet, Queen's Printer for Ontario, 2007.

[26] W. Claassens (2016). *Importance of ventilation in commercial greenhouses.* [Online] Available: http://www.hydroponics.com.au/issue-119-importance-of-ventilation-in-commercial-greenhouses [Accessed: January 18, 2016]

[27] R. Thayer (2015). *Carbon Dioxide Enrichment Methods.* [Online] Available: http://www.hydrofarm.com./resources/articles/co2_enrichment.php [Accessed: January 18, 2016]

[28] R.C. Morrow, "LED lighting in Horticulture," *HortScience*, vol.43, no. 7, pp.1947-1950, December 2008

[29] B. Santosh and N.P. Singh, "Guidelines for Water Quality Management for Fish Culture in Tripura," ICAR Research Complex for NEH Region, Tripura Center Publication no. 29, 2007.

[30] A. Bhatnagar and P. Devi, "Water Quality Guidelines for the Management of Pond Fish Culture," *International Journal of Environmental Sciences*, vol. 3, no. 6, pp. 1980 – 2009, 2013.

[31] N.M. Stone and H.K. Thomforde, "Understanding Your Fish Pond Water Analysis Report," Cooperative Extension Program. University of Arkansas at Pine Bluff Aquaculture/Fisheries, 2004.

[32] A. E. Ogbeibu and R. Victor, "Hydrological Studies of Water Bodies in the Okomu Forest Reserves (sanctuary) in Southern Nigeria", Physico-Chemical Hydrology, Tropical Freshwater Biology, 4, pp 83-100, 1995.

[33] P.K. Weber-Scannell and L.K. Duffy, "Effects of Total Dissolved Solids on Aquatic Organisms: A Review of Literature and Recommendation for Salmonid Species", *American Journal of Environmental Sciences* 3 (1), pp. 1-6, 2007.

[34] S.K. Grag and A. Bhatnagar, "Effects of varying doses of organic and inorganic fertilizers on plankton production and fish biomass in brackish water ponds", *Aquaculture Research*, vol. 27, no. 3, pp 157-166, 1996.

[35] ACF Greenhouses. *Greenhouse Supplies Guide.* [Online] Available: http://littlegreenhouse.com/guide2.shtml [Accessed:October 15, 2015]

[36] H.P. Garg and J. Prakash, *Solar Energy: Fundamentals and Applications*, 1st rev. ed. New Delhi: Tata McGraw-Hill Publishing Company Limited, 2000.

[37] M. B. New. "Feed and Feeding of Fish and Shrimp," Aquaculture Development and Coordination Programme ADCP/REP/87/26, FAO, Rome, 1987.

[38] J. Kepenyes and L. Varadi, "Aeration and Qxygenation in Aquaculture," Inland Aquaculture Engineering, FAO, Rome, 1984.

[39] C.S. Tucker and L. R. D'Abramo, "Managing High pH in Freshwater Ponds," SRAC Publication no. 4604, July 2008.

[40] R. Stevens. *Fish Pond Water Quality: As simple as Chemistry 101.* [Online] Available: https://www.noble.org/news/publications/ag-news-and-views/2009/july/fish-pond-water-quality-as-simple-as-chemistry-101 [Accessed:October 15, 2015] .

[41] C. Folke and N. Kautsky, "The Role of Ecosystems for a Sustainable Development of Aquaculture," *Ambio*, vol. 18, no. 4, pp. 234-243, 1989.

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Real Time Monitoring of Field Crops Using Zigbee

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Abstract—**Agricultural parameters need constant controlling and monitoring to ensure that the crop fields are well taken care of. With the use of wireless sensor network technology crop fields can be continuously controlled and monitored. Therefore a proposed idea is to establish a system which consists of multiple mobile base stations forming a network to control and monitor field crops over a large area or different locations. The connection between different sensor nodes will be through wireless sensor network and between different base stations will be through Ethernet. The sensors are wirelessly interfaced with each other so they can communicate and form a network. This system is advantageous as it enables the farmers or users to control and monitor crop fields in faraway areas, reduces the consumption of energy, easy to implement and effectively saves the lifetime of a sensor network.**

Keywords— Agriculture, Wireless Sensor Network, Base Station, Ethernet, Crop Field.

I. INTRODUCTION

Wireless sensor network is an evolving technology for wide range of wireless environments all over the world. A wireless sensor network is a group of intelligent sensor nodes with a communications capability and infrastructure for monitoring and recording conditions at remote locations. Commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, gas content, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions [2]. A sensor network is a deployment of several devices equipped with sensors that perform a collaborative measurement process. Any value is measured from a sensor such as temperature sensor and any protocol is used to communicate the measured information such as Zigbee with its wireless communication modules. Lastly an external system is used up to show the data which is recorded. Normally these sensor nodes consist of three components the sensing, processing and communicating parts.

Some advantages of using Wireless Sensor Networks include:

- It is easy to implement.
- It is cheap or affordable.
- It uses less power consumption.
- It is environment user friendly

The Fig.1 illustrates a typical wireless sensor network composed of multiple sensor nodes:

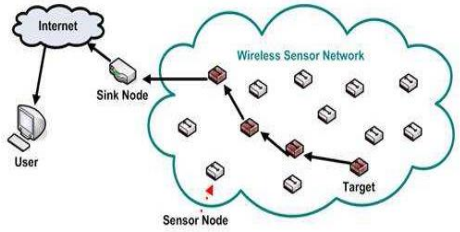

Fig.1. Typical Wireless Sensor Network [3]

In agriculture, wireless sensor network can be used to enhance in optimum production. The modern technology used is applicable in almost every aspect including medical, home, industries etc. most countries including Botswana rely mostly in agriculture especially field crops. Therefore, a system which will be used to control and monitor agricultural parameters over a large area or different locations is suggested. The user will be able to get real time data faraway.

A. Why mobile base stations?

Sensor nodes which are close to the base station and are one hop away from the base station, their energy gets depleted more as compared to other distributed sensor nodes [1]. They relay information for other nodes to the base station through it. When the energy gets depleted, many sensor nodes will not be able to communicate with the base station therefore network not operational [1]. By moving our base stations it will be able to have close access to other sensor nodes and the hop count between them to the base station will be less. This reduces energy consumption of the sensor node close to the base station at that time.

B. Why multiple base stations?

Deployment of multiple base stations to the network reduces the average number of hops between the sensor nodes and their corresponding base stations. Using a single base station in the network the average hops taken by a sensor node

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far away from the base station are more. Therefore deploying multiple base stations in the network as proposed reduces the average hops taken by the sensor nodes. That is, it reduces the energy spent by sensor node when relaying sensed data from other nodes towards the base station. Sensor nodes will be able to send their data to any of the base stations. This results in increased network lifetime as well as improved throughput [2].

C. *Why Zigbee technology?*

In this present communication world there are various high communication standards available. Most of them require being of low energy consumption and latency. Zigbee technology is best suited as it provides a cheaper and offers best communication. It characteristics makes it suitable for most applications including home automation, industrial control, smart metering, smart grid metering etc. Zigbee communication technology operates in short distances and provides a safe and reliable. Various parameters are collected using sensors and transmitted to the base station for analysis.

II. Literature Review

Current researches show that Wireless Sensor Network is a technology that has been applicable for many years and it is being used in different applications. The sensor technology provides a solution to design and develop many types of wireless sensor applications including the military, homes, agriculture, medical and environment monitoring [3]. It assists and improves work performance both in the field of industry and our daily life. Wireless sensor network technology is equipped with devices that can measure or detect any changes or different parameters such as humidity, gas content, temperature, water content etc. These devices are called sensor nodes. They have found applicability in agriculture where it can be used to monitor field crops. Within the agricultural sector wireless sensor network is used and according to different authors there is a use sensor nodes, battery as the power supply, use of different microcontrollers to process the measured parameters , use of Zigbee transceiver modules and personal computer for data visualization.

Traditionally, researchers in memory have aimed to keep procedures for the different wireless sensor network systems not to be different. However, such a narrow focus enables new ideas to be used like the proposed idea of powering with solar panels to cater when it is night. It has been researched that monitoring agricultural parameters like crop fields is not improving. Therefore, a number of researchers have come up with different ideas on how to monitor crop field parameters to optimize crop production. These parameters include pH, water content and temperature. Some of the ideas are summarized as follows. In this paper, it was proposed to implement an ARM7 microprocessor with multiple sensors such as temperature, humidity and water level sensor, Zigbee wireless, battery and GSM modem. If the values captured by the sensors reach a certain threshold ARM processor indicates an alarm. Parameters are sent to farmer in a form of text message. This system aims at bringing desirable results to future farmers [4]. This paper presents an intelligent system, which is an automatic irrigation system which is based on sensor nodes. The main aim of the proposed idea is to monitor paddy crop fields in a wireless manner. It uses Matlab application to analyse the results [5]. The development of GSM based intelligent wireless automatic system is based on the use of wireless sensor network real time monitoring. It introduces the use of different kinds of sensors like temperature, humidity and also a based remote control of irrigation automation [6]. The proposed system for monitoring farm fields in real time in [7] uses greenhouse automation system. It involves adding more sensors to the network which will detect more parameters including flood monitoring, wind speed and wind direction. The drawback of the system is that the network does not reduce the energy consumption used by sensor nodes within the network. Introducing more sensors means more energy consumption by the sensor nodes near to the base station.

In [8], the proposed system uses Zigbee technology. The system is an automatic irrigation system which helps to detect the conditions of the soil for irrigation. If the sensed data matches the threshold values the, then the irrigation starts automatically. The system proves to be effective as the results show that farmers can use it to monitor their field crops in remote areas. The system for monitoring crops in [9], proposes a system which is automatic. It determines the soil moisture of the crops and maintains the moisture level at a particular level. The proposed system in [10], introduces Precision Agriculture (PA). The system enables the farmer to keep track of the environmental conditions including temperature, humidity etc. The paper in [10], proposes an embedded system for automatic irrigation which makes use of Wireless Sensor Networks. The system is placed in the roots of the plant for real time infield sensing and control of an irrigation system. The parameters to be monitored are temperature and soil moisture. The system is found to be feasible and come as a benefit to the farmers in terms of time and cost.

III. Proposed System

This project is about controlling and monitoring agriculture parameters for field crops. Therefore a proposed idea is to establish a system which consists of multiple mobile base stations forming a network to control and monitor field crops over a large area or different locations. The connection between different base stations will be through Ethernet. The Ethernet will be connected to the internet that users can access in remote areas and get real time information. This system is efficient as it is most suitable for non-reachable places like rural areas. It is also suitable as it effectively saves energy consumption and increase the lifetime of the available sensor network. The following Fig.2 shows the proposed system transmitter block diagram. The Fig.3 shows the proposed system receiver block diagram.

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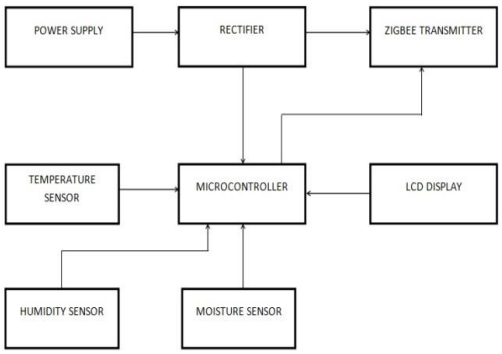

Fig.2. Transmitter Block Diagram

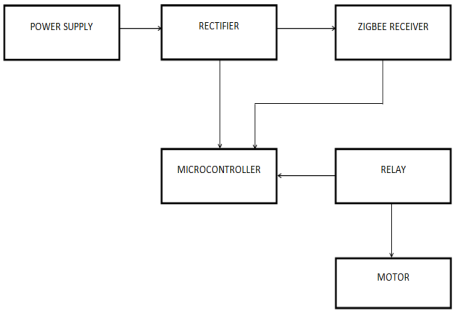

Fig.3. Receiver Block Diagram

The power supply to be used will be powering several nodes including the microcontroller and the three sensors. A rectifier is an electrical device used to convert an alternating current to direct current. It will be used to convert the power supplied to be used by the nodes. The sensors to be used are the temperature, humidity and moisture which will be placed in the fields for collecting the sensed data. Soil moisture sensor is a device used to measure the volumetric of water content of the soil [11]. It gives readings of the water in the soil and makes it ideal for the farmer to take necessary action. The microcontroller to be used is the PIC16F877A with 20MHz operating frequency. The microcontroller is suitable because it is powerful and yet easy to program with 368 bytes of data memory. It operates at 2V to 5.5V of voltage. It has an analog to digital converter, 8 channels of 10-bit Analog-to-Digital (A/D) converter.

The data sensed will be transmitted through separate boards including the transmitter module to the receiver module. No other components like the MAX 232 and MAX233 are needed. These features make it suitable for automotive, industrial applications. It will be used to collect some environmental information and perform some data conversion. It is also responsible for managing other nodes in the system. This microcontroller is suited for remote applications especially with low power consumption and high speed capabilities [10]. The sensed information is displayed on the LCD display showing the results obtained. The sensed information is converted into digital with the help of converter and it is transmitted to LCD to display. Then this information is carried to the ZigBee transmitter node. The Fig.4 shows the transmitter circuit diagram. The Fig.5 shows the receiver circuit diagram.

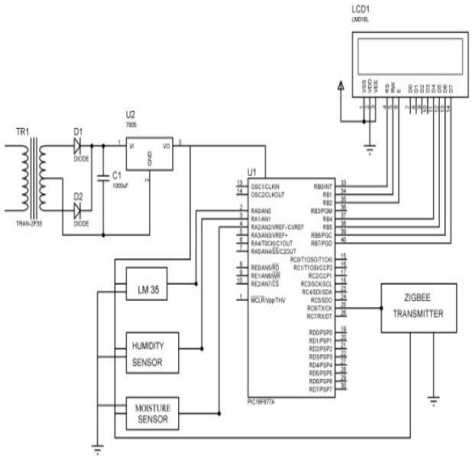

Fig.4. Transmitter Circuit Diagram

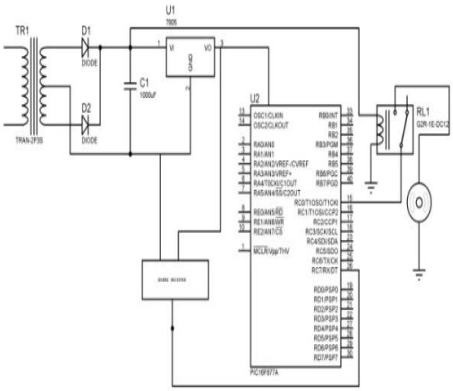

Fig.5. Receiver Circuit Diagram

IV. RESULTS

The system works in two parts being the transmitter and the receiver. They called as transmitter and receiver parts. The Hardware model for the transmitter section is shown in Fig.5 and the receiver section is shown in Fig.6

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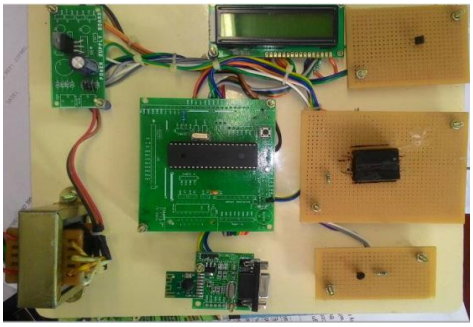

Fig.6. Transmitter Prototype

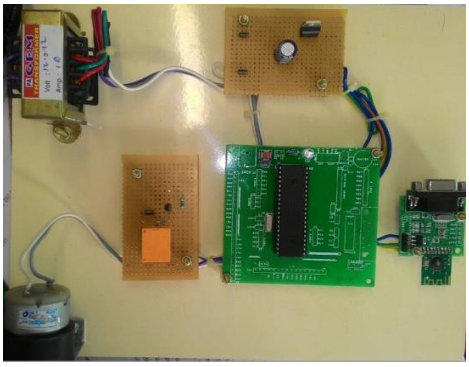

Fig.7. Receiver Prototype

V. Conclusion

The proposed system includes cheap crop field monitoring system that is able to help farmers or users to achieve maximum productivity. A system that monitors and controls field crops over a large area or different locations with multiple mobile base stations. This project is expected to yield good results and an intelligent system for farmers to appreciate. The use of wireless sensor network in agriculture will help farmers to have exact values and make decisions based on them to improve productivity.

References

[1] R. C. D. R. K. Alka Kalra, "Role of Zigbee Technology in Agriculture Sector," Chandigarh, INDIA, 19-20 March 2010.

[2] Wireless Sensor Networks: http://www.searchdatacenter.techtarget.com.

[3] H. K. A. B. Nidhi Patel, "Wireless Sensor Network Using Zigbee," IJRET: International Journal of Research in Engineering and Technology, vol. 02, no. 06, pp. 1038 - 1042, Jun-2013.

[4] F. Y. E. S.Shanthini, "Real Time Application Of Paddy Field Monitoring Using Zigbee Network," International Journal of Applied Theoretical Science and Technology, vol. 1, no. 2, pp. 35-37, July 2015.

[5] Rashmi Jain, "Automatic Irrigation System For Agriculture Field Using Wireless Sensor Network (WSN)," International Research Journal of Engineering and Technology (IRJET), vol. 03, no. 04 , pp. 1602 - 1605, Apr-2016.

[6] Gulhane, "Survey of Implementation of Wireless Sensor Network for Real Time Monitoring System," International Journal of Engineering Research and Management Technology, vol. Volume 3, no. Issue 2, pp. Pg 3914 - 3920, 2016 March

[7] D. Mehetre, "An Automatic Irrigation System using Zigbee in WSN".

[8] P. Patil, "Wireless Sensor Network for Precision Agriculture," in IEEE, 2011.

[9] S. T. Kiruthika M, "Parameter Monitoring for Precision Agriculture," October 2015.

[10] R. A. P. Nilesh D. Kuchekar, "GSM Based Advanced Water Development System for Irrigation using a Wireless Sensor Networks and Android Mobile," International Journal of Electrical, Electronics and Data Communications, vol. Volume 3, no. Issue 8, p. Pg 52 to 57, August 2015.

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Modelling and Simulation of a Smart Instrumentation Mechanism for a Grid-Connected Household Hybrid Power System

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Abstract—Renewable energy technologies range from the well-established, such as hydropower, to the emergent, such as a wind-solar hybrid system. Each technology has its own individual instrumentation requirements to measure and control system variables. This project entails design and development of an effective instrumentation system for a hybrid solar-wind system for households, which will be able to transfer excess power produced into the national grid and establish participants to become independent power producers. Designing an instrumentation system for this hybrid system will require us to measure the following variables: Dc Voltage, Dc Current, Dc Power, Ac Voltage, Ac Current, Ac Power, Wind Direction and speed. Measurements and approximations to be used in this project are obtained from a study undertaken during a site visit to an existing solar system. They will be fed into the simulation using MATLAB-Simulink to be able to have a close estimate of efficiency and other parameters. Power produced in such a hybrid system can be used to supplement the already existing grid power. An effective instrumentation system as this is a bonus to the still under development smart grid systems, through the use of intelligent electronic devices (IED's) control commands can be issued to monitor the system remotely.

Keywords— Photo Voltaic Cell, Instrumentation, Grid, Intelligent Electronic Devices, Hybrid System.

I. INTRODUCTION

In rural areas in Botswana such as the cattle posts, 90% of households have realized the importance of renewable and clean energy sources as they employ the use of solar panels for charging their auxiliary devices such as cell phones and radio's. This has raised an important fact which is that rural areas have implemented and realized the importance of renewable energy technologies more than urban areas [1-3]. To curb this anomaly, a more accountable model is suggested in this project. As one of the objectives above stated, the development of the instrumentation system will entail households to sell their excess power produced from their own wind-solar systems to power utility companies. A smart metering system will measure excess power. Produced and send it into the national grid, this will be recorded on the smart meter so that it can be claimed back. As mentioned in the project abstract, for effective mass deployment of renewable energy technologies, we need to have an intelligent electric grid or smart grid system whereby control, monitoring and islanding can be conducted without effort [6]. Our electricity infrastructure is on the cusp of game changing investments, embedding sensors, communications throughout the system from generation to consumers. These investments have opened entrepreneurial innovation and the single largest source of global warming pollution to vast new diversity of clean and renewable resources. The smart grid at its core will be facilitating the mass deployment of technologies such as the Hybrid power system this project is undertaking.

A. Why Hybrid?

In a hybrid power system, more than one type of electricity generation system is utilized. In some existing systems only one of the two sources is renewable and the other may be of fossil fuels. This approach is viewed as defeating the logic behind global warming as the extra non-renewable source is an addition to the already existing emission problem causing global warming. In this project a more direct approach to reduce a household's carbon footprint is taken. Intermittent energy resources such as wind and solar are very inconsistent, a hybrid of the two is more ideal.

B. Grid Connected

The usual practice nowadays is to link home based energy sources with the electric grid. This means that during the day the electricity generated by the PV system can either be used immediately or be sold to the utility corporations. In the evening when the photovoltaic system is non-operational the power can be bought back from the network. In analysis of this system, the grid acts as an energy storage system which makes having a battery bank optional.

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II. Literature Review

A similar approach of designing a Hybrid power system was taken [4-5], in their case they proposed four renewable energy sources; wind turbine, biomass plant, photovoltaic modules and solar thermal modules. This novel approach was necessitated by wind and solar data collected from site which further proved the feasibility of the power system. The initial investment cost is a bit high for the average household but returns are rapid once the system is running fault proof and connected to the electric grid. Excess power sold to the utility price at the agreed local tariffs can lead to zero electricity bills for any consumer.
A similar project was carried out in [6-8] with control of the photovoltaic module and wind generation system being handled by a micro-controller

Design of a Photovoltaic panel entails connecting solar cells together such that each cell contributes a voltage of 0.6V to contribute to the final open-circuit voltage. Background knowledge on semiconductors is critical to design of an efficient PV module. Semiconductors are used as photovoltaic energy conversion devices through the p-n junction theory. To be able to alter the electrical characteristics of a material, doping is introduced such that there is an intentional introduction of impurities into its regular crystal lattice form. This process is what leads to the formation of p-n junctions in the materials. If the material being doped has more electrons in the valence gap (outermost shell) than the semiconductor, the doped material is referred to as an n-type semiconductor. Conversely if the material has fewer electrons in the valence gap than the semiconductor it is referred to as a p-type semiconductor. Current is able to flow as a result of the photovoltaic effect which is result of the p-n junction formations above. Before all this can happen a photon which is an elementary particle of light needs to enter a photovoltaic material. This particle can be reflected, absorbed or transmitted through. If absorbed by a valence electron, the energy of the electron is increased by the amount of energy of the photon. If the energy of the photon is greater than the valence gap energy, then this causes the electron to jump into the conduction band where it can now move freely. This electron can be moved back and forth using an electric field across the front and back of a Photovoltaic material. This mechanism is what creates the primary product which is a current or flow of electrons.

The efficiency of Photovoltaic cell is defined as the maximum electrical power output divided by the incident light power. Efficiency of a Photovoltaic cell is mostly reported at a cell temperature of 25°C and incident light at an irradiance of 1000W/m² which is one of the parameters used in the simulation of the Photovoltaic panel in Simulink [9]. In practice solar cells are either connected in series or in a parallel formation. Connecting them in parallel means the voltage remains the same but current is doubled and in series formation this means current remains the same but voltage increases.

A. Charge Controller

Charge controller is present in both of the energy sources. Since the scope of this report is on the solar side, more emphasis will be on it as the project is still on the solar model phase. A charge controller prevents the batteries from overcharging. Batteries used in this model are Deep-cycle lead-acid.

B. Batteries

Batteries are a requirement in hybrid power systems as they supply power during the night time when sunlight irradiation is not present or simply when the system cannot meet the demand. Selection of battery type and size depends on two factors which are load and availability requirements. Before the latter factors can be considered there is one critical one which is the area of placement. Batteries should operate without extreme temperatures, this means the area of placement should be well away from direct sunlight and ventilation should be present [11] Failure to observe this has reduced the life of some battery banks in previous projects. There are various types of batteries present in the market such as lead-acid, nickel hydride, nickel cadmium and lithium. A type is chosen depending on where it is going to be utilized. For instance car batteries which are lead-acid batteries are not designed to endure regular and repeated deep discharges which occur most frequently in battery banks designed for household loads. Renewable energy resources such as the one's wind and solar are intermittent in nature which means they fluctuate according to weather conditions which result in an unreliable power output. Batteries are a solution to this predicament as they supply a steady output.

C. Grid-Tie Inverter

A grid-tie inverter is a power inverter that converts direct current into alternating current suitable for injection into the national electricity grid. This is usually done at 120V RMS at 60Hz or 240V RMS at 50Hz. For successful integration with the grid, a grid tie inverter must satisfy the following conditions initially:

- The magnitude of the voltage output must equal of the grid
- The phase of the inverter output must be in synchronization with that of the grid
- The frequency of the inverter output must be equal with that of the grid.
- The phase sequence must also be in synchronization with the grid[10]

After the requirements above have been followed, the flow of real power and reactive power must be maintained. Real power is the portion of power that results when averaged over a complete cycle of alternating current waveform that produces a net transfer of energy in one direction. The Reactive power is the portion that is due to stored energy which returns to the source after every cycle.

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In order to improve solar PV efficiency, there are various algorithms available that have been implemented. Such are the Perturb and Observe mechanism and the incremental conductance algorithm. Perturb and Observe mechanism aims to extract the maximum power that is available regardless of available temperature and irradiance. Research has shown that when load is directly connected to the system this decreases efficiency. It is based on the maximum transfer theorem which states that to obtain maximum external power from a source with a finite internal resistance, the resistance of the load must equal the resistance of the source as viewed from its output terminals. Initially the voltage and current are measured, their product which is power is sent to a decision node to determine whether the input power is greater than or equal to the measured power during last iteration. If this condition is true, the same process of comparing the input voltage with last input voltage is done. On a Yes result, a decision is taken to increase voltage and vice versa for a No result.

The Perturb and observe algorithm is one mostly used to obtain the maximum power point; it has its shortfalls which other algorithms capitalize on. Such disadvantages of the P&O algorithm are that it may not be able to track the peak power under fast varying atmospheric conditions. This is due to the fact that it operates in a way of a control system which has to produce feedback for the next inputs to be implemented. If it cannot cope with the rapidly changing conditions the maximum power point may not be discovered every cycle. The perturb and observe mechanism is shown in Fig.1.

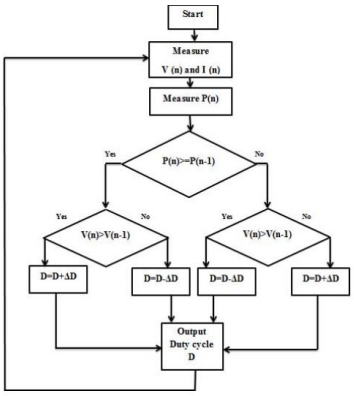

Fig.1. Perturb and Observe Algorithm

III. Simulation Of The Proposed System

The Fig.2 shows the complete photo voltaic system. Fig.3 and Fig.4 explains the simulation diagram for load switch controller and completer battery charge controller and battery banking system. The MATLAB code above has two functions which work to break and open when called upon by the IF conditions. If the state of charge of a battery is 80% or greater, the battery may start supplying the load. Internally this entails breakage of the links of the PV source to avoid overcharging. When the state of charge of the battery reaches 40%, the PV Array breaker links are closed triggering opening of the load breaker links and beginning of charging.

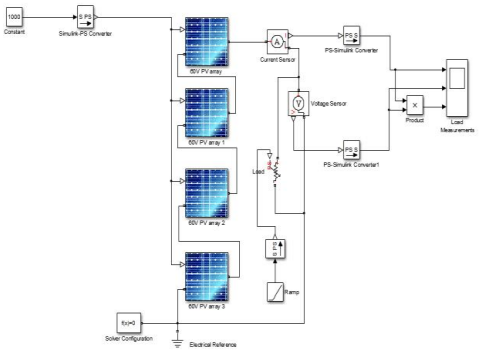

Fig.2. Complete Photo Voltaic System

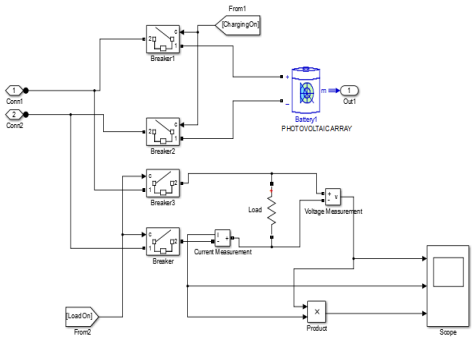

Fig.3 Load Switch Controller

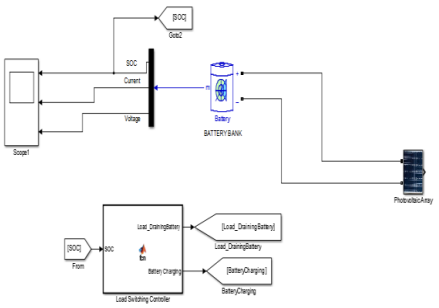

Fig.4.Complete Battery Charge Controller and Battery Bank System

IV. Simulation Results

The Fig.5 shows the current output waveform and the Fig. 6 shows the voltage output waveform. The Fig.7 shows the

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power output. The battery bank performance results are shown in Fig.8, Fig.9 and Fig.10.

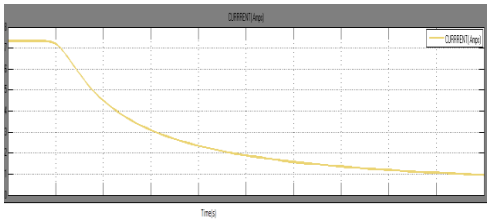

Fig.5. Current decreases from 7Amps with time as the load is connected to the hybrid system

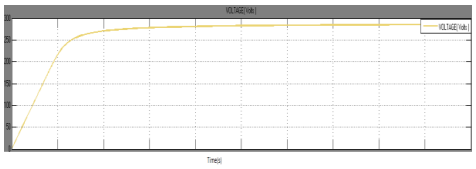

Fig.6. Voltage rises from 0v to a steady state value of 270v

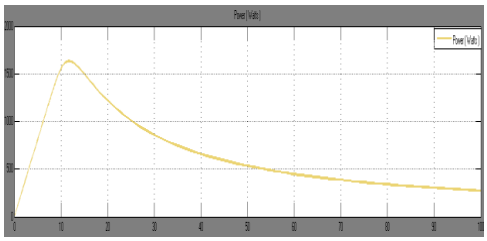

Fig.7. Power Output

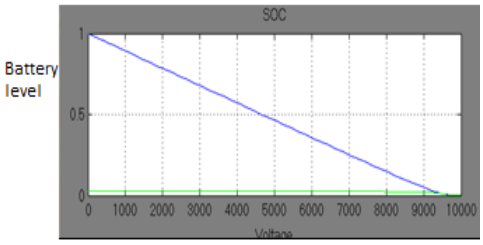

Fig.8. Battery Bank Current

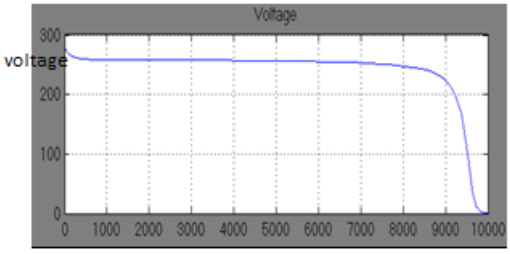

Fig.9. Battery Bank Voltage

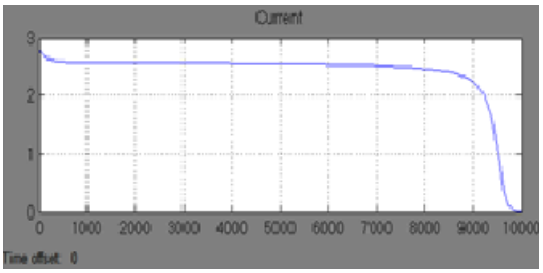

Fig.10. Power supplied to loads by battery bank

IV. Conclusion

Hybrid power systems are the way to go in this time and age in order to fully harness our natural resources and reduce the earth's carbon footprint. If every household was to have such as system installed, the energy crisis would be solved.

References

[1] Fesl, Raif Bayir, Mahmut OZER,"Design and Implementation of a Domestic Solar-Wind HybridEnergySystem", 2010pp29-33.

[2] T. Guna Sekar and R. Anita, "Design and Implementation of Solar PV for Power Quality Enhancement in Three-Phase Four-Wire Distribution System", Journal of Electrical Engineering and Technology, vol. 10, no. 1, pp. 75-82, 2015.

[3] A Review on Hybrid solar/wind/ hydro power generation system", International Journal of Current Engineering and Technology, 2011.

[4] R. stories, "Eskom wants your excess solar power | IOL", Iol.co.za, 2017. [Online]. Available: http://www.iol.co.za/business-report/economy/eskom-wants-your-excess-solar-power-1801501. [Accessed: 30- Jan- 2017].

[5] "A Review on Hybrid solar/wind/ hydro power generation system", International Journal of Current Engineering and Technology, 2011.

[6] Solar PV-Wind Hybrid Power Generation System, 1st ed. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 2017, pp. 1-5.

[7] D. Gopi Krishna, Preventive Maintenance of Wind Turbines Using Remote Instrument Monitoring System, 1st ed. kansas: IEEE, 2017, pp. 1-4

[8] Arjun A. K., Athul S., Mohamed Ayub, Neethu Ramesh, and Anith Krishnan," Micro-Hybrid Power Systems – A Feasibility Study", Journal of Clean Energy Technologies, Vol. 1, No. 1, January 2013,pp27-32.

[9] J.B.V.Subrahmanyam, P.K.Sahoo and Madhukarreddy," Local PV-Wind hybrid systems development for supplying electricity to industry"Acta Electrotechnica,Vol.53,No.1,2012,pp10-15

[10] N.Sivaramakrishna & Ch.Kasi Ramakrishna Reddy," Hybrid Power Generation through combined solar –Wind power and modified solar panel" International Journal of Engineering Trends and Technology (IJETT) - Volume4Issue5- May 2013,pp1414-1417

[11] H. Dagdougui et al. " A dynamic optimization model for smart micro-grid: integration of a mix of renewable resources for a green building'' International Environmental Modelling and Software Society (iEMSs)- February 2010,pp20-22

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Energy Calculation for the Design and Implementation of a Solar System

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Abstract—The project focused on one of the factors that affect the world at large which is the energy crisis. It is very clear that Grid power can no longer sustain the world on its own as fossil fuels are disbursed at a very high rate. This project focuses more on the solar energy as a way of supplementing the already existing grid power. Energy from the sunlight is harnessed using photovoltaic cells/ panels which work with charge controllers to charge the battery storage and an inverter to invert dc current to AC current that will be supplied to the various loads. Energy calculations will be done to correctly estimate the amount of power that will be needed to power up a certain location or area. Calculating cable sizes for the system will be done using software called power plus which is very convenient and easy to use. Generally other calculations can be done online or manually. Design and implementation of the project will be done in real time with a smaller model to show the working capabilities of any given system. The system will include PV array which harvest energy from the sunlight, then the charge controller, which regulates charging of the battery bank/storage. This will be followed by an inverter which then inverts the DC current to AC current to be used in the load.

Keywords— Photo Voltaic Cell, AC Current, Battery, DC Current.

I. Introduction

Its history is from the 7th century to date. We started using it to make fire were the sun's heat was concentrated through glass or mirror [5]. Nowadays we have solar powered buildings, vehicles; basically anything that needs electricity can be powered by solar. Solar energy is radiant heat and light from the sun that is harnessed using the proper techniques and the ever changing technologies such as photovoltaic, solar heating, solar thermal energy etc. Similarly, solar energy is the energy from the sun which without it all life on earth will end, solar energy is also a major source of energy because of its large amounts of energy freely available for use if harvested by the modern techniques [4]. Solar energy is a very important renewable source of energy and can be characterized in two technologies, which are active and passive solar, photovoltaic cells depending on how the they convert or distribute solar energy into solar power.

A. Passive Solar

Passive solar system was use by early people, who built their houses using clay or stones which will absorb the sun's heat during the day so as to keep it warm during the night. Modern day technology has seen constructors constructing buildings using large double or triple paned windows that get direct sunlight to capture and magnify the sun's warmth. Other methods of passive solar energy capture are using stone flooring and using thick insulated walls to keep the energy in buildings.

B. Active Solar

Active solar energy systems use the same principles as those of passive solar energy except that in active solar energy a fluid like water is used to absorb the heat. A solar collector placed on the roofs of buildings heats the fluid and then pumps it through a system of pipes to heat the whole building.

C. Photovoltaic Cells

Photovoltaic cells, commonly known as solar panels are more involved than passive or active solar energy systems, as they convert sunlight to electricity using thin sheets of silicon. People in remote areas such as mountain tops and islands, cattle post, camp sites etc. often use photovoltaic cells to generate electricity for their homes and businesses.

II. Proposed System

The Botswana International University of Science and Technology (BIUST) is a great science and technology school to do one's studies. The major area of concern is how the university is lacking behind in the use of alternative energy sources such as solar, wind mills etc. Efforts have been seen in our water heating system as it is solar powered and energy efficient also saving money yearly.

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The use of fossil fuels and coal used by major industries to produce power has led to increased greenhouse gases in the atmosphere which cause negative climate change and problems to the environment. Also the prices of resources are rising yearly which calls for change. Therefore, more ways to reduce these problems have to be implemented to turn BIUST main hostels into a green energy zone.

The design and implementation of a solar system in BIUST main hostels will be a major technological growth to the institution and will benefit it in many ways. Using the sun as the ultimate energy source is the best solution as we will have less gas emissions, reducing global warming due to greenhouse gasses, as long as the right technology is used to harness the power. In this case a photovoltaic system ("a system that converts energy from sunlight directly into electricity") will be implemented, and has proved to be feasible as the cost of solar implementation is declining [2]. Solar provides clean energy, also helps in annual savings on electricity bills and the structure of the school allows to build a solar plant as there is ample space [1-3].

III. Proposed System Design

A. *Photo Voltaic Module/ Solar Panel*

Photovoltaic is the conversion of light into electricity at the atomic level. Some materials show a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are caught, electric current results that can be used as electricity. Traditional solar cells are made from silicon, are commonly flat-plate, and mostly are the most efficient. Second-generation solar cells are called thin-film solar cells because they are made from amorphous silicon or non-silicon materials such as cadmium telluride [5]. Thin film solar cells use layers of semiconductor materials that are a few micro meters thick. Because thin film solar cells are flexible, they can double as rooftop shingles and tiles, building facades, or the glazing for skylights. Third-generation solar cells are being constructed from a variety of new materials excluding silicon, these materials include solar inks, using conventional printing press technologies, solar dyes, and conductive plastics. Some new solar cells use plastic lenses or mirrors to concentrate sunlight onto a tiny piece of high efficiency PV material. The PV material is costlier, but because so little is required, these systems are becoming cost effective for use by utilities and industry [6]. Nevertheless, because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the brightest parts of the country (sunniest parts).

B. *Photo Voltaic Module Performance*

The performance of PV modules and arrays are usually rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are well-defined by a module (cell) operating temperature of 25 oC, and incident solar radiant level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always characteristic of how PV modules and arrays work in the field, actual performance is usually 85 to 90 percent of the STC rating[3] [6]. Photovoltaic modules today are very safe and reliable products, with minimal failure rates and service lifetime of 20 to 30 years.

C. *Battery*

An electric battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices such as flashlights, smartphones, and electric cars. Many types and classifications of batteries are manufactured today, each with specific design and performance characteristics suited for particular applications. Each battery type or design has its individual strengths and weaknesses [7]. In PV systems, lead-acid batteries are most common due to their wide availability in many sizes, low cost and well understood performance characteristics. In a few critical, low temperature applications nickel-cadmium cells are used, but their high initial cost limits their use in most PV systems [8]. There is no "perfect battery" and it is the task of the PV system designer to decide which battery type is most appropriate for each application. In general, electrical storage batteries can be divided into two major categories, primary and secondary batteries. Primary batteries can store and deliver electrical energy, but cannot be recharged. Typical carbon-zinc and lithium batteries commonly used in consumer electronic devices are primary batteries. Primary batteries are not used in PV systems because they cannot be recharged. A secondary battery can store and deliver electrical energy, and can also be recharged by passing a current through it in an opposite direction to the discharge current. Common lead-acid batteries used in automobiles and PV systems are secondary batteries. Table 1 lists common secondary battery types and their characteristics which are of importance to PV system designers.

D. *Charge Controllers*

Charge controllers are included in most photovoltaic systems to protect the batteries from overcharge or excessive discharge. Overcharging can boil the electrolyte from the battery and cause failure. Allowing the battery to be discharged too much will cause premature battery failure and

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possible damage to the load. The controller is a critical component in the PV system. A controller's function is to control the system depending on the battery state-of-charge (SOC). When the battery nears full SOC the controller redirects or switches off all or part of the array current. When the battery is discharged below a pre-set level, some or the entire load is disconnected if the controller includes the low voltage disconnect (LVD) capability. Most controllers use a measurement of battery voltage to estimate the state-of-charge. Measuring battery temperature improves the SOC estimate and many controllers have a temperature probe for this purpose.

E. Inverters

Inverters which are also known as Power conditioning units are necessary in any stand-alone PV system with ac loads. The choice of inverter will be a factor in setting the dc operating voltage of your system. When specifying an inverter, it is necessary to consider requirements of both the dc input and the ac output. All requirements that the ac load will place on the inverter should be considered, not only how much power but what variation in voltage, frequency, and waveform can be tolerated. On the input side, the dc voltage, surge capacity, and acceptable voltage variation must be specified. Selecting the best inverter for an application requires a study of many parameters. The choice of inverter will affect the performance and reliability of a PV system.

IV. Energy Calculations

When sizing a photovoltaic system for a stand-alone photovoltaic power system, five steps are involved for a process which will permit the photovoltaic system designer or user to correctly size a system based on users expected needs, goals and budget. These steps are;

1. Estimating the electric load.
2. Sizing of an inverter
3. Sizing of batteries
4. Sizing an array
5. Sizing a charge controller

The Table.1 shows the energy calculation. The total number of lights was collect and their power ratings. Then the total wattage was found by multiplying the total number of light with the wattage of the light. This was done separately for light that had the same wattage. Then the operating hours for different rooms was estimated. The average daily load was computed by multiplying the total wattage by the hours of use.

Table 1. Energy Calculation

	No. of rooms lights	Balcony lights	Bathrooms lights	Inner lighting	Laundry rooms lights	Outside lighting
Total lights	528	48	144	248	12	76
Fluorescent	129* (18W) 135* (36W)	0	144*(36W)	64* (36W)	12*(36W)	0
Normal (12W)	0	48* (12W)	0	184* (12W)	0	76* (12W)
Total wattage (W)	7182	576	5184	4512	432	912
Hours of use (hrs)	8	6	6	8	8	8
Total watthours (Wh)	57456	3456	31104	36096	3456	7296

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Total Watts = 18798 W
Total Watt Hours= 138864Wh

A. *Size of PV Module*

(Ppv)= energy consumption / (efficiency* sun hours)
Size of PV Module = 138864/6
=23144W
Using a 300 W solar world panel we get
No. of panels=23144W/300W
=77.15
=78 (300W) panels

B. *Battery Sizing*

3000Ah 2V batteries will be used for the project, as there will be days without enough sunlight, usually during cloudy days, our days of autonomy (days of useable storage) will be 3 days. The depth of discharge will be 40% and an efficiency of 80%. Size of battery (Ah) = (power consumption * days of autonomy)/ (efficiency* depth of discharge* battery voltage)
= (138864*3)/(0.8*0.4*2)
=650925 Ah
Since we are using a 3000Ah 2V battery; to find the total number of batteries we will use;
= 650925Ah/3000Ah
=216.97 batteries
= 217 batteries

C. *Inverter Calculations*

If the total Wattage of the system is 18798 W, the inverter should be 30% bigger than the system size. This implies that for this case the inverter should be at least 24437.4 W. we further divide the power by efficiency to get our rating in VA which is the standard rating for Victron Energy inverters and other inverters at large.[2] The new rating for the inverter should at least be;
24437.4/0.8 = 30546.75 VA
Since 10000VA inverters will be used then;
30546.75VA / 10000V =4 (10000VA inverters)

D. *Charge Controller Sizing*

Solar charge controller rating = (short circuit current of panel* number of panels) * 1.3
(9.83A*78) *1.3 =996.76A
i.e. 10* MPPT 150/100-MC4
(100A controllers)

V. Conclusion

The main aim of the project was to calculate the amount of power that the BIUST main hostels will need to be totally off grid, and as such the main aim was reached as the energy calculations were done. The total power consumption was calculated and found to be 136884Wh and the project required 78 300W panels, 217 2V/3000Ah batteries, 4 10000VA inverters and 10 100A charge controllers.

References

[1] Fesl, Raif Bayir, Mahmut OZER,"Design and Implementation of a Domestic Solar-Wind HybridEnergySystem", 2010pp29-33.

[2] T. Guna Sekar and R. Anita, "Design and Implementation of Solar PV for Power Quality Enhancement in Three-Phase Four-Wire Distribution System", Journal of Electrical Engineering and Technology, vol. 10, no. 1, pp. 75-82, 2015.

[3] A Review on Hybrid solar/wind/ hydro power generation system", International Journal of Current Engineering and Technology, 2011.

[4] R. stories, "Eskom wants your excess solar power | IOL", Iol.co.za, 2017. [Online]. Available: http://www.iol.co.za/business-report/economy/eskom-wants-your-excess-solar-power-1801501. [Accessed: 30- Jan- 2017].

[5] "A Review on Hybrid solar/wind/ hydro power generation system", International Journal of Current Engineering and Technology, 2011.

[6] Solar PV-Wind Hybrid Power Generation System, 1st ed. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 2017, pp. 1-5.

[7] D. Gopi Krishna, Preventive Maintenance of Wind Turbines Using Remote Instrument Monitoring System, 1st ed. kansas: IEEE, 2017, pp. 1-4

[8] Arjun A. K., Athul S., Mohamed Ayub, Neethu Ramesh, and Anith Krishnan," Micro-Hybrid Power Systems – A Feasibility Study", Journal of Clean Energy Technologies, Vol. 1, No. 1, January 2013,pp27-32.

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Investigation of flow inside sharp bend elbows using Numerical Fluid Mechanics.

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Bent pipes and ducts are used extensively in the industrial complexes mainly due to space constraints. However, bends in pipes and ducts cause pressure losses and generate flow separation inside in the pipes and ducts reducing the efficiency of fluid transport. Numerical investigations of turbulent air flows inside sharp bend elbows with different angles of bend were conducted using ANSYS FLUENT the commercially available CFD software. Computational fluid dynamics simulations were performed using FLUENT software with 2D, steady, turbulent and incompressible flow conditions assumed. Standard k-ε turbulence model was used to calculate turbulence quantities. The predictions of mean velocity profiles of the air flow inside the sharp 90° elbow duct were compared against the experimental results obtained using laser Doppler Anemometry (LDA) and other available computational studies. Reasonable agreement was obtained. The present computational study was extended to flows inside the bend elbow with bend angle ranging from 0 deg to 150 deg, from the point of view of calculating pressure loss due to the bend and to capture secondary flow characteristics in the elbow region.

Keywords : Bent ducts , CFD , FLUENT , turbulence model

INTRODUCTION

Bends are an important part of any pipeline network system as they provide flexibility in routing or carrying of the fluid through various systems. These pipe bends are used in industries mainly in, among other things, ventilation pipes, heat exchangers and turbine machineries, and even in car engines and many other engineering fields and applications such as, High Temperature Gas Cooled Reactor (HTGR), Pressurized Water Reactor (PWR), CANDU type reactor, torus reactor, oil and gas production field with their distribution networks, heat exchangers, internal combustion engines, solar collectors, the cooling system of processing industries, electronic components and nuclear power plants. Some of these duct systems and multi duct conveying systems consist of not only 90 degree bends (often curved and sharp) but also other angles due to limitations of space. Although pipe bends are unavoidable, they are a source of complex secondary flows, as a result of recirculation zones, losses of energy and pressure, and also variable heat transfer rates which may affect overall performance or present other design constraints. In other instances presence of geometries producing high total pressure losses or heat transfer maybe intentional, but there is need for them to be accompanied by detailed understanding and/or predictive techniques.

One of the main characteristics of fluid flow through pipe bends are the presence of adverse pressure gradient developed by the centrifugal force acting on the flow. Due to the presence of centrifugal force and pressure gradient, the fluid moves towards the outer side of the bend and comes back towards the inner side. For a tough bend curvature, this adverse pressure gradient near the inner wall may start the flow separation developing a secondary flow allowing a large increase in pressure loss. This increase of pressure loss experienced in the pipe bends are generated by friction and momentum exchanges appearing from the change of flow direction. Reynolds number, bend curvature ratio and bend angle are the important factors. Therefore investigations of flows through these pipe bends are of great significance in understanding and improvement of their performance and minimization of the losses in pressure and energy especially. Even more interesting is that curved elbows cause less energy loss than sharp elbows but their production is more costly than sharp elbow bends.

Energy loss in sharp elbows is caused by formation of separation zones, which appears just after the corner and stability of separation, is questionable, and therefore numerical prediction of flow in sharp elbow becomes difficult. Hence the need which will be undertaken in the present study, to study other possible ways that can help address the problems of high energy loss, reduce flow separation and secondary flow effects on fluid flow through sharp bends by investigating the effects of redirecting fluids sharply using various angles of 30 degree multiples starting with the 30 degree angle to the 120 degree angle bend.

Flow pattern in 90 degree pipe bends with different curvature ratio and different Reynold's number has been studied by P. Dutta and M. Nandi [1]. It was reported that the normalized mean velocity profile has a low dependency on Reynold's number for low curvature ratio and for high curvature ratio it tends to recover its fully developed shape while Reynold's number is increasing. It was also discovered that swirl intensity has a weak dependence on Reynolds number and high dependence on curvature ratio as also witnessed by Kim et al., [2]. Flow separation in common 90 degree bends was studied by numerical methods based on CFD by Dutta et al., [3], and it was discovered that starting point of flow separation moves upstream in the bend as Reynolds number increases, while reattachment moves downstream, this trends corresponds to the dependence of Reynolds number on total pressure loss, as also seen by Tanaka et al., [4] and is consistent with experimental results of Takamura et al, and Kimura et al.[5, 6]. 2-D analysis of Turbulent fluid flow of forced convective heat transfer in elbow duct of rectangular cross-section, with uniform wall temperature conditions and different inlet uniform velocities of fluid flow was done by Debnath et al., [7]. It was seen that there was generation of recirculation at different bend positions. The recirculation was however strongest at the upper limb of the duct. It was also realized that secondary flow of recirculation strongly influences the main stream flow as well as the heat transfer phenomena. Three dimensional single phase turbulent flow within 90° pipe bend was studied by computational fluid dynamics method using k-ε turbulent model by Dutta et al., [8]. Experimental data of Sudo et al.,[9] was successfully applied to validate the model used. Reasonable agreement was obtained. It was observed that, for increase in Reynolds number, the flow recovers its fully developed velocity profile. This observation is also consistent with experiments carried out by Kim et al, [2], and Zagarola, and Smits [10]. A reverse flow was observed due to the adverse pressure gradient at the outlet of the

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bend where the momentum is lower than that near free stream, by which the velocity near the wall reduces and the boundary layer thickens[8].

PROBLEM DEFINITION.

The main objective of the present study is to investigate the effects of multiples of 30° angle pipe bends [ranging from 0°{a straight duct} to 120°] on a turbulent single phase fluid flow. The study will mainly be focused on pressure loss caused by these types of sharp bends, the length of the separation zones and the effect of Reynolds number on the separation length. Pressure loss on a 90˚ sharp bend will be studied. A comparison of the performance of the two turbulence models K-omega and k-epsilon will also be made. However, some preliminary results are only presented in this paper.

MATHEMATICAL EQUATIONS

In this section , we present the governing equations of the fluid flow inside the bent ducts are presented. The flow is assumed to turbulent, steady, incompressible and two-dimensional. Hence the governing equations are the Reynolds Averaged Navier-Stokes equations describing the mean flow distributions inside the duct. These equations are given below :

Momentum Equation in x-direction

$$\frac{\partial}{\partial x}(\rho\overline{u}\overline{u}) + \frac{\partial}{\partial y}(\rho\overline{v}\overline{u}) - \frac{\partial \bar{P}}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\partial}{\partial x}(\rho\overline{u'u'}) \quad (1)$$

Momentum Equation in y-direction

$$\frac{\partial}{\partial x}(\rho\overline{u}\overline{v}) + \frac{\partial}{\partial y}(\rho\overline{v}\overline{v}) = -\frac{\partial \bar{P}}{\partial y} + \mu\left(\frac{\partial^2 \bar{v}}{\partial x^2} + \frac{\partial^2 \bar{v}}{\partial y^2}\right) - \frac{\partial}{\partial x_i}(\rho\overline{v'u'}) \quad (2)$$

Continuity Equation

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) = 0 \quad (3)$$

Since the flow is assumed to be turbulent the k-ε turbulence model has been used to capture turbulence quantities. The k-ε turbulence model equations are given here. For this model the transport equation for ƙ is derived from the exact equation, but the transport for Ɛ was obtained using physical reasoning and is therefore similar to the mathematically derived transport equation of ƙ, but is not exact. The turbulent kinetic energy ƙ, and its rate of dissipation Ɛ, for this model are obtained by the following equations.

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_i}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + \rho\varepsilon + S_k \quad (4)$$

$$\frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_i}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{K} + S_\varepsilon \quad (5)$$

Where Gκ represents the generation of turbulent kinetic energy the arises due to mean velocity gradients. S_ε and S_k are source terms defined by the user.

$C_{1\varepsilon}, C_{2\varepsilon}$ and C_μ are constants that have been determined experimentally and are taken to have following values;

$$C_{1\varepsilon} = 1.44\ ,\ C_{2\varepsilon} = 1.92\ ,\ C_\mu = 0.09$$

σ_k are σ_ε turbulent Prandtl numbers for the turbulent kinetic energy and its dissipation rate. These have also been derived experimentally and are defined as follows.

$$\sigma_k = 1.0\ ,\ \sigma_\varepsilon = 1.3$$

The turbulent viscosity at each point is related to the local values of turbulent kinetic energy and its dissipation rate by:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}\ ,\ G_k = -\overline{\rho u_\iota' u_\jmath'}\frac{\partial u_j}{\partial x_i} \quad \text{and S}=\sqrt{2S_{ij}S_{ij}}$$

GRID INDEPEDENCE AND VALIDATION OF OUR WORK.

At the very beginning of our study, our present model and simulation setup are first validated against the existing experimental and numerical data presented in[10,11], For that intention, same geometrical configuration of [11] is adopted, only difference being mine is a 2-D geometry while theirs is a 3-D. and the velocity profiles of present computations was compared to the velocity profile of [11]. The results in Fig. 1 show reasonably good agreement with both experimental data of [11] and numerical data of [10], thus validating our model and methodology.

Grid independence study was carried out using several grid sizes. The pressure loss is calculated at the end of each simulation. Grid sizes wer varied until the differences between two successive grid sizes was found to be less tan 0.1 % .This grid independence was achieved for 244,708 nodes in the computational domain. Pressure loss between inlet and outlet boundaries was used to arrive at the grid independent results. Hence a grid size of about 245000 nodes was used for all simulations subsequently.

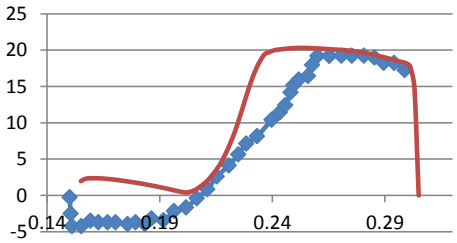

Fig.1 Comparison of velocity profile near the outlet. Symbols with blue line are Experimental data Brown line is the present computations.

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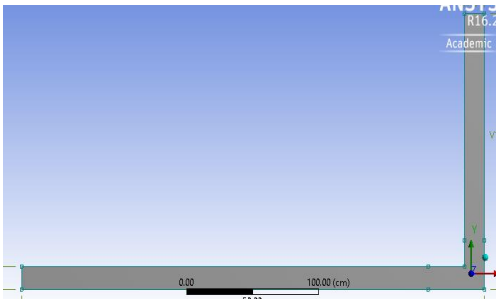

Fig 2 : The geometry with 90 deg sharp bend

Fig. 2 shows the 90° geometry that was used to validate the results and establish grid independence. After validation of the model the current study was extended to other configurations with angles 0°, 30°, 60° and 120° ducts. The duct with bend angle 0° is a straight duct.

RESULTS AND DISCUSION.

Table 1 below and the Fig 3 below show the pressure drop between the inlet and outlet boundaries of various configurations for both the K-epsilon and k-omega turbulence models.

Now on the Table 1 as in Fig 3 looking specifically at the column for percentage pressure drop between inlet and outlet, it can clearly be seen that the pressure loss increases as the bend angle increases. From the Table 1 and Fig 3 it can be seen that for the straight duct both turbulence models predict the same pressure loss. For lower angle the k-omega turbulence model predicts lower values and for higher angled ducts k-epsilon turbulence models predicts higher values of pressure loss.

Angle of the duct	**k-epsilon**			**k-omega**		
	Inlet	outlet	**% pressure drop**	inlet	Outlet	**% pressure drop**
0	101347	101325	**0.0217**	101347	101325	**0.0217**
30	101353	101325	**0.0276**	101349	101325	**0.0236**
60	101376	101325	**0.0503**	101373	101325	**0.0473**
90	101415	101325	**0.0887**	101417	101325	**0.0907**
120	101467	101325	**0.1399**	101475	101325	**0.1478**

Table 1: Pressure drop for ducts with various bend angles computed with k-ε and k-ω turbulence models

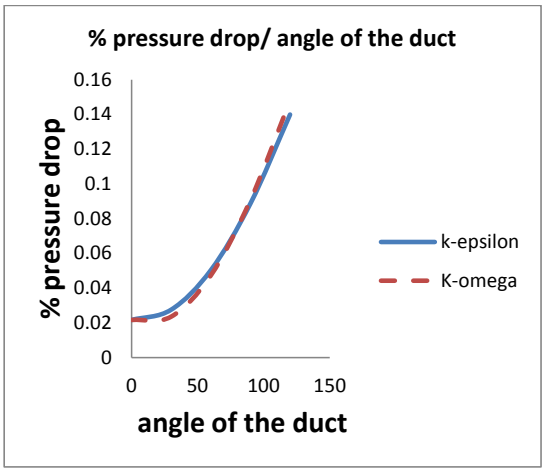

Fig 3 : Pressure loss with duct bend angles for both turbulence models.

Angle of duct	Separation length. (cm)	Separation length/diameter
0°	0	0
30°	0	0
60°	38.38	2.56
90°	71.782	4.782
120°	84.7	5.65

Table 2 : Separation length for various duct bend angles

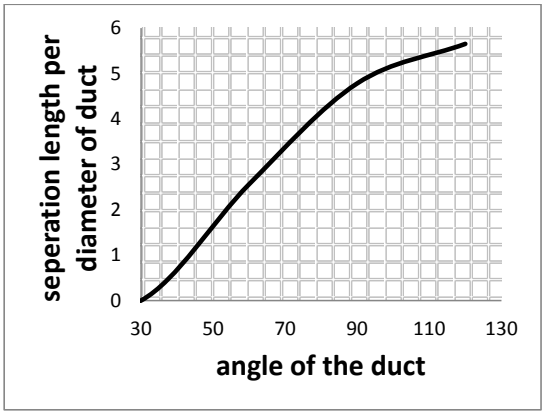

Fig 4 Variation of separation length inside the bend duct for various angles

Now from Table 2, and Fig. 4 above its clear that the separation length inside the duct increases as the duct bend angle increases. It should be noted that the separation length for the straight duct and

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30 deg duct are almost zero meaning that there was no flow separation inside both the straight duct and 30 deg bend angle duct.

Velocity [m/s]	Reynolds number [×10^4]	Percentage pressure drop	Separation length (cm)	Separation length/diameter
5	5.1344	0.02467	66.73	4.45
6.25	6.4180	0.04000	69.63	4.642
7.5	7.7016	0.05228	70.13	4.675
8.75	8.9852	0.06933	71.63	4.775
10	10.26688	0.08874	71.73	4.782

Table 3 : Effect of Reynolds number on pressure loss and separation length

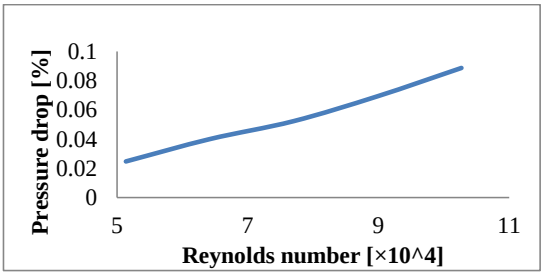

Fig 5 : Variation of Pressure drop with Reynolds number.

Fig 5 shows the variation of pressure loss with Reynolds number. It can be seen from Fig 6 and Table 3 that pressure loss increases as the Reynolds number is increased.

Fig 6 shows the variation of separation length inside the 90 deg bend duct with Reynolds number. It can be seen from Fig 6 and Table 3 that the separation length inside the 90 deg sharp bend duct increases as the Reynolds number is increased.

The present study shows that bent ducts suffer flow efficiency in fluid transport on account of pressure loss as well as the separation zones inside the duct both of which increase as the bend angle increases, thus increasing the performance deteriation of the ducts.

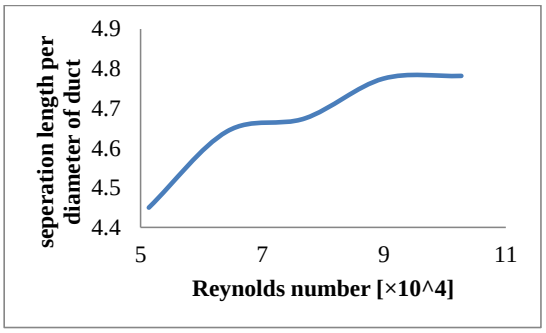

Fig 6 Variation of Separation length with Reynolds number

6. Conclusions

Turbulent flow of single phase incompressible fluid through pipe bends of 30° multiple [ranging from 30° to 120°] has been simulated numerically using k-ε Turbulence modeling in the present study. The validation of 2D models used for the present study with experiments and numerical results reported for 90 deg bend duct indicates a reasonably good agreement. The following conclusions can be made from the present study. It was found that the pressure loss increases with Reynolds number for 90 deg bend duct. Pressure loss increases as the duct bend angle increases. The separation zone size increases inside the 90 deg bend duct increases with increasing Reynolds number. Pressure loss increases with increasing duct bend angle. K-ε turbulence model and k-ω were compared and it was discovered that as far as pressure loss between inlet and outlet of the ducts is concerned, they performed relatively the same.

REFERENCES.

[1] Prasun Dutta and Nityananda Nandi; Effect of Reynolds number and curvature ratio on a single phase turbulent flow in pipes. 2015..

[2] Kim, J. Yadav M. and Kim, S. Characteristics of secondary flow induced by 90 degree elbow in turbulent pipe flow, engineering applications of computational fluid mechanics, 8(2), 229-239, 2014

[3] 3. Prasun Dutta, Sumit Kamur Saha, Nityananda Nandi, Naitri Pal; Numerical study on flow separation in 90 degree pipe bend under high Reynolds number by k-ε modelling, 2015.

[4] M. A. Tanaka, H. Ohshima, H. Monji; Numerical investigation of flow structure in pipe elbow with large eddy simulation approach, in: ASME 2009 Pressure Vessels and Piping conference, American society of Mechanical Engineers, 2009, pp. 449-458.

[5] H. Takamura, S. Ebara, H. Hashizume, K. Aizawa, H. Yamano; Flow visualization and frequency characteristics of velocity fluctuations of complex turbulent flow in a short piping under high Reynolds number condition, J. Fluids Eng. 134(10) (2012)m101201.

[6] A. Ono, N. Kimura, H. Kamide, A. Tobita, Influence of elbow curvature on flow structure at elbow outlet under high Reynolds number condition, Nucl. Eng. Des. 241 (11) (2011) 4409-4419

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

[7] R. Debnath, A. Mandal, S. Majumber, S. Bhattacharjee and D. Roy; Numerical Analysis of Turbulent Fluid Flow and Heat Transfer in a Rectabgular Elbow. 2014.

[8] Prasun Dutta, Sumit Kumar Saha, and Nityananda Nandi. Computational study of turbulent flow in pipe bends, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 11 (2015)

[9] K. Sudo, M. Sumida, and H. Hibara; Exprimental investigation on turbulent flow in a circular-sectioned 90-degree bend, Experiments in Fluids, vol. 25, no 1, pp 42 -49, 1998.

[10] M. V. Zagarola, and A. J. Smits, 'Scaling of the mean velocity profile for turbulent pipe flow', Physical review letters, vol. 78 no. 2, pp.239, 1997..

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Analysis of the Axisymmetric far wake

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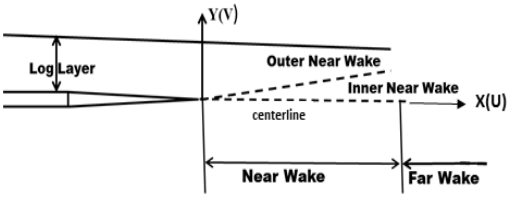

Abstract. **The axisymmetric turbulent far wake of a long slender cylinder is being studied. Classical analytical solutions describing the wake width and the velocity defect are presented. The governing equations have been solved with appropriate boundary conditions and a scaling analysis to obtain a similarity equation for the mean velocity distributions. Solutions of the velocity distributions are presented in terms of the hypergeometric function known as the Whittaker function. Validation of the analysis is done with available experimental data.**

Keywords. *Axisymmetric flow, far wake, mean velocity, half wake thickness.*

I. INTRODUCTION

The wake is the region that is produced behind an object placed in a freestream and manifest itself in the form of a velocity deficit profile. It is in this region that the flow is usually dominated by separation and reattachment or trailing edge singularities [1]. Wakes are known to have a nonlinear spread rate but are however similar to other free shear flows like jets and plumes which exhibit a self-similarity beyond a certain downstream distance such that, a characteristic length and velocity can be used to scale all distance and velocity of the flow [2].

The wake region can be divided into three regions; the near wake, outer near wake and the far wake. The near wake and the outer near wake exist in the locus immediately after the trailing edge where the flow regime is highly influenced by the initial conditions of the boundary layer at the trailing edge of the body [1, 3], whilst the far wake is the region further downstream of the trailing edge where the flow properties are generally expected to be less influenced by the trailing edge conditions. A schematic depiction of the flow regions is shown in figure 1 below.

Fig. 1. Different flow regions of the wake

The far wake is an intrinsic flow region which has found itself as a subject of interest. The literature involves both the study of the two dimensional wake and the axisymmetric case [4-11]. In the far wake, it is observed; from the mentioned studies, that there is a centerline velocity decay which is coupled by a wake extent growth. Basically, the region is characterized by slower rates of growth of wake width and a decay of the centerline velocity than in the near wake. Both these characteristics exist in the 2 dimensional and the axisymmetric case. However, in the two dimensional case, the wake width and the centerline velocity defect are known to grow linearly as $x^{\frac{1}{2}}$ and $x^{\frac{-1}{2}}$, [4-6], where as investigations of the axisymmetric case have shown that the centerline velocity defect decays as $x^{\frac{-2}{3}}$ and the wake width grows as $x^{\frac{1}{3}}$ [2,7]. Understanding the axisymmetric far wake has indeed attracted a lot of keenness; experimental studies have been conducted in order to explore behavioral and flow properties in the far wake, among them, Carmody [8], Gibson et al [9], Chevray [10] and Bevilaqua and Lykoudis [11]. In these works, similarity profiles of the flow formed within a particular downstream distance. Various self similarity distances were obtained corresponding to different geometries, which one could assume, the shape of the geometry to be the attributing factor. For instance, Chevray [10] obtained mean flow of a spheroid in the range $3 < {}^{x}/_{D} < 6$ while Carmody's results indicate similarity at ${}^{x}/_{D} = 15$ when studying the axisymmetric wake of a disc, and Gibson et al [9] reported decay of mean and variance of velocity and temperature down to ${}^{x}/_{D} = 60$, when they investigated a sphere using hot wires and pitot tubes. Bevilaqua and Lykoudi's [11] also made very significant observations when they studied the self preservation of the axisymmetric wake on a sphere and

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a porous disc with the same drag. They observed that, self preservation is a process which develops gradually with downstream distances, and first to preserve is the mean velocity profile, then the Reynolds stresses and later the turbulent moments. Bevilaqua and Lykoudi [11] further challenges the common believe of Townsend [6] that, turbulence forgets how it was created. Results from [11] indicate that the self similarity of mean velocity and Reynolds stress profiles are different and are not in the same manner. Rind [12] also studies the effects of free stream turbulence on wakes using direct numerical simulation and wind tunnel experiments.

The current study is concerned with a description of the far wake of a long slender cylinder with a sharp trailing edge, with initial conditions in terms of self-similarity solutions of the governing equations. This will thus provide a rationale and addressing questions regarding performances of similar axisymmetric bodies such as autonomous mobile axisymmetric devices in both aero and marine design and research. Engineers and designers could find optimal criteria in designing both aero and hydro driven devices from a better understanding and point of view and applying relevant knowledge such as, idyllic ways of minimization of drag, optimal body design enabling reduction of propulsive power for an efficient operation of an autonomous water vehicle etc. We present the classical results of the wake width and the centerline velocity by applying a reasonable asymptoticity on the governing equations of motion. The classical results are obtained which are also seen in the works of [2, 7, 12] when they studied an axisymmetric shape in the form of a sphere. Agrawal and Prasad [2] used the Gaussian profile as the best fit to describe velocity defect and gave an equation that describes the streamwise velocity. Rind [12] provides an analysis of equations describing the development of shear flow for incompressible axisymmetric far wake where [12] applies the momentum flux equation after a scaling analysis to obtain similarity solutions and obtains expressions for the mean centerline velocity and the wake width growth. The analysis of [12] follows the general description given by Tennekes and Lumley [13]. This study shall follow the analysis presented in [13] of which we shall further obtain a similarity solution for the mean velocity defect of the far wake.

II. ANALYSIS

In this section, we present an analysis on the equations of motion to provide solutions describing the mean velocity defect and the wake width of the far wake. The analysis is also given by [13]. The equations of motion are given by

$$\frac{1}{\mathrm{y}}\frac{\partial \mathrm{yV}}{\partial \mathrm{y}}+\frac{\partial \mathrm{U}}{\partial \mathrm{x}}=0. \tag{1}$$

$$\mathrm{yU}\frac{\partial \mathrm{U}}{\partial \mathrm{x}}+\mathrm{yV}\frac{\partial \mathrm{U}}{\partial \mathrm{y}}=\frac{1}{\rho}\frac{\partial\{\mathrm{y}\tau\}}{\partial \mathrm{y}}. \tag{2}$$

where the isotropic form of the shearing stress is given by $\tau=\rho\epsilon\frac{\partial U}{\partial y}$ and ϵ represents the eddy viscosity.

In the far wake stream, it can be assumed that the streamwise and cross stream mean velocities are small compared with the freestream velocity. Hence the minimum velocity defect which occurs at the outer layer of the wake should be zero, while the maximum velocity is measured from the centerline. It is also assumed that the pressure gradient is negligible. Hence, with these assumptions, the equation of motion to describe the flow in the far wake of a body of revolution reduces to,

$$U_\infty\frac{\partial \bar{U}}{\partial x}=\frac{1}{y\rho}\frac{\partial(y\tau)}{\partial y}. \tag{3}$$

Where $\bar{U}=(U_\infty-U)$.

Following [USA], the assumptions made are that the velocity distribution in different crossections of the wake are similar and that the wake radial width b And the velocity defect on the center line vary with x according to some power law. The assumptions can be expressed as

$$y=\eta x^n \tag{4}$$

$$b=kx^n \tag{5}$$

$$\bar{U}=U_\infty\frac{F(\eta)}{x^m}. \tag{6}$$

Where m and n are unknown constants. Applying Prandtl's mixing length hypothesis, $\epsilon=L^2\left|\frac{\partial U}{\partial y}\right|$, and the turbulent stress will be given as

$$\tau=\rho L^2\left|\frac{dU}{dy}\right|\frac{dU}{dy}. \tag{7}$$

L defines the mixing length. Using equation (6), we obtain

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$$\frac{dU}{dy} = \frac{U_\infty}{x^{m+n}} F'(\eta) \tag{8}$$

(‘) represents differentiation with respect to η. Applying Prandtl’s assumption that the mixing length is proportional to the wake width

$$L \propto b \Longrightarrow L \propto x^n. \tag{9}$$

Then from equation (),

$$\tau \propto x^{2n} \left| \frac{U_\infty F'(\eta)}{x^{m+n}} \right| \frac{U_\infty}{x^{m+n}} F'(\eta). \tag{10}$$

Or

$$\tau = C_1 x^{-2m} [F'(\eta)]^2 . \tag{11}$$

Which after substitution and simplification, we get the expression for $\frac{1}{y\rho}\frac{\partial(y\tau)}{\partial y}$ as

$$\frac{1}{y\rho}\frac{\partial(y\tau)}{\partial y} \approx x^{-(2m+n)} \left[\frac{(F'(\eta))^2}{\eta} + 2F'(\eta)F''(\eta) \right]. \tag{12}$$

Also we have

$$U_\infty \frac{\partial U}{\partial x} \approx x^{-(m+1)} [mF(\eta) + n\eta F'(\eta)]. \tag{13}$$

From the equations above

$$x^{-(m+1)} [mF(\eta) + n\eta F'(\eta)] \approx x^{-(2m+n)} \left[\frac{(F'(\eta))^2}{\eta} + 2F'(\eta)F''(\eta) \right]. \tag{14}$$

For both sides of this equation to be of the same order of x it requires that

$$x^{-(m+1)} = x^{-(2m+n)} . \tag{15}$$

Which yields

$$m + n = 1. \tag{16}$$

We obtain a second equation between and *m* and *n* by making use of the equation describing the drag coefficient. The drag coefficient is constant and it is assumed that at the far wake the velocity defect is much smaller than the free stream velocity. The drag coefficient is calculated as

$$C_D = \frac{D_r}{1/_2 \rho U_\infty A} . \tag{17}$$

D_r defines the drag and the drag in this case is calculated by the relationship between aerodynamic drag and the momentum change given by,

$$D_r = \rho \int_0^{2\pi} \int_0^{\infty} y U_\infty \bar{U} dy d\theta. \tag{18}$$

Based on the stated assumptions equation (17) simplifies to

$$D_r = 2\pi\rho U_\infty \int_0^{\infty} \bar{U} dy . \tag{19}$$

From equation (6) and (19) we get after simplification

$$\int_0^{\infty} F(\eta)\, \eta x^{2n-m} d\eta \; = C_4. \tag{20}$$

Hence

$$x^{2n-m} = 1. \tag{21}$$

Where C_4 defines a constant. Therefore

$$2n - m = 0. \tag{22}$$

Solving equations (18) and (24) gives

$$m = \frac{2}{3} \quad \text{and } n = \frac{1}{3}. \tag{23}$$

These values are the same as those found by [5]. Hence we can write the equations (4-6) as

$$y = \eta x^{\frac{1}{3}}. \tag{24}$$

$$b = k x^{\frac{1}{3}}. \tag{25}$$

$$\bar{U} = U_\infty \frac{F(\eta)}{x^{\frac{2}{3}}}. \tag{26}$$

III. SIMILARITY SOLUTION FOR MEAN VELOCITY PROFILE

In this section, we seek to find a solution that will describe the velocity profile in the far wake region after making a constant assumption on the eddy viscosity. A second order differential equation is

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obtained after applying appropriate transformations and introducing an eddy viscosity model which appropriately describes the flow at the far wake. In order to get a solution of equations (1) and (2), we seek a similarity of solution of the form

$$\bar{U} = W_0\, F(\eta), \tau = \rho W_0^2 g(\eta). \tag{27}$$

Where $\bar{U} = U_\infty - U$ and $\eta = y/b$, and W_0 and b are the local velocity and length scales, respectively. From equation (1) we get an equation of V as

$$\begin{aligned} &V \\ &= \frac{-U'_\infty\, \eta b}{2} + \frac{bW'_0}{\eta}\int F\eta d\,\eta \\ &- \frac{W_0\, b'}{\eta}\int F'\,\eta d\eta. \end{aligned} \tag{28}$$

Substituting the expression for V into equation (2) yields,

$$\begin{aligned} &-U_\infty U'_\infty + \eta F'\left\{\frac{U_\infty\, b'}{W_0} + \frac{bU'_\infty}{2W_0} - Fb'\right\} \\ &- F\left\{\frac{bU_\infty\, W'_0}{W_0^2} + \frac{bU_\infty}{W_0} - \frac{bFW'_0}{W_0}\right\} \\ &- \frac{F'}{\eta}\left\{\int \frac{W'_0}{W_0} F d\eta - \int b'F'\,\eta d\eta\right\} - \frac{(\eta g)'}{\eta} \\ &= 0. \end{aligned} \tag{29}$$

At large distances from the body, the velocity defect is small, that is, $W_0 \ll U_\infty$, and the terms of second order are also small and hence the equation (5) reduces to;

$$\eta F'\left(\frac{U_\infty\, b'}{W_0}\right) - F\left(\frac{W'_0 U_\infty\, b}{W_0^2}\right) - \frac{(\eta g)'}{\eta} = 0. \tag{30}$$

In order to determine the velocity profile F, it is necessary to invoke a turbulence closure model. Thus, for example, we introduce a constant eddy viscosity;

$$g = \frac{-\nu_\tau}{W_0\, b} F'. \tag{31}$$

Under this assumption we get a solution for (30) as

$$\begin{aligned} &F \\ &= \frac{K_1 \exp(\frac{-B_2\eta^2}{4})}{\eta} Whittaker\, M\left(\frac{B_2 + B_3}{2B_2}, 0, \frac{-B_2\eta^2}{2}\right) \\ &+ \frac{K_2 \exp(\frac{-B_2\eta^2}{4})}{\eta} Whittaker\, W\left(\frac{B_2 + B_3}{2B_2}, 0, \frac{-B_2\eta^2}{2}\right). \end{aligned} \tag{32}$$

Where K_1 and K_2 are constants.

$$B_2 = \frac{U_\infty b' b}{\nu_\tau} \tag{33}$$

$$B_3 = \frac{W'_0 U_\infty b^2}{W_0 \nu_\tau} \tag{34}$$

Following [14], The Whittaker functions are solution to the differential equation (34), defined by

$$\begin{aligned} &WhittakerM \\ &= e^{\frac{-B_2\eta^2}{4}} \eta^{\frac{1}{2}} M\left(-\frac{B_3}{2B_2}, 1, \frac{-B_2\eta^2}{2}\right). \end{aligned} \tag{35}$$

And

$$\begin{aligned} &WhittakerW \\ &= e^{\frac{-B_2\eta^2}{4}} \eta^{\frac{1}{2}} U\left(-\frac{B_3}{2B_2}, 1, \frac{-B_2\eta^2}{2}\right) \end{aligned} \tag{36}$$

M and U are related to the Kummer function and are given by

$$\begin{aligned} &M\left(\frac{-B_3}{2B_2}, 1, \frac{-B_2\eta^2}{2}\right) \\ &= \sum_{n=1}^{\infty} \left(\frac{-B_3}{2B_2}\right)_n \frac{(^{-B_2\eta^2}/_2)^n}{(n!)^2} \end{aligned} \tag{37}$$

$$\begin{aligned} &U\left(\frac{-B_3}{2B_2}, 1, \frac{-B_2\eta^2}{2}\right) \\ &= \frac{1}{\Gamma(B_2)}\left\{M\left(\frac{-B_3}{2B_2}, 1, \frac{-B_2\eta^2}{2}\right)\ln\left(\frac{B_2\eta^2}{2}\right)\right. \\ &+ \sum_{n=1}^{\infty}\left(\frac{-B_3}{2B_2}\right)_n \frac{(^{-B_2\eta^2}/_2)^n}{(n!)^2}\left[\psi\left(\frac{-B_3}{2B_2} + n\right)\right. \\ &\left.\left. + \psi(1+n)\right]\right\} \end{aligned} \tag{38}$$

Here $\psi\left(\frac{-B_3}{2B_2} + n\right)$ is the logarithmic derivative of the gamma function Γ and is given by

$$\begin{aligned} \psi\left(\frac{-B_3}{2B_2} + n\right) &= \frac{1}{(n-1) + \left(\frac{-B_3}{2B_2}\right)} \\ &+ \frac{1}{(n-2) + \left(\frac{-B_3}{2B_2}\right)} + \cdots + \frac{1}{\left(\frac{-B_3}{2B_2}\right)} \\ &+ \psi\left(\frac{-B_3}{2B_2}\right) \end{aligned} \tag{39}$$

And

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$$\left(\frac{-B_3}{2B_2}\right)_n = \left(\frac{-B_3}{2B_2}\right)\left(\frac{-B_3}{2B_2}-1\right)\ldots\left(\frac{-B_3}{2B_2}+n-1\right). \quad (40)$$

In the neighborhood of $\eta=\infty$, the functions $M\left(\frac{-B_3}{2B_2},1,\frac{-B_2\eta^2}{2}\right)$ and $U\left(\frac{-B_3}{2B_2},1,\frac{-B_2\eta^2}{2}\right)$ behave asymptomatically and for $\eta\to\infty$, their behavior are given by

$$M\left(\frac{-B_3}{2B_2},1,\frac{-B_2\eta^2}{2}\right) = \frac{1}{\Gamma\left(\frac{-B_3}{2B_2}\right)} e^{\frac{-B_2\eta^2}{2}}\left(\frac{-B_2\eta^2}{2}\right)^{\frac{-B_3}{2B_2}-1}[1+O(\eta^{-1})] \quad (41)$$

And

$$U\left(\frac{-B_3}{2B_2},1,\frac{-B_2\eta^2}{2}\right) = \left(\frac{-B_2\eta^2}{2}\right)^{\frac{B_3}{2B_2}}[1+O(\eta^{-1})]. \quad (42)$$

Hence our solution for large η becomes

$$F = \left(\frac{-B_2\eta^2}{2}\right)^{\frac{-B_3}{2B_2}} e^{\frac{-B_2\eta^2}{2}}\left\{\frac{K_1}{\sqrt{\eta}\Gamma}\left(\frac{-B_2\eta^2}{2}\right)^{-1} e^{\frac{-B_2\eta^2}{2}} + \left(\frac{-B_2\eta^2}{2}\right)^{\frac{B_3}{B_2}}\frac{K_2}{\sqrt{\eta}}\right\} + O(\eta^{-1}) \quad (43)$$

From equation (43), it is clear that the exponential term will dominate more than the other terms in the equation. Hence we can conclude that the similarity mean velocity defect decays exponentially for large values of the similarity variable η for very large streamwise distances.

IV. COMPARISON WITH EXPERIMENTAL DATA

Analytical results given by the analysis in section 2 are compared with experimental data of Jimmenez et al [15]. They conducted experimental studies on axisymmetric body with a Reynolds number ranging between 1.1×10^6 and 67×10^6. For this study, the data pertaining to the Reynolds number of 1.1×10^6 was used. In the experimental study, the pressure gradient was negligible hence the data sets are best suit for validating this work.

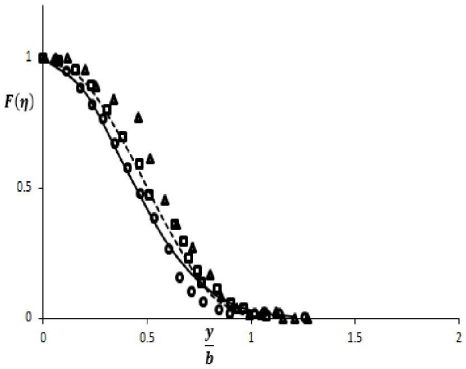

Fig. 2. Mean velocity profiles in similarity variables, ○ x/d= 15, □ x/d= 12, △ and x/d= 9, —— exponential decay, - - - - analysis.

Figure 2 shows mean velocity profiles in the far wake flow of the data set of the three stream wise distances. Also shown in the figure is the exponential curve given by equation (46). The data fits well with the similarity equation.

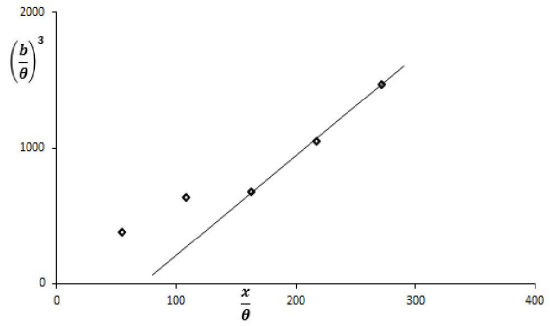

Fig. 3. Streamwise development of the wake half thickness, —— analysis.

Figure 3 shows the variation of the wake half thickness given by equation (25). In figure 3, it is seen that there is a disagreement in the data pertaining to the region of the stations in the near wake, however the data

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pertaining to the "later wake" the figure 3 shows good agreement between the data and the analytical results.

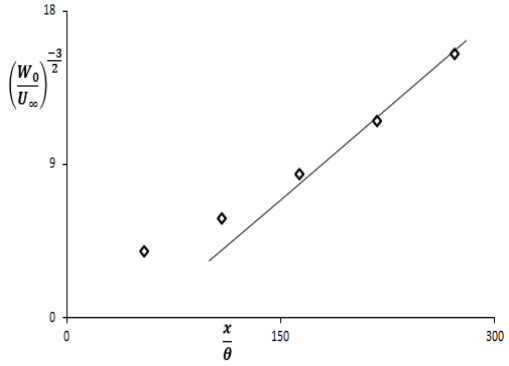

Fig. 4. Streamwise development of inverse of maximum velocity defect , —— analysis.

Figure 4 show the variation of inverse of maximum velocity defect. They show the relationship for the inverse maximum velocity deficit as given by equation (28). The experimental data shows agreement for data pertaining to the far wake region.

V. CONCLUSIONS

A theoretical analysis of the governing equations in the axisymmetric far wake of a long slender cylinder has been carried out and compared with experimental data. The results obtained show the self-similarity of the axisymmetric far wake. The half wake thickness and inverse maximum velocity defect agree very well with the data of Jimmenez et al [15]. Also shown is good agreement of the experimental data with the similarity solution to the mean velocity which is shown to decay exponentially. All in all, the results of self-similarity analysis agree well with the available experimental data of the far wake.

REFRENCES

[1] A. Prabhu and V. C Patel, Analysis of turbulent wakes, IIHR Report No. 253, August 1982.

[2] A. Agrawal and A.K Prasad, Intergral solution for the mean flow profiles of turbulent jets, plumes and wakes, Journal of fluids engineering, vol. 125, September 2003.

[3] N Subaschandar and A Prabhu, Turbulent near wake development behind a flat plate, Aerospace science and technology, no.2, Elsevier, 1999.

[4] N Subaschandar, Mean velocity characteristics in the far wake behind a GAW(2) airfoil, MATEC Web of confrences, MIMT, 2016, EDP Sciences.

[5] H Schilchting, Boundary layer theory, McGraw-Hill Book Co., New York, 1968

[6] A.A Townsend, Turbulent Shear flow, Oxford University Press, G.B., 195

[7] P. B. V Johansson and W. K George, The far downstream evolution of the high Reynolds number axisymmetric wake behind a disc, part 1, Sign point statistics, J. Fluid Mech, vol. 555, pp. 363-385 (2006).

[8] T. Carmody, Establishment of the wake behind a disk, Journal of Basic Engineering, 86, pp. 869-882, (1964).

[9] C.H Gibson, C. C Chen and S. C Lin, Measurements of turbulence velocity and temperature fluctuations in the wake of a sphere, AIAA, 6(4), pp. 642-649, (1968).

[10] R. Chevray, The turbulent wake of a body of revolution, J. of Basic Engineering, pp. 275-284, (1968).

[11] P. M Bevilaqua and P. S. Lykoudis, Turbulence memory in self -preserving wakes, Journal of Fluid Mechanics, 89(3), pp. 589-606, (1978).

[12] E. Rind, Turbulent wakes in turbulent streams, PhD thesis, University of South Hampton, (2011).

[13] H. G. Heinrich and D. J. Eckstrom, Velocity distribution in the wake of bodies of revolution based on drag coefficient, Technical documentary report, ASD-TDR-62-1103, Project number 6065, Task number, 606503, (1963).

[14] M. Abromowitz, I. A Stegun., Handbook of mathematical functions, Dover Pub. Inc., New York, USA, 1972.

[15] J. M Jimenez, M. Hultmark and A. J Smits, The intermediate wake of a body of revolution at high Reynolds numbers, J. Fluid Mech. Vol. 659, pp. 516-539 (2010).

[16] C. Ostowari and R. H Page, Velocity defect of axisymmetric wakes, Experiments in fluids, 7; 284-285,1989.

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Employing the Internet of Things in Vehicle Monitoring

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***Abstract*— This paper proposes a system for remotely monitoring the behavior of a vehicle. It monitors a vehicle in terms of four parameters which are engine temperature, rotational speed of the crankshaft and as well as the frequency and amplitude due to the vibration of the vehicle engine. These parameters can be used to trace malfunctions leading to abnormalities in the parameters. Diagnostics data are sent to the vehicle owner and it's mechanic through the Cloud. The owner of the vehicle and the mechanic can visualize the data on their smart phones. A Liquid Crystal Display screen on the dashboard also shows the values of the parameters being continuously measured. An application was created for the system to allow for visualization of diagnostics data, manual scanning of the vehicle and determination of it's location. The system has stored threshold values for the parameters being monitored. If a threshold value is exceeded, the system sends a notification to the owner and the mechanic. Four Internet of Things protocols are used to send data. These are General Packet Radio Service, Wireless Fidelity, Bluetooth and Zigbee. The system architecture allows vehicles to serve as relays for each other in some situations. The relay actions are achieved by Bluetooth and Zigbee. The system was simulated in Proteus professional software and it was found to be operational. A prototype was also constructed and tested, and proved to be functional. The application could also receive notifications accordingly.**

Keywords*— *Remote Vehicle Diagnostics, General Packet Radio Service, Global Positioning System, 3G/4G, On-Board Diagnostics

I. INTRODUCTION

The Internet of Things (IoT) is a network formed by everyday objects connected to the Internet in order to enable them to communicate with the rest of the world. Through the use of communication modules, sensors, actuators and other electronic components, objects can be linked to the Internet for remote monitoring and control. The sensors gather measurement information which is sent to remote base stations by the communication modules. The communication modules also receive control instructions meant for actuators**.** Remote Vehicle Diagnostic (RVD) systems are one of the applications under IoT. They allow mechanics to monitor vehicles remotely. Different setups of RVD's have been deployed. However they come with some drawbacks. Nille et al. [3] proposed the use of a microcontroller (MCU) and an Android phone as an RVD. The MCU based diagnostics tool picks up diagnostics data and feeds it to the Android which then uploads to a server. In case of no cellular network coverage, the Android won't upload data, which limits the remote monitoring capability of the technique. Ferhatović et al. [4] created an RVD based on Global System for Mobile Communications (GSM). It consists of On-Board Diagnostics Version 2 (OBD-II) scanner, MCU and a GSM module which exchanges control instructions and diagnostics results with a remote server through Short Message Service (SMS). The system is limited only to GSM networks. Nkenyereye and Jang [5] proposed an RVD system that uses OBD-II scanner and an Android tablet. The Android tablet allows for on-board diagnostics by providing an interface and serves as 3G/4G and Hypertext Transfer Protocol (HTTP) based gateway to connect a vehicle with remote servers. The methodology will be functional only in case of 3G and 4G networks and HTTP supporting platforms. Wenjun et al. [6] designed a system that performs real time car monitoring using OBD and Global Positioning System (GPS). Results are sent to servers using GPRS which means in the absence of GPRS connections, there won't be remote monitoring. Al-Taee et al. [7] designed an RVD based on GPS and GPRS. During operation, the OBD scanner reads the vehicle faults and sends them to remote servers using GPRS. The system will also be deficit of remote monitoring capability if there is no GPRS service. Zachos and Srinivasa proposed usage of Zigbee for monitoring the military vehicles of the United States of America (USA) in [9]. The system was tested using Zigbee radios. Due to the shorter range of Zigbee, vehicles to be monitored must be closer to the base station to stay in connection. Patil and Kakatkar [10] developed a system for monitoring a car and its driver. The car is monitored using OBD while two sensors are used to check the driver for alcohol and seat belt connection. Wi-Fi is used for uploading data to a server. The system will not operate in the absence of Wi-Fi access points. Chen and Wei [11] assembled an OBD-II scanner, GPS and 3.5G module for remote diagnostics of a vehicle. The 3.5G module sends the results of OBD-II and GPS to a remote vehicle surveillance server. Since the system is dependent only on

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3.5G networks, it is not suitable for operation in areas without the coverage of 3.5G networks. Kumbar et al. [12] designed a system for accessing vehicle data including diagnostics data. The authors use GPRS to access the data. The system is only bound to GPRS, which will disable the data access system when there is no GPRS service.

PROPOSED SYSTEM

The system proposed in this paper addresses the limitations of communications. It integrates four communication standards to provide vehicles with connectivity at if not all times. These are GPRS, IEEE 802.11 (Wi-Fi), IEEE 802.15.1 (Bluetooth), and IEEE 802.15.4 (Zigbee). Bluetooth and Zigbee are meant for vehicles to serve as relays in certain situations. These would be when there is congestion in Wi-Fi networks, lack of access points for GPRS and Wi-Fi. Fig. 1 shows such a relay system of vehicles in a real community.

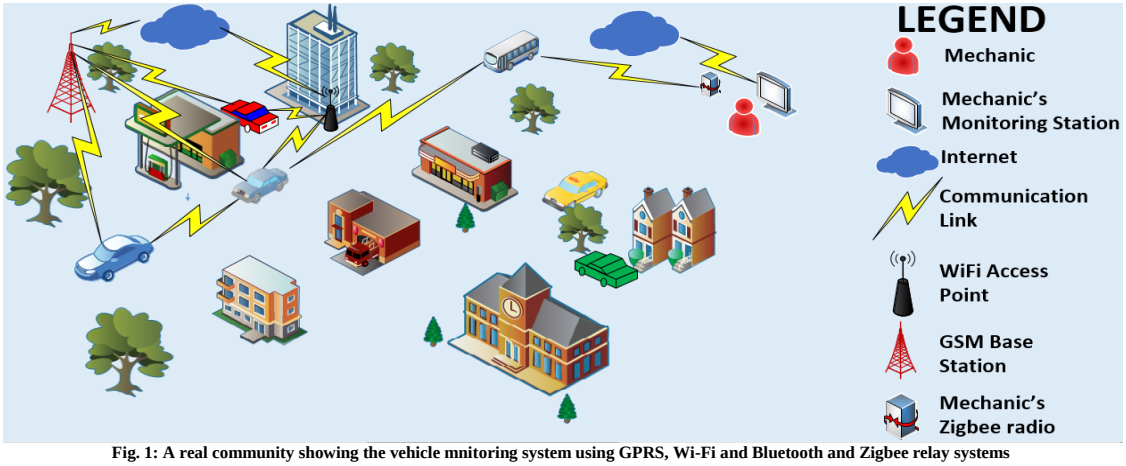

Fig. 1: A real community showing the vehicle mnitoring system using GPRS, Wi-Fi and Bluetooth and Zigbee relay systems

The system monitors a vehicle in terms of engine temperature, engine vibration amplitude and frequency and crankshaft rotational speed. Morad and Alrajhi [8] mentioned that the causes of engine overheating may be due to plugged radiators, stuck thermostats and cooling system problems. These incidents therefore drive the motivation for monitoring a vehicle engine temperature. Although assumed to be constant, variations in the rotational speed of the crankshaft can be an indication of engine misfire as stated by Bohn et al. [2]. In this system, the malfunction is detected by monitoring the crankshaft rotational speed. According to AlDhahebi et al. [1], too much vehicle vibrations lead to vehicles being uncomfortable and leaving the passengers with blurry visions. Nopiah et al. [14] stated some of the causes of engine vibration as malfunctions due to piston striking, motor control, driving wheel, suction system, cooling fan, motor surface and exhaust. The sensors used are the LM35 for temperature, piezoelectric diaphragm for vibration and hall-effect for rotational speed. These are interfaced to PIC16F877A MCU for processing. A Liquid Crystal Display (LCD) provides results to those on-board the vehicle while GPRS, Wi-Fi, Bluetooth and Zigbee modules send data to the cloud. The system proposes to use SIM900A GSM module for providing GPRS connection, ESP8266 Wi-Fi module, HC-05 Bluetooth module and Xbee Pro radio for utilization of Zigbee. Fig. 2 is the flowchart of the system while the circuit diagram is shown in Fig. 3.The values of engine temperature, rotational speed, frequency and amplitude are determined and stored. If a value exceeds the threshold, this initiates the transmission of a notification to the owner and the mechanic through the Cloud. The notification would be about the abnormal parameter. The algorithm searches for the available IoT protocols and use the first detected one for data transmission. From the cloud, data can be accessed by the vehicle owner and it's mechanic. Visualization of the vehicle performance is done on an Android based application specially designed for the system. The application is named "SmartCar" as shown in Figs. 4 and 5. Both the owner and the mechanic have the application. If the threshold values are exceeded, notifications are sent to the application via the Cloud.

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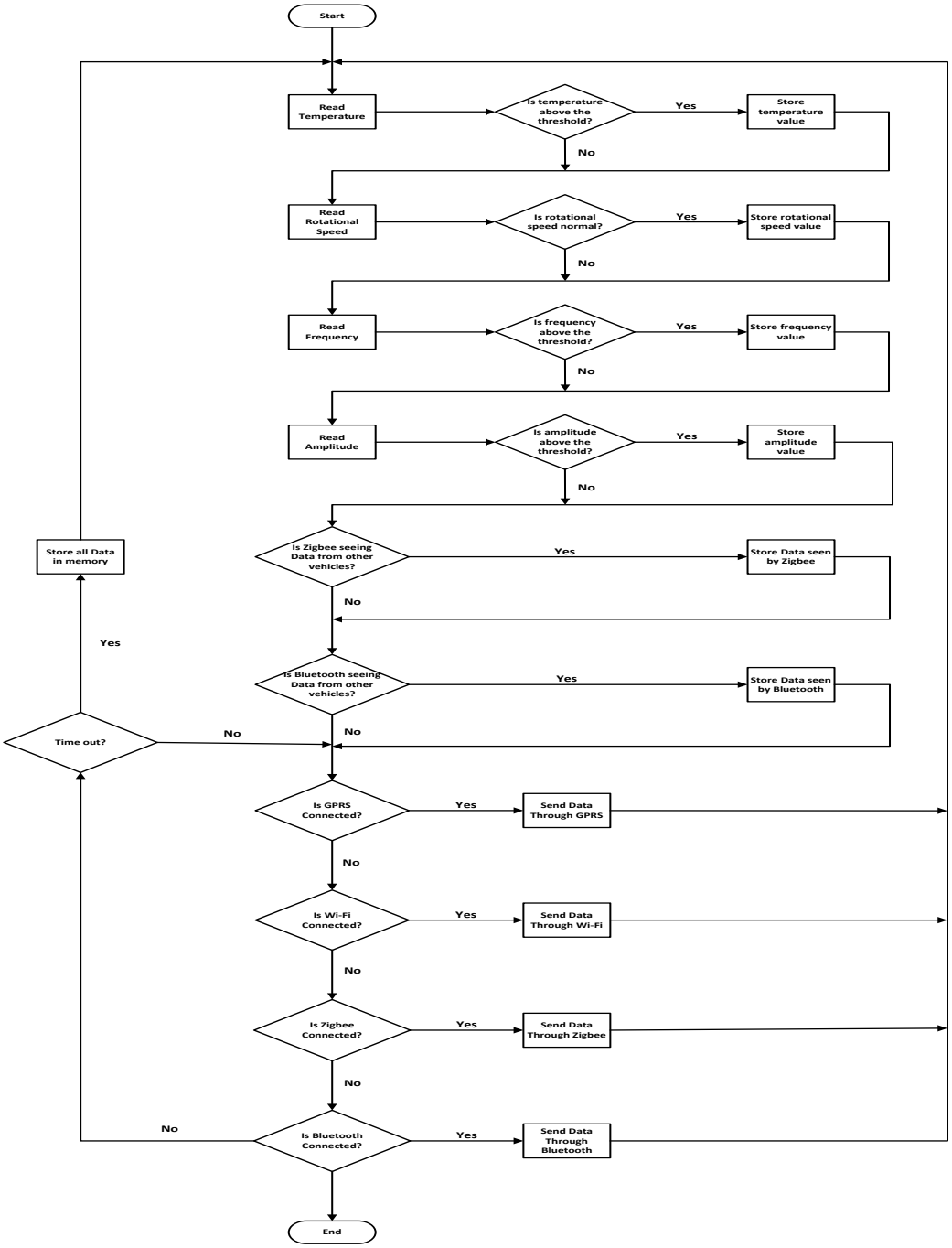

Fig. 2: Flowchart of the vehicle monitoring system

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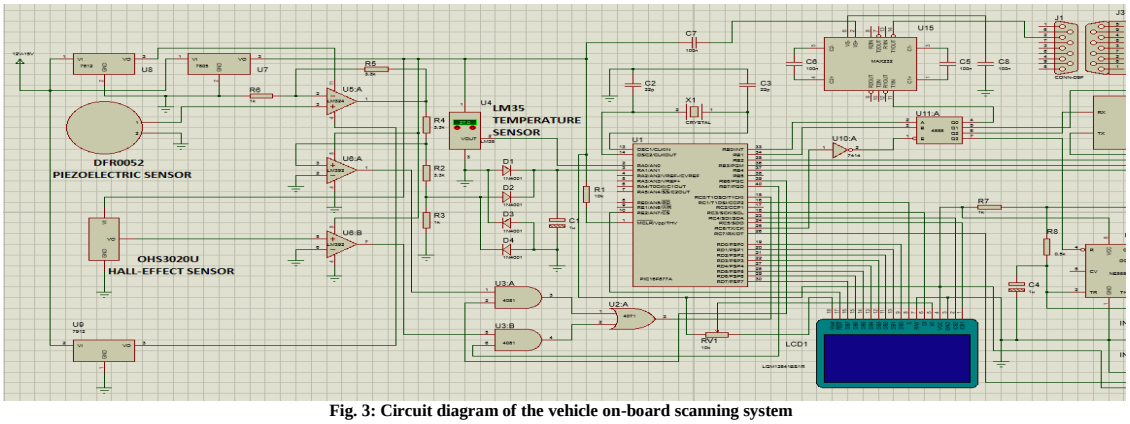

Fig. 3: Circuit diagram of the vehicle on-board scanning system

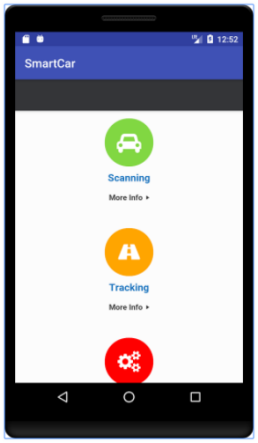

Fig. 4: SmartCar application showing the buttons

Fig. 5: SmartCar application showing manual scanning of a vehicle in progress

EXPERIMENTAL SETUP

The system was tested both in simulation and hands on ways. In simulation the software Proteus 7 Professional was used. The communication modules were replaced by virtual terminals which could display the data sent from PIC16F877A.

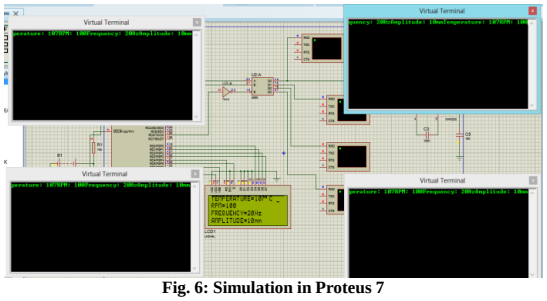

Fig. 6: Simulation in Proteus 7

In doing the hands-on work, only one sensor was available being the LM35 temperature sensor. The hall-effect and piezoelectric sensors were replaced by function generators to provide signals as if they were coming from the two sensors.

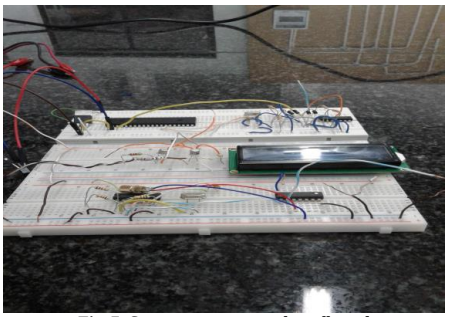

Fig. 7: System prototype on breadboard

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A source of heat was used to provide heat that would be dissipated by a vehicle engine. In building the circuit, the modules of GPRS, Wi-Fi, Bluetooth and Zigbee were not included as they were not available, but instead they were replaced by Light Emitting Diodes (LED's) which blinked as data passed through them. The application also demonstrated the ability to display notifications from the vehicle on-board hardware that picked up diagnostics data as notifications could be sent to the application through the web.

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REFERENCES

[1] A. M. AlDhahebi, J. K. Junoh and A. Ahmed, "A review on the major sources of the interior sound vibration and riding comfort in vehicles," International Conference on Mathematics, Engineering and Industrial Applications 2016 (ICoMEIA2016), pp. 1-9, 2016.

[2] C. Bohn, O. Magnor and M. Schultalbers, "State Observer based Analysis of Crankshaft Speed Measurements with Application to Misfire Detection," 2005 Conference on Control and Automation (ICCA2005)," pp. 239-244, 2005.

[3] G. Nille, D. Yadav, V. Jadhav and P. Nagargoje, "Wireless Vehicle Monitoring and Safety System," European Journal of Advances in Engineering and Technology, pp. 90-94, 2015.

[4] L. Ferhatović, A. Lipjankik and A. H. N. Nosović, "System for Remote Diagnostic of Vehicle Defects," 17th Telecommunications Forum TELFOR 2009, pp. 1323-1326, 2009.

[5] L. Nkenyereye and J. W. Jang, "Adaptive In-Car External Applications using Nomadic Smartphones and Cloudlets," International Journal of Control and Automation, vol. 8, pp. 75-80, 2015.

[6] L. Wenjun, Z. Yiming and L. Wenbin, "A Wireless and Real-Time Monitoring System Design for Car Networking Applications," International Journal of Antennas and Propagation, vol. 2013, pp. 1-5, November 2013.

[7] M. A. Al-Taee, O. B. Khader and N. A. Al-Saber, "Remote Monitoring of Vehicle Diagnostics and Location Using a Smart Box with Global Positioning System and General Packet Radio Service," IEEEXplore, pp. 1385-1388, 2007.

[8] M. M. A. Morad and J. Alrajhi, "The Effect of High Temperature on Engine Performance in Kuwait Conditions," Journal of Mechanical Engineering and Automation, vol. 4, pp. 55-62, 2014.

[9] M. P. Zachos and P. Srinivasa, "Vehicle Embedded Health Monitoring and Diagnostic System," 2009 IEEE AUTOTESTCON, pp. 1-6, 2009.

[10] R. R. Patil and M. N. Kakatkar, "A Review on Remotely Monitoring a Car to Improve its Occupant Safety," International Journal of Advanced Research in Computer and Communication Engineering, vol. 5, pp. 541-543, May 2016.

[11] S. H. Chen and Y. Wei, "A Study on Speech-Controlled Real-Time Remote Vehicle On-Board Diagnostic System," Proceedings of the International MultiConference of Engineers and Computer Scientists, vol. I, 2010.

[12] V. S. Kumbar, S. Bharwadaj, Nagalaxmi B. V and A. P. Jetly, "Cellular Remote Vehicle Data Access," 2007 3rd Institution of Engineering and Technology Conference on Automotive Electronics, pp. 1-3, 2007.

[13] Y. Zhang, M. Salman, H. S. Subramania, R. Edwards, J. Correia, G. W. Gantt Jr, M. Rychlinksi and J. Stanford, "Remote Vehicle State of Health Monitoring and Its Application to Vehicle No-Start Prediction," 2009 IEEE AUTOTESTCON, pp. 88-93, 2009.

[14] Z. M. Nopiah, A. K. Junoh and A. K. Ariffin, "K-means clustering and neural network for evaluating sound level vibration in vehicle cabin," Journal of Vibration and Control, vol. 21, pp. 1698-1720, 2013.

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Remote Sensing as a tool for drought monitoring and assessment in Botswana

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Abstract: *There is large consensus among the scientific community that the global climate is changing and that climate change will accelerate the hydrological cycle with increased frequency of occurrence of flood and drought events. Botswana is characterized by an arid to semi-arid climate with low annual rainfall amounts in most parts of the country. Climate change is expected to exacerbate the impacts already being felt from a highly variable natural climate and most of the impacts will be imposed on communities whose livelihoods largely depend on rainfed agriculture. Droughts are a common and recurrent feature especially in most arid regions of the world. In order to safeguard livelihoods and food security against the adverse impacts of droughts, drought preparedness and early warning must be prioritized in policy making. Provision of timely information that informs the decision making process under the context of droughts requires monitoring tools that are able to capture both historical and real time events and at the same time being flexible and adaptive to different conditions. Most parts of southern Africa are characterized by paucity of observed station data which makes them limited in spatial and temporal coverage in such instances, satellite imagery can therefore be used as surrogate monitoring data. For a long time satellite-based remote sensing has been used to reliably monitor environmental activities. One advantage of remote sensing is that it provides continuous data with a large spatial coverage. This study explores the use of remote-sensed data in near real time monitoring of droughts in Botswana. Satellite-based drought indices are assessed and a comparison is made relative to the standardized precipitation index (SPI) which is derived from observed station data. Positive correlations (>05) exist between SPI and the remote sensed indices indicating that satellite based indices can be used to reliably inform drought risk management.*

Keywords: drought monitoring, remote sensing, indices SPI, Botswana

Introduction

Drought is a recurrent event that occurs as a result of prolonged periods of below average precipitation. Extended periods of drought have caused immense human suffering, social and economic losses as well as threatening environmental sustainability (Sharma et al., 2009). Natural climatic variability is the major driver of droughts particularly in the dry arid and semi-arid regions of the world. Climate is expected to worsen the negative impacts of drought (Mir et al. 2012) on livelihoods with significant negative social and economic effects. Compared to floods, droughts develop slowly and can only be recognized once people and the environment start to feel their impact. Although it is difficult to avoid droughts, their impacts can be averted through an understanding of their nature and occurrence. Timely early warning systems and appropriate drought risk management strategies can only be achieved when the droughts are objectively defined and quantified (Smakhtin and Hughes, 2004). Compared to floods, droughts develop slowly and can only be recognized once their effects are evident on the people and the environment (Vicente-Serrano and Lopez-Moreno, 2005) therefore it is quite difficult to determine the onset and cessation of droughts.

Drought can be quantified from parameters such as rainfall, temperature, soil moisture and streamflow. In contrast to the use of raw data such as rainfall or temperature a number of drought indices can be derived which show the occurrence, magnitude, intensity and duration of a drought event (Zarger et al., 2011; Hayes, 2006). These climate-based indicators are, however, limited by lack of adequate spatial coverage since most of the data are obtained from station observations which are sparsely located most of the times thus compromising their reliability (Brown et al., 2002). The data sources for these indicators can be obtained from station observations or from satellite imagery. Station observed data have shortfalls of limited spatial and temporal coverages.

On the other hand remote sensing has the capability of providing data covering larger and ranging from local to regional scales as well as with finer temporal resolutions. The standardised precipitation index (SPI, Mckee et. al, 1993) depends on rainfall as the single input variable; it assesses drought conditions based on the probability of long term precipitation. To assess the severity of wet and dry spells the index considers cumulative precipitation deficits at various spatio-temporal scales and quantifies precipitation anomalies as a single numeric value (Hou et al., 2007). On the other hand a vegetation index can also be calculated from satellite spectral signatures obtained from radiation absorption in the red and near infrared bands of the electromagnetic spectrum, these indicate the vegetation condition as well the dynamics of vegetation at different stages. Green vegetation has high absorption of radiation in the red band and high reflection in the infrared region and satellite remote sensors are able to quantify the fraction of radiation that is absorbed by the

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photosynthetically active material. The normalized difference vegetation index (NDVI, Tucker, 1979) is the most commonly used form of remote sensed data (Rulinda et al., 2010). NDVI does not specifically give a reflection of the drought conditions but merely indicates vegetation health and density. Nonetheless, it can be transformed to other forms of drought monitoring indices such as the vegetation condition index (Kogan, 1997), the decile index and the aridity index anomaly. The vegetation condition index (VCI) indicates how close the NDVI for a particular period such as a month is close to the long term minimum NDVI.

Botswana (Fig 1) is a semi-arid country with very high dependence on rain-fed subsistence agriculture. Natural climatic variability together with erratic rainfall patterns have resulted in low total annual rainfall and consequently high uncertainty in water resources availability. Agricultural production is therefore susceptible to climatic variability and to the frequent occurrence of droughts. Continuous monitoring of droughts and provision of early warning systems is therefore crucial in safeguarding agricultural productivity. This study aims to use remote sensing to assess the droughts that have occurred in the past in Botswana. The standardized precipitation index (SPI) is employed to validate the remote-sensed droughts.

Fig 1: *Location of Botswana*

Materials and Methods

FEWSNet 10-daily rainfall estimates and daily potential evapotranspiration estimates as well as SPOT NDVI (pre-2014) and PROBA-V NDVI (post 2014) were used to generate the satellite-based indices for the period 2000-2016. The SADC-MESA drought monitoring software (DMS) was used to generate the indices. A comparative analysis of the indices against the standardized precipitation index (SPI) was also performed. Station rainfall data for the period 1980-2016 were obtained from the Department of Meterological Services. The 6-monthly SPI was generated using the SPI package (Berguria et al., 2014) found in the R- software package (http://www.R-project.org/). Time series data of cumulative precipitation over the period of study are compiled after which the data are fitted to a two-parameter gamma distribution. A cumulative probability density function for any given amount of precipitation is calculated from the fitted distribution and then it is transformed to a standard normal distribution with a zero mean and standard deviation of one to give the SPI value.

Results and Discussion

Selected indicators for assessing drought conditions in Botswana for the period of October 2015 to March 2016 relative to the long term conditions are presented in Fig 2. Clearly rainfall is a major driver to the availability or nonavailability of water as such the plant-based remote sensing indicators of water. The results confirm that although NDVI is a good indicator of vegetation health it is not necessarily a drought index. NDVI simply shows the vegetation health status with respect to a certain period (whether dry or wet). Therefore it is possible to show a positive condition (green) of vegetation NDVI even during drought conditions for example if there was improvement from extreme to moderate conditions. The VCI and the rainfall deciles appear to be in sync with the cumulative rainfall and can be reliable drought indices. Both indices show that below normal conditions were experienced in most parts of the country during the period of study, with extreme drought conditions in the southern parts of the country whereas areas in the north experienced relatively wet conditions. Areas of high drought potential (red) were observed more in the south for both VCI and the decile indices. More than 30% of the country was under severe to extreme drought conditions. 22% of Botswana had a VCI less than 36, indicating unusually poor conditions in some parts of Botswana while about 3% of the country had a VCI value > 64, indicating fairly good conditions. Significant correlations (Table 1) were observed between the anomalies of VCI and SPI for the period under observation. This may be attributed to the fact that precipitation is the major driver for both indices and as such vegetation health is sensitive to precipitation especially after prolonged periods of antecedent dry conditions. This observation is also supported by the high correlations obtained for the districts in the south which happen to be areas of less rainfall and therefore more prone to droughts than the northern areas. Generally in all cases the correlations are strong (R2>5) because most of the vegetation growth is rainfed while conditions in the country remain semi-arid in nature.

Table 1: Correlation VCI - SPI

District	R^2 (VCI-SPI)
Ngamiland	0.498
Central District	0.613
North East	0.574
Ghanzi	0.627
Kweneng	0.69
Kgatleng	0.715
Southern	0.648
South East	0.687
Kgalagadi	0.755

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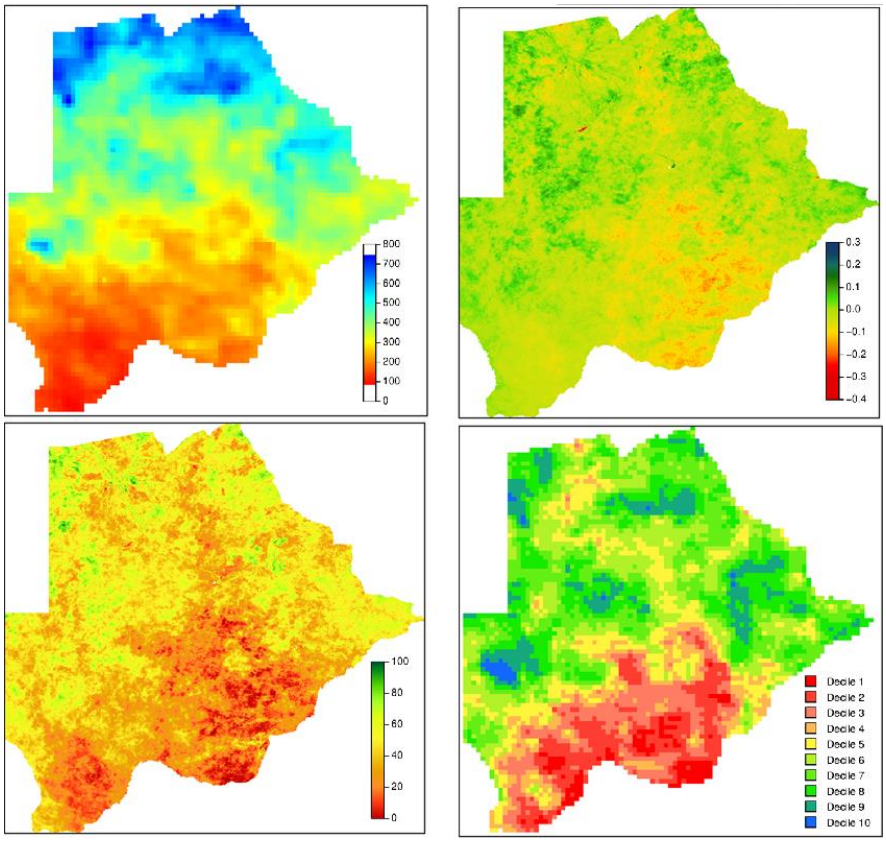

Fig 2: Figure 2: Drought indicator maps for Botswana, October 2015-March 2016. a) cumulative rainfall b) NDVI c) VCI d) rainfall decile

Conclusion

An attempt was made to assess drought conditions in Botswana using remote sensed indices as a proxy to indices derived from station data. Generally it can be concluded that the southern parts of the country are more drought prone than areas in the north. Positive correlations were obtained between the vegetation condition index and the SPI indicating that remote sensed indices can be adequately used to monitor droughts in arid and semi-arid areas. Based on the VCI a and the rainfall deciles large part of the country was under a high drought risk for the 2015-16 agricultural season. Remote sensed indices derive their strength in that they can be produced at various spatial scales ranging from local to regional and can be used for assessment in areas where there is sparse statin data. Both the indices based on station observed data and on remote sensing can be used to complement each other in order to produce more certain drought assessment results which can better inform the drought risk management process.

REFERENCES

[1] Beguería, S., Vicente-Serrano, S.M., Reig, F, Latorre, B., Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int. J. Climatol. 34, 3001-3023, 2014.

[2] Hayes M J., 2006. Comparison of Major Drought Indices. National Drought Mitigation Center. http://drought.unl.edu/Planning/Monitoring/ComparisonofIndicesIntro.aspx.

[3] Hou, Y.Y., He, Y.B., Liu, Q.H. and Tian, G.L., Research progress on drought indices. Chin. J. Ecol. 26, 892-897, 2007.

[4] McKee, T.B., Doesken, N.J., Kleist, J. The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology 1993. Proceedings of the 8th Conference on Applied Climatology. AMS, Boston, MA, 1993: 179-184.

[5] Rulinda, C. M., Bijker, W., Stein, A. Image mining for drought monitoring in eastern Africa using Meteosat SEVIRI data. Int. Journal of Applied Earth Observation and Geoinformation 2010; 12 (Supplement 1), S63-S68.

[6] Sharma, A., Dadhwal, V.K., Jeganathan, C. and Tolpekin, V., Drought monitoring using the Standardised Precipitation Index: A case study for

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the state of Karnataka, India. Geospatial Application Papers: Environment-Forest, 6pp, 2009. www. gisdevelopment.net/ application/natural_hazards/drought.

[7] Smakhtin, V.U., Hughes, D.A. Review, Automated estimation and analyses of drought indices in South Asia. Working Paper 83, Drought Series paper 1,Colombo, Sri Lanka. International Water Management Institute; 2004.

[8] Tucker, C. J. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 1979; 8(2): 127-150.

[9] Vicente-Serrano, S.M. and Lopez-Moreno J.I., 2005. Hydrological response to different time scales of climatological drought: an evaluation of the Standardized Precipitation Index in a mountainous Mediterranean basin. Hydrol. Earth Syst. Sci., 9, 523-533.

[10] Zarger A., Sadiq R., Naser B., Khan F.I.. A review of drought indices. Environ. Rev 2011; 19: 333-349.

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Species diversity and abundance of lepidopteran stem borer natural enemies in Botswana

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Abstract— Africa hosts significant lepidopteran stem-borers which are attacked by a diversity of natural enemies in their natural and cultivated environments. To determine diversity, relative abundance of stem-borer natural enemies and associated host plants, field surveys were conducted during 2014/15 and 2015/16 austral summer on natural and cultivated habitats across Botswana. In cultivated habitats, the common larval parasitoids recorded were *Cotesia flavipes*, and *C. sesamiae*, and pupal parasitoids *Pediobius furvus* and *Gambroides nimbipennis* while in natural habitats, larval parasitoids *Chelonus curvimaculatus* and *Goniozus indicus* and a pupal parasitoid, *Dentichasmias busseolae* were recorded. Furthermore, predatory ants (*Linepithema humile*, *Crematogaster peringueyi* and *Aenictus* species) were recorded in both cultivated and natural habitats. Cultivated and natural Poaceae; maize, sorghum, sweet sorghum, *Echinochloa pyramidalis*; natural Typhaceae, *Typha latifolia* and natural Cyperaceae-*Schoenoplectus corymbosus* and *Cyperus dives* formed the major plants hosting stemborers and related natural enemies. *Chilo partellus* and *Sesamia* spp. were the major parasitoid hosts with *C. partellus* predominating in cultivated habitats and *Sesamia jansei* in natural habitats. Larval parasitism ranged from 2.1-34.7% and 3.3-14.3% while pupal parasitism ranged from 6.1-10.6% and 6.7-9.1% in cultivated and natural habitats respectively. Parasitoids relative abundance ranged from 1.1-41.6% and 4.8-38.1% in cultivated and natural habitats respectively, with *C. flavipes* dominating in cultivated and *C. curvimaculatus* in natural. Overall, our results show that cultivated and natural environments in Botswana harbour parasitoid faunal diversity that may be worth conserving for future efficacy of biological control programmes, and an equally diverse flora hosting these stem-borers.

Keywords—biodiversity; biological control; Lepidoptera; parasitoids; plant-insect-interactions

I. Introduction

Lepidopteran stem borers are the main destructive insect pests of cereal crops (maize, sorghum and millet) in sub-Saharan Africa accounting for ~5-75% of potential crop yield losses [1; 2; 3; 4]. The abundance and distribution of cereal stem borers may be influenced by abiotic factors such as temperature and precipitation, and biotic factors such as natural enemies and alternative host plants [5; 6]. Understanding the diversity, spatial distribution, relative abundance and ecological contribution of stem borer natural enemies in natural and agroecosystem environments is significant in ensuring ecosystem stability and putting in place the integrated pest management approach [7]. Stem borer natural enemy species diversity and abundance can vary across different landscapes, and diversity and distribution may be under threat due to global climate change [8; 9]. Through extensive field surveys, we assessed the diversity and abundance of stem borer natural enemies and their associated hosts in both cultivated and natural landscapes in Botswana. Such information is crucial in explaining the potential roles of

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natural enemies in regulating insect pest populations, and may help in developing biological pest management systems.

2. MATERIALS AND METHODS

Field surveys on cereal crops and natural host plants were conducted in all the ten districts of Botswana during 2014/15 and 2015/16 austral summers. Natural lepidopteran stem borer host plants were sampled (i) around cereal crops, (ii) in open patches along forest roads, (iii) on banks of streams or rivers (iv) in swamps and (v) in national parks. For cultivated cereal crops, sweet sorghum, maize, millet and sorghum fields were selected every 10–15 km along minor and major roads in each respective district. Potential host plants exhibiting damage symptoms (dead hearts, scarified leaves, larval entry and exit holes and the presence of frass) were dissected in the field and borer life stages found were placed individually in 30 ml plastic vials containing artificial diet [10; 11]. Predatory insects, parasitoid cocoons or mummified larvae were placed individually in labelled plastic vials without diet, while pupae found were placed in the same plastic vials with a water-soaked cotton wool to avoid desiccation related mortality. All the vials were taken to the laboratory for subsequent incubation. In the laboratory, larvae, pupae and parasitoid cocoons were incubated at 25 ± 1^{o}C, 65 ± 10% and L12:D12 photocycle [10; 5] in climate chambers (HPP 260, Memmert GmbH + Co.KG, Germany) until moth or parasitoid adult emergence.

Host plant-parasitoid and stem borerarasitoid interaction networks were analysed in R using 'BIPARTITE' package [12]. Parasitoid species diversity in natural and cultivated habitats was computed using Simpson's diversity index [13]. Parasitism rate for larvae, pupae and relative abundance of each parasitoid were calculated as outlined by [14; 15; 16].

3. RESULTS

Parasitoid species diversity was significantly higher in cultivated (D = 0.23) than natural habitats (D = 0.14) (see Table 1). Nineteen (16 larval, 3 pupal) parasitoid species were recovered from three stem borer species in cultivated hosts while 11 parasitoid species (9 larval, 2 pupal) were recovered from 7 stem borer species in natural hosts (Table 1). Furthermore, 3 predator species were recovered from both cultivated and natural habitats (Table 1). The stem borer – parasitoid interaction network showed a moderate Shannon interaction diversity (H' = 2.56) and a low generality (G_{qw} =1.23). Similarly, the host plant–parasitoid interaction showed moderate Shannon interaction diversity (H' = 2.93) and generality (G_{qw}) of 1.81. A total of 19 different parasitoid species were recovered from *C. partellus* in both cultivated and natural habitats (Fig 1A). In addition, a total of 11 maize and 10 sweet sorghum parasitoid species were recovered from stem borer species in cultivated habitats (Fig 1B). Furthermore, 4 parasitoid species were recorded parasitising stem borers attacking *Schoenoplectus corymbosus* in natural habitats (Fig 1B).

The highest level of parasitism was recorded in cultivated habitats compared to natural habitats. Larval parasitism ranged from 2.1- 34.7% and 3.3- 14.3% in cultivated (Table 2A) and natural (Table 2B) habitats respectively. In addition, pupal parasitism ranged between 6.1- 10.6% and 6.7- 9.1% in cultivated and natural habitats respectively (Tables 2A and B). Larval and pupal parasitoids relative abundance ranged from 1.1- 41.6% in cultivated and 4.8-38.1% in natural habitats (Fig. 2A and B). Hymenopteran parasitoids were more abundant than Dipteran parasitoids in both habitats accounting for 21 and 6 respectively.

4. DISCUSSION

Prior to this study, only nine parasitoids and no predatory species had been reported attacking lepidopteran stem borers in Botswana [17; 18]. Therefore, in addition to previous records, the present study reports 24 different parasitoids and 3 predatory species both in cultivated and natural host plants in the country. Our results showed a higher parasitoid diversity in cultivated than natural habitats in keeping with studies by [14] that reported a high parasitoid diversity in cultivated habitats in the coastal region of Kenya. The moderate Shannon interaction diversity and low generality recorded in this study for both stem borer–parasitoid and host plant–parasitoid interactions indicate on average that each stem borer species was attacked by one to two parasitoid species [see 19]. This also implies that every host plant hosted stem borers that were attacked by one to two parasitoid species. *Chilo partellus* was the most commonly targeted stem borer species by parasitoids and predators in cultivated habitats whilst in natural habitats *Sesamia* species were the most commonly targeted may be due to abundance of *C. partellus* and *Sesamia* species in cultivated vs natural habitats respectively. The larval parasitoids *C. flavipes* and *C. sesamiae* and pupal *P. furvus* were the most prevalent species, in keeping with previous results from eastern Africa [14; 5]. In natural habitats, the Cyperaceous host plant, *S. corymbosus* had the highest stem borer parasitoid diversity, in keeping with results by [4]. The graminaceous crops *Z. mays* and *S. bicolor*, had the highest stem borer parasitoid diversity, may be because cultivated plants constituted an important resource with higher levels of nutrients and low allelochemical toxicity relative to natural host plants [20; 5].

In cultivated habitats larval and pupal parasitism ranged 2.1-34.7% and 6.1- 10.6% respectively, in keeping with previous reports in east Africa for both larval [21; 5] and pupal [14] parasitism. Larval and pupal parasitism levels were also higher in cultivated than natural habitats, in agreement with results by [22]. Low parasitisation levels in natural habitats may be caused by lower densities of stem borers relative to cultivated habitats [5; 23] and this may have negative consequences on parasitoid host searching efficiency as in e.g. [24]. *Cotesia flavipes* recorded the highest larval parasitism levels in cultivated habitats (Table 2A), in corroboration with [25], who reported higher larval parasitism by *C. flavipes* in cultivated relative to natural habitats.

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Larval parasitoids *C. flavipes* and *C. sesamiae* and pupal parasitoid *P. furvus* had a higher relative abundance compared to other parasitoid species in cultivated habitats. This may imply that *C. flavipes* and *C. sesamiae* may potentially share the same habitat regardless of whether they are attacking the same host or not [26]. *Chelonus curvimaculatus* was recovered in both habitats, and had a higher abundance in natural than cultivated habitats. This implies that this parasitoid can switch habitats, hence can be used in classical biological control, in addition to *C. flavipes* and *C. sesamiae*.

In conclusion, the current study documents novel diversity of stem borer natural enemy species in Botswana, and their interactions with host stem borers and host plants in both natural and agroecosystems. Therefore, Botswana landscapes host parasitoid faunal diversity that may be worth conserving for future efficacy of biological control programmes, and an equally diverse fauna and flora hosting parasitoid-host stem borer interactions.

Figures and Tables

Table 1: Details of natural enemy species recovered from stem borers on cultivated and natural host plants in Botswana, and information on associated locality, parasitoid family, stem borer host and the developmental stage from which the parasitoid was isolated.

Location	Parasitoid species	Family	Habitat	Stem borer	Host stage
Chanoga	*Pediobius furvus* Gahan	Eulophidae	C	Cp	P
Mogobane					
Modipane					
Tsootsha					
Oodi	*Euvipio rufa* Szepligeti	Braconidae	C	Cp	L
Mabele			C	Con	L
Maun	*Gambroides nimbipennis* Seyrig	Ichneumonidae	N	Tot	P
Mabele			C	Cp	P
	Goniozus indicus Ashmead	Bethylidae	C	Cp	L
Maun			N	Sj	L
Kazungula			N	Sn	L
Oodi	*Cotesia flavipes* Cameron	Braconidae	C	Cp	L
Seleka					
Bobonong					
Ramatlabama					
Mabele					
Glen valley					
Ramotswa	*Cotesia sesamiae* Cameron	Braconidae	C	Cp	L
Tlokweng					
Hatsalatladi					
Dithojane	*Chelonus curvimaculatus* Cameron	Braconidae	C	Cp	L
Moshupa			N	Cp	L
Maun			N	Sj	L
Gaborone Dam			N	Sj, Cp	L
Glen valley	*Dolichogenidea polaszeki* Walker	Braconidae	C	Cp	L
Qabo	*Stenobracon rufus* Szepligeti	Braconidae	C	Cp	P
Lobatse	*Temelucha picta* Holmgren	Ichneumonidae	C	Cp	L
Chanoga	*Chalcidoidea* sp	Encrytidae	C	Cp	L
Bookane	*Ceraphronidae* sp	Ceraphronidae	C	Cp	L
Ditladi	*Eichneumonidea* sp	Braconidae	C	Sc, Cp	L
Mabutsane	*Rhaconotus* sp	Braconidae	C	Cp	L
	Norbanus sp	Pteromalidae	C	Sc, Cp	L
Kumakwane	*Linepithema humile* Mayr	Formicidae	C	Cp	L
Ndumba					
Parakarungu			N	Es	P
Maun			N	Es	L
Nxamaseri			N	Es	L
Kasane,	*Aenictus* sp	Formicidae	C	Sc	L
Mochudi			C	Cp	P
Matlapana					
Martins Drift			N	Es	L
Hatsalatladi	*Crematogaster peringueyi* Emery	Formicidae	C	Sc	L
Ramotswa					
Maun			N	Sj	L
Kasane	*Bracon testaceorufatus* Granger	Braconidae	N	Sc	L
Kanye	*Dentichasmias busseolae* Heinrich	Ichneumonidae	N	Tot	P
Kasane	*Cremastinae* sp	Ichneumonidae	N	Sc	L
Maun	*Cercerinae* sp	Philantenidae	N	Sj	L
Nxamaseri	*Formicidae* sp	Formicidae	N	Es	L
Samedupi	*Syzeuctus* sp	Ichneumonidae	N	Tot, Sj	L
Hatsalatladi	*Descampsina sesamiae* Mesnil	Tachinidae	C	Cp	L
Qabo					
Mabutsane	*Sturmiopsis parasitica* Curran	Tachinidae	C	Cp	L
Oodi	*Sepsidae* sp	Sepsidae	C	Cp	L
Hatsalatladi	*Chloropidae* sp	Chloropidae	C	Cp	L
Gatsatsa					
Satau	*Siphona murina* Mesnil	Tachinidae	N	Sn, Sp	L
Shakawe	*Phoridae* sp	Phoridae	N	Es	L

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C, cultivated; N, natural; Cp, *Chilo partellus*; Con, *Concofrontia* sp; Sj, *Sesamia jansei*; Sn, *Sesamia nonagrioides*, Tot, *Totricidae* sp; Sc, *Sesamia calamistis*; Es, *Eldana saccharina*; Sp, *Sesamia perplexa*; L, larva; P, pupa

Table 2A: Larval and pupal parasitism in cultivated host plants in Botswana.

Host Plant Species	Host species	Parasitoid species	% Parasitism
Maize	*Chilo partellus*	*Cotesia flavipes*	34.7 (33)
		Cotesia sesamiae	18.8 (13)
		Euvipio rufa	4.3 (2)
		Sepsidae sp	2.1 (1)
		Pediobius furvus	8.5 (5)
		Descampsina sesamiae	5.9 (1)
		Chalcidoidea sp	7.7 (1)
		Telemucha picta	2.9 (1)
		Dolichogenidea polaszeki	6.3 (1)
		Stenobracon rufus	6.1 (2)
Sorghum	*Chilo partellus*	*Cotesia flavipes*	5.7 (2)
		Cotesia sesamiae	12.5 (2)
		Chloropidae sp	4.5 (2)
		Descampsina sesamiae	6.3 (1)
		Ceraphonidae sp	7.1 (1)
Sweet sorghum	*Concofrontia* sp	*Euvipio rufa*	5.9 (1)
	Sesamia calamistis	*Echneumonidea* sp	2.8 (1)
	Chilo partellus	*Cotesia flavipes*	17.6 (3)
		Cotesia sesamiae	29 (9)
		Goniozus indicus	5.9 (1)
		Rhaconotus sp	4.3 (1)
		Norbanus sp	4.3 (1)
		Sturmiopsis parasitica	4.3 (1)
		Chelonus curvimaculatus	9.1 (1)
		Echneumonidea sp	3.2 (1)
		Gambroides nimbipennis	10.6 (3)

( ) number of parasitised hosts

Table 2B: Larval and pupal parasitism in natural host plants in Botswana.

Host Plant Species	Host species	Parasitoid species	% Parasitism
Sorghum bicolor subsp *arundinaceum*	*Sesamia calamistis*	*Bracon testaceorufatus*	4 (1)
	Sesamia nonagrioides	*Siphona murina*	3.3 (1)
Schoenoplectus corymbosus	*Sesamia jansei*	*Goniozus indicus*	4.8 (1)
		Cercerinae sp	9.5 (2)
	Tortricidae sp	*Chelonus curvimaculatus*	14.3 (3)
		Dentichasmias busseolae	9.1 (2)
Cyperus dives	*Chilo partellus*	*Chelonus curvimaculatus*	7.8 (5)
Oryza longistaminata	*Sesamia nonagrioides*	*Goniozus indicus*	3.5 (1)
Typha latifolia	*Sesamia jansei*	*Gambroides nimbipennis*	6.7 (1)
	Tortricidae sp	*Syzeuctus* sp	4.2 (1)
Chrysopogon nigritanus	*Sesamia calamistis*	*Cremastinae* sp	4 (1)
Cyperus papyrus	*Eldana saccharina*	*Formicidae* sp	3.8 (1)
Vossia cuspidata	*Sesamia perplexa*	*Siphona murina*	4.5 (1)
Echinochloa pyramidalis	*Sesamia jansei*	*Syzeuctus* sp	5.2 (1)
Cyperus papyrus	*Eldana saccharina*	*Phoridae* sp	3.7 (1)

( ) number of parasitised hosts

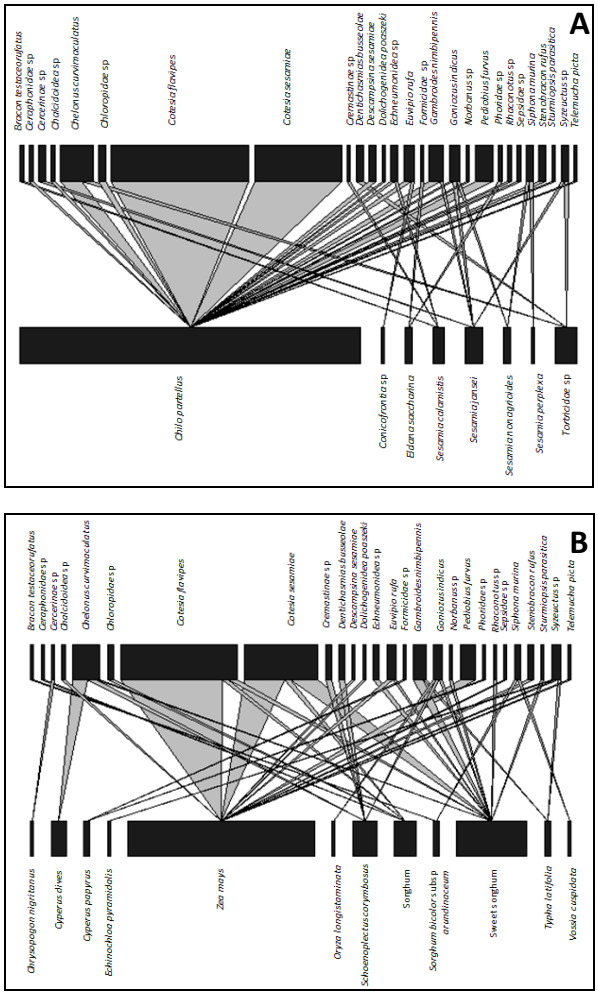

Fig. 1: Quantitative bipartite interaction networks for (A) stem borer - parasitoid and (B) host plant - parasitoid in cultivated and natural habitats in Botswana

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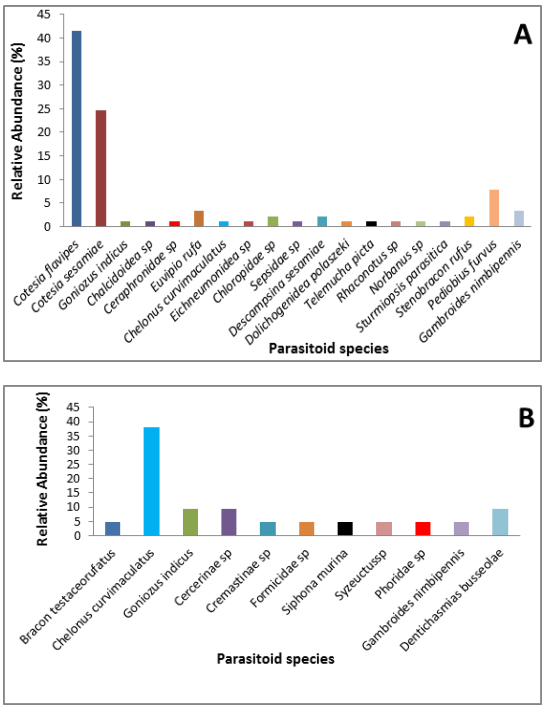

Fig. 2: Relative abundance of cereal stem borer parasitoids in (A) cultivated and (B) natural habitats in Botswana

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REFERENCES

[1] De Groote H (2002) Maize yield loss from stemborers in Kenya. Journal of Insect Science 22: 89–96.
[2] Kfir R, Overholt WA, Khan ZR, Polaszek A (2002) Biology and management of economically important lepidopteran cereal stemborers in Africa. Annual Review of Entomology 47: 701–713. PMID: 11729089.
[3] Kipkoech AK, Schulthess F, Yabann WK, Maritim HK, Mithöfer D (2006) Biological control of cereal stem borers in Kenya: A cost benefit approach, Annales de la Société entomologique de France (N.S.): International Journal of Entomology 42: 519-528
[4] Moolman HJ, Van den Berg, J, Conlong D, Cugala D, Siebert SJ, Le Ru BP (2013) Diversity of stemborer parasitoids and their associated wild host plants in South Africa and Mozambique. Phytoparasitica 41: 89-104
[5] Mailafiya DM, Le Ru BP, Kairu EW, Calatayud PA Dupas S (2009) Species diversity of lepidopteran stem borer parasitoids in cultivated and natural habitats in Kenya. Journal of Applied Entomology 133: 416-429
[6] Addo-Bediako A, Thanguane N (2012) Stemborer distribution in different sorghum cultivars as influenced by soil fertility. Agricultural Science Research Journal 2: 189- 194.
[7] Conlong DE, Rutherford SR (2009) Conventional and New Biological and Habitat Interventions for Integrated Pest Management Systems: Review and Case Studies using *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Chapter 10, pp 241-261. In Peshin, R and Dhawan, A.K. (Eds). Integrated Pest Management: Innovation-Development Process, Vol.1. Ch. 10. Springer, Dordrecht, The Netherlands. ISBN 978-1-4020-8991-6 (Print); 978-1-4020-8992-3 (online). DOI 10.1007/978-1-4020-8992-3_10.
[8] Batalden RV, Oberhauser K, Peterson AA (2007) Ecological niches in sequential generations of eastern North American Monarch butterflies (Lepidoptera: Danaidae): the ecology of migration and likely climate change implications. Environmental Entomology 36: 1365–1373.
[9] Kodjo TA, Komi A, Mawufe AK, Komlan W (2013) Maize stemborers distribution, their natural enemies and farmers' perception on climate change and stemborers in southern Togo. Journal of Applied Biosciences 64: 4773-4786
[10] Onyango FO, Ochieng'-Odero JPR (1994) Continous rearing of the maize stem borer *Busseola fusca* on an artificial diet. Entomologia Experimentalis et Applicata 73: 139-144
[11] Tefera T, Mugo S, Tende R, Likhayo P (2010) Mass Rearing of Stem borers, Maize weevil and Larger grain borer Insect Pests of Maize. CIMMYT. Nairobi.
[12] Dormann CF, Fruend J, Bluethgen N, Gruber B. (2009) Indices, graphs and null models: analyzing bipartite ecological networks. The Open Ecology Journal 2: 7–24.
[13] Simpson EH (1949) Measurement of diversity. Nature 163: 688.
[14] Zhou G, Overholt WA, Kimani-Njogu SW (2003) Species richness and parasitism in assemblage of parasitoids attacking maize stem borer in coastal Kenya. Ecological Entomology 28: 109–118.
[15] Dejen A, Getu E, Azerefegne F, Ayalew A (2013) Distribution and Extent of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) Parasitism in Northeastern Ethiopia. International Journal of Insect Science 5: 9-19
[16] Rahaman MM, Islam KS, Jahan M, Mamun MAA (2014) Relative abundance of stem borer species and natural enemies in rice ecosystem at Madhupur, Tangail,

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

Bangladesh. Journal of the Bangladesh Agricultural University 12: 267–272, ISSN 1810-3030

[17] Conlong DE, Graham DY (1988) Notes on the natural host surveys and laboratory rearing of *Goniozus natalensis* Gordh (Hymenoptera: Bethylidae), a parasitoid of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) larvae from *Cyperus papyrus* L. in Southern Africa. Journal of the Entomological Society of Southern Africa 51: 115-127

[18] Obopile M, Mosinkie KT (2003) Natural enemies of lepidopterous stemborers on maize and sorghum in Botswana. UNISWA Journal of Agriculture 11: 64-69

[19] Helena, M., Peixoto, P., Pufal, G., Staab, M., Martins, C.F., Kleins., A.M. (2016). Diversity and specificity of host-natural enemy interactions in an urban-rural interface. Ecological Entomology 41: 241-252.

[20] Ofomata VC, Overholt WA, Lux SA, Van Huis A Egwuatu RI (2000) Comparative studies on the fecundity, egg survival, larval feeding and development of *Chilo partellus* (Swinhoe) and *Chilo orichalcociliellus* strand (Lepidoptera: Crambidae) on five grasses. Annals of the Entomological Society of America 93: 492-499.

[21] Matama-Kauma T, Schulthess F, Ogwang JA, Mueke JM, Omwega CE (2007) Distribution and relative importance of lepidopteran cereal stemborers and their parasitoids in Uganda. Phytoparasitica 35: 27-36

[22] Mailafiya, D.M., Le Ru, B.P., Kairu, E.W., Dupas, S. and Calatayud, P.A. (2011) Parasitism of lepidopterous stemborers in cultivated and natural habitats. Journal of Insect Science 11: 1-19

[23] Moolman J, Van den Berg J, Conlong D, Cugala D, Siebert S, Le Ru BP (2014) Species diversity and distribution of lepidopteran stem borers in South Africa and Mozambique. Journal of Applied Entomology 138: 52-66

[24] Udayagiri S, Welter SC (2000) Escape of *Lygus hesperus* (Heteroptera: Miridae) eggs from parasitism by *Anaphesiole* (Hymenoptera: Mymaridae) in strawberries: plant structure effects. Biological Control 17: 234-242.

[25] Sétamou M, Jiang N, Schulthess F (2005) Effect of the host plant on the survivorship of parasitized *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) larvae and performance of its larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). Biological Control 32: 183-190.

[26] Overholt WA, Songa JM, Ofomata V, Jeske R (2000) The spread and ecological consequences of the invasion of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) in Africa. In E. E. Lyons and S. E. Miller Invasive species in eastern Africa: Proceedings of a Workshop held at ICIPE, July 5-6, 1999. ICIPE Science Press, Nairobi

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Investigation of Geotechnical Properties of Gravel Materials for Improved Quality of Unpaved Roads

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ABSTRACT
Addressing issues of quality in gravel material by introducing proper testing of material will greatly reduce poor gravel road performance and the costs of maintenance. Locally, shortage of land and settlement in rural areas increases considerably every year and gravel roads are increasingly becoming important and useful. Nevertheless, gravel roads are faced by deterioration by different factors, and because of these factors, corrugation, potholes, ruts, dust (loose gravel), and loss of gravel, stoniness and cracking will be the final output on gravel roads. Researchers have focused on improving performance through monitoring and improving maintenance procedures in order to increase the life of unsealed roads worldwide. This study investigates the geological properties of gravel materials from borrow pits that are currently being used within Palapye for improved quality of unpaved roads. This study involves carrying out full tests on samples collected from borrow pits including the Lecheng borrow pit and comparing the results with the set quality standards for gravel material from Botswana Bureau of Standards which positively contributes to the economy of Botswana and to the development goal of achieving good quality gravel roads.

Keywords: Quality; Gravel material; unpaved roads performance

I. INTRODUCTION

Gravel is very useful as a road construction material for both sealed and unsealed roads. In unsealed roads, gravel usually gets lost during the life of the road because no surface mix has been used or applied to hold it in place. Therefore the required characteristics of gravel for sealed roads will always be different from those of unsealed roads. There are many factors that affect the performance of a gravel road, and these include those related to shape and those related to the properties of the gravel material being used. On the basis of shape, the main idea is for drainage, to keep water away from the surface of the road.

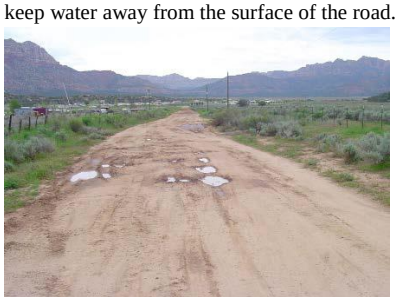

Figure 1: Shows how water contributes to gravel road deterioration [1].

The suitability of a gravel material differs according to how it is going to be used. Base course gravel requires large amounts of coarse particles and less amount of fine particles, whereas for surface gravel enough amounts of fines are necessary for providing the binding characteristics. One biggest problem in gravel roads is wash boarding, whose primary cause is poor gradation. Gradation is the most important element of gravel that needs to be considered carefully, a blend of coarse particles has to form a tight surface, and fine particles will act as a binder to fill the spaces between the coarse particles. Good surface gravel should have top-sized stone no larger than ¾ inches or certainly no larger than 1 inch. It should have a good percentage of true fines (material that passes a number 200 sieve). The ideal percentage of fines should run somewhere between 7 and 12% of the total sample passing the number 200 sieve [2]. Surface gravel roads are faced by a lot of problems including corrugation, gravel loss and bearing capacity failures. Therefore a proper selection of gravel

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material is essential for excellent performance and life of a gravel road.

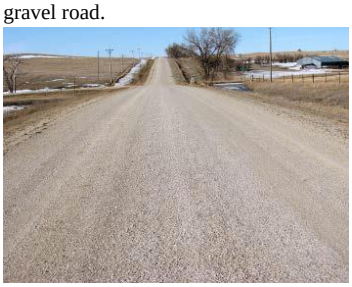

Figure 2: Example of a very good gravel road [1].

Gravel roads are increasingly becoming important and useful in developing countries such as Botswana. As the population continues to increase there comes a need for any state to offer land to its citizens for settlement, with limited availability of land, settlement in rural areas increases considerably. This can be challenging in developing countries such as Botswana in terms of transportation network. Proper attention has to be given to improving the transportation network in order for people in rural areas to be connected to the social and economic development of the state. However construction and maintenance of sealed or paved roads can be highly costly so attention should be given to other cheaper alternatives. Gravel or unpaved roads are very cheap to construct as compared to sealed or paved roads, which is why they are normally adopted for rural areas. This calls for attention to be given to the quality and performance of gravel roads and the material that is being used for construction. Nevertheless gravel roads can be very costly to maintain, especially when the material that is used is not of the required quality. Problems with wash boarding, rutting in wet weather or loosening (floating) in dry weather are greatly reduced when some money is spent on testing the material for quality, and maintenance costs are greatly reduced, as sourced out from the Federal Highway Administration (FHWA) [1]. There is not "one size fits all" gravel, different uses require different types of material and only by testing can you really determine if it is suitable for a specific purpose [2]. All managers and decision makers in local government need a good understanding of the benefit of testing the material in order to work towards better quality in road. Knowing about the importance of quality gives power to decision makers to specify good materials, to know when to accept or reject materials, and to communicate better with crushing contractors, consultants, commercial suppliers and others involved in the business of constructing and maintaining roads [1]. Pits and quarries can change as material is removed over the years, so testing prior to use can also solve many problems that can show up later.

Material quality is of utmost importance, if money is spent on testing and analysis of the material to check the geological and geotechnical properties to ensure quality, the costs of maintenance are greatly reduced [1].

II. LITERATURE REVIEW

Botswana and many other African countries are landlocked, and roads are the main modes of transport that are being used more than other modes of transport. In 1993 the roads department in Botswana sourced out some important figures through the Botswana Road Maintenance Study Report. These figures are shown in a table below as obtained from the Rural Road Management in Botswana article by Khan. There are about 18 327 km of roads in Botswana, which are divided into four categories based on importance. The Roads Department and Local Councils own about 48% and 52% of roads respectively [5].

Table 1: The road network in Botswana [5].

Type of roads	**Description of roads**	**Responsibility**	**Total: km (%)**
Primary roads	Major national highways	Roads Department	3,789 (21%)
Secondary roads	Secondary national highways that connect at least two district headquarters	Roads Department	4,882 (27%)
Tertiary roads (rural roads)	Rural roads that connect at least two villages	Local Councils	2,644 (14%)
Access roads (rural roads)	Village internal roads	Local Councils	6,922 (38%)
Total			18,237 (100%)

However, in 2011 Ministry of Transport and Communications (MOTC) noted in the Botswana Roads-Basic Facts report that the public highway network consists of 6116 km of paved and 2 800 km of unpaved road. This is complemented by a further 9000 km of District roads which fall under the responsibility of the District [6].

However, when we look closely at the figures, a major share of responsibilities is on the local council's side, and as shown on the table above, the councils are mostly responsible for rural roads which connect villages both internally and externally. This means that the rural roads dominate in the roads network of Botswana, and the numbers continue to increase as years pass.

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Nevertheless, gravel roads are faced by deterioration by different factors, and because of these factors, corrugation, potholes, ruts, dust (loose gravel), loss of gravel, stoniness and cracking will be the final output on gravel roads [4]. Khan further noted that road performance assessment and maintenance is considerably being neglected, and more emphasis is on road construction. Using the council maintenance-budget data for the current and previous years, it appears that maintenance funding has been reduced, whereas the road network has increased by almost 50% in the last two years. This indicates that maintenance is not getting proper attention [5]. Gravel roads are adopted in almost all cases because of low costs of construction, but maintenance costs for gravel roads (or just rural roads) can be very high especially if material used does not meet the proper quality standards. When combinations of factors that cause deterioration meet a poor gravel road material, the rate of deterioration increases highly, performance is lowered, and the frequency of need for maintenance continues to increase considerably.

Therefore material quality is highly important to the performance and life span of a gravel road. Emphasis on the gravel material quality and characteristics can limit deterioration factors and improve performance. However a lot of attention is on the construction stage, the performance stage, and the maintenance procedures, and the analysis and rating of material is not getting proper attention. Engineers frequently write ideal specifications for gravel that is not obtainable, and contracts are let to use practical grades, on a price or availability basis [3]. This being the case, the government ends up dealing with the consequences of poor gravel material, because a lot of compromises were made on quality, on a price or availability basis.

Although this study is based on gravel material quality, it is only limited to that and does not get much into how gravel deteriorates, it focuses on what good gravel is made of and how to obtain it, and this is only limited to the Palapye region.

III. METHODOLOGY

Data Collection. Data was collected in the form of tests on the samples collected from Lecheng Borrow Pit. Four laboratory tests were carried out on each sample, and these are; Sieve Analysis, Atterberg Constants Determination, California Bearing Ratio (CBR), Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) Determination.

IV. DATA ANALYSIS AND DISSCUSSION OF RESULTS

Since the investigation process is still ongoing, only sample 1 of stockpile B from Lecheng Borrow Pit was used for this paper to present the geotechnical properties the stockpile.

To analyze the results, they were capture in an excel sheet and were presented in tables and graphs for easy reading and interpretation. They were used again for comparison with the Botswana Bureau of Standards specifications with the aim of determining whether they fall within the boundaries of quality or not.

Table 2 shows results from sieve analysis process giving a grading modulus of 2.47, a percentage (by mass) of 31.2% passing the 2.00 mm sieve, and a percentage of 19.8% passing the 0,425 mm sieve.

Table 2: Sieve Analysis results.

SIEVE APERTURE (MM)	MASS RETAINED (g)	PERCENTAGE RETAINED (g)	PERCENTAGE PASSING (%)
75.000			
53.000			99.9
37.500	476	23.0	76.9
25.500	163	7.9	69.0
19.000	125	6.0	63.0
13.200	92	4.4	58.6
9.500	142	6.9	51.7
6.700	139	6.7	45.0
4.750	110	5.3	39.7
2.360	176	8.5	31.2
1.180	38	1.8	29.4
0.600	73	3.5	25.9
0.425	126	6.1	19.8
0.300	86	4.2	15.6
0.150	132	6.4	9.2
0.075	150	7.2	2.0
<0.075	20 + 22	2.0	DUST CONTENT (g) : 20
TOTAL	2070	99.9	GRADING MODULUS:2.47

Table 3 summarizes the atterberg constants, giving a Liquid Limit of 21.9, a Plastic Limit of 18.3, a Plasticity Index of 3.6 and a Linear Shrinkage of 2.0%.

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Table 3: Atterberg Constants

	MOISTURE CONTENT			PLASTIC LIMIT	
TIN NUMBER	A33	C6		42.00	LL = 21.9
MASS TIN & WET MATERIAL (g)	20.30	20.05		20.05	PL = 18.3
MASS TIN & DRY MATERIAL (g)	18.35	18.15		18.35	
MASS TIN (g)	9.40	9.40		9.10	PI = 3.6
MASS MOISTURE (g)	2.00	1.90		1.70	
MASS DRY MATERIAL (g)	9.00	8.80		9.30	
% MOISTURE	22.20	21.60		18.30	
NUMBER OF TAPS	18.00	26.00		LINEAR SHRINKAGE= 2.0 %	
SHRINKAGE (mm)	3.00				

The graph in figure 3 plots the Dry Density values at varying amounts of water as shown in table 4, in order to determine the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD). The graph gives an MDD of 2073 kg/m and an OMC of 8.3%.

Table 4: Maximum Dry Density and Optimum Moisture Content.

HYDROSCOPIC	0.6	0.8	0.7	Ave = 0.7
% ADDED	4%	6%	8%	10%
ML	280	420	560	700
MOULD NUMBER	B22	B22	B22	B22
MOULD FACTOR	4456	4456	4456	4456
WT. MOULD + WET SOIL	9356	9590	9753	9701
WT. MOULD	4701	4701	4701	4701
WT. WET SOIL	4655	4889	5052	5000
WET DENSITY (kg/m)	2074	2179	2251	2228
CONTAINER NUMBER	A1	A2	A8	A5
WT. CON + WET SOIL	500	500	500	500
WT. CON + DRY SOIL	478	468	460	452
WT. WATER	22	32	40	48
WT. DRY SOIL				
MOISTURE CONTENT (%)	4.6	6.8	8.7	10.6
DRY DENSITY (kg/m)	1983	2040	2071	2014
	M.D.D: 2073		O.M.C: 8.3	

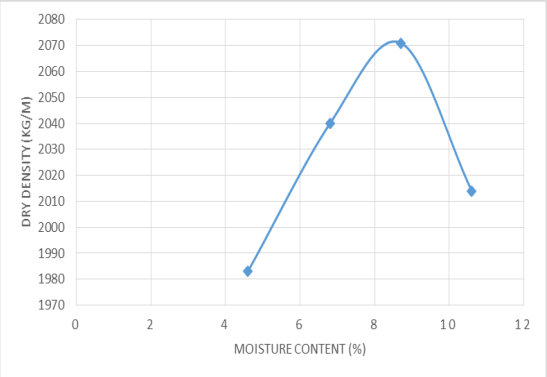

Figure 3: Dry Density against Moisture Content for determination of OMC and MDD.

Below is a table that summarizes all the tests that were carried out on the sample, by outlining the important parameters that are being used for classification.

Table 5: A summary of the important parameters of the sample.

LECHENG BORROW PIT	
STOCKPILE B; SAMPLE 1	
GRADING MODULUS	2.47
% PASSING 2.00 mm SIEVE	31.20
% PASSING 0.425 mm SIEVE	19.8
LIQUID LIMIT	21.90
PLASTIC LIMIT	18.30
PLASTICITY INDEX	3.60
LINEAR SHRINKAGE	2.00

Discussion of results and findings: To analyze the results, the BOBS specifications for roads which are outlined in Part 32, were used for classification, and determination of suitable use of the material. Table 3B of the BOBS Part 32 and the table showing a summary of the important parameters of the material, show that the gravel material under investigation, complies with the requirements of Grade 5. This implies that this material qualifies to be used as a compacted pavement layer.

Conclusion: The findings of this research reveal the importance for testing of gravel material before actually being used for construction. It shows that there is no "one size fits all" type of gravel, different uses require different types of material and only by testing can you really determine if it is suitable for a specific purpose.

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REFERENCES

[1] FHWA. (2015, August). Gravel Roads Maintenance and Design Manual. Brookings.

[2] Gianfrancisco, S., & Jenkins, S. (2000). *Gravel Roads.* Montana: Department of Civil Engineering Montana State University.

[3] Herbert L. Nicholas, J. (2005). *Moving the Earth: The Workbook of Excavation, 5th Edition.* New York: Mc Graw Hill.

[4] Kassa, G. M. (2015). *Modelling of Gravel Loss for Unsealed Roads.* Addis Ababa.

[5] Khan, M. U. (2012, november 14). Rural Road Management in Botswana. p. 113.

[6] MTC. (2011). *Ministry of Transport and Communications*. Retrieved from www.gov.bw: http://www.gov.bw/en/ministries--authorities/ministries/ministry-of-transport-and-communications/departments/department-of-roads/divisions/

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Geotechnical Investigation of Borrow-Pit Material Quality for Construction of Sustainable Gravel Roads in Palapye- Botswana

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Abstract—The Geotechnical investigation of the gravel material used in the construction of gravel roads in Palapye is important as it ensures that the quality of the gravel material used complies with the Botswana Bureau of Standards (BOBS), Road Department standard and the Client standard Botswana International University of Science and Technology (BIUST). The geotechnical investigation also helps the contractors to construct gravel roads of high quality that can last longer without developing gravel road defects such as potholes, dust, stoniness and corrugation. It helps reduce the cost incurred to maintain the gravel roads. This study investigates the quality of the gravel material used to construct gravel roads in Palapye. The Atterberg limit tests (shrinkage limit, Plastic limit and liquid limit tests) and the moisture and dry density tests are being carried out at Rockefeller Laboratories to test the quality of the gravel material. Rockefeller is the company currently constructing the BIUST access road and they want to ensure that the quality of the gravel material they are using complies with the BOBS.

Keywords: Geotechnical Investigation, quality, gravel material.

INTRODUCTION

Gravel material refers to the unconsolidated material composed of particles of different range sizes. Gravel is a mixture of three sizes or types of material: stone, sand and fines (12). Gravel is composed of soil material between 2mm and 6mm. Gravel roads are the unpaved or untarred roads made of the gravel material.

Gravel material is largely composed of the pebbles of 4 to 63, sand of 0.063 to 2mm and the finer particles (8). A good gravel material should be well graded from the coarse particles to the finer particles. The mineralogical composition of the gravel material depends on the mineralogical composition of the parent rock. Most of the gravel material in Botswana is formed through weathering of granite rocks. Granite is mostly composed of quarts and feldspar with minor mica, amphiboles and other minerals (9)

Gravel is formed due to the process of weathering and deposition of rock particles containing pebbles, sand and finer particles. Gravel is either a natural gravel or crushed stone to form gravel (4). Natural gravel is formed from materials of a weathered rock and crushed stone is when the rock is artificially broken down into pieces and graded to certain sizes to produce an aggregate in a quarry (8). Crushed stone is mostly used when the natural gravels are not available.

Gravel material is used in construction of roads (both tarred and untarred roads), construction of foundations and as a subbase for pavements. Gravel material forms the bases of every construction project. The performance of the gravel road depends on the; Quality of the gravel, the load of the vehicles using the gravel, the design of the gravel.

LITERATURE REVIEW

Classification of gravel material

(1), highlighted that gravel material is classified using the soil classification systems. Soil classification system is simply categorising of soil in groups based on the properties of the soil. Soil classification systems rely on physical and the engineering properties of the soil. Different classification systems classify the soil into many different groups. The two mostly used systems are the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO)

The Unified Soil Classification System (USCS) uses the grain size analysis and the atterberg limit tests to group the soils into two major groups (2). The system groups the soil into 6 groups and each group is denoted with a letter or symbol. According to (1), a soil is classified as a gravel or sandy soil if more than 50% is retained on a No.200 sieve and as a fine grained soil if 50% or more passing through a No.200 sieve. Below is the table that shows how the soils are grouped and

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the symbols used when using the Unified Soil Classification System (USCS).

According to (2), the Association of State Highway and Transportation Officials (AASHTO) is used to classify soils used in the construction of highways and it uses the grain size analysis, liquid limit and plasticity index and the soil type and group name are determined from the AASHTO table. Also according to (1) The AASHTO classifies the soils into seven major groups A-1 to A-7. A-1 to A3 are coarse grained soils (gravels and sands) whereas A-4 and A-7 are mostly finer materials(silt and clays).

Gravel Roads

Gravel road refers to a road made of gravel material (material containing the coarse, medium and small amount of fine particles) that are not paved or sealed with any material. Similarly, (13), defines unsealed roads as a road that has no permanent surface proofing of water in contrast of sealed roads. Meanwhile some Authors define a gravel road as any unpaved road.

A gravel road is composed of three layers which are the roadbed, the subgrade, and the surface layer (7). The road bed is indigenous soil evenly graded to make it uniform. The subgrade is the gravel material with bigger particles to improve drainage and to make a more stable base. The top layer is the surface layer made of mostly medium grained gravel of uniform size.

Gravel Road Defects

The rate at which the gravel material is deteriorated is mainly affected by the quality of the gravel material, the design of the gravel road, number and the gross weight of the vehicles using the gravel road, the environmental effects such as floods or rainfall amount (13). Poor quality gravel and a large number of vehicles can cause further weathering of gravel material into smaller pieces that will be easily eroded. Poor design of the gravel also worsens the impacts of environmental issues such as floods. The gravel road defects are:

Potholes

Potholes are bowl-shaped, round and elongated depression in gravel road surface (7). Similarly according to (10) potholes are depressions or holes in the road surface. The pot holes may differ in sizes and the intensity along the whole road. The major contributing factors to potholes are: poor road design, poor and unevenly compaction, low quality gravel material, cracked road (7).

The potholes may be joined together or evenly spaced. Potholes are controlled by reshape or regrade to cut out the potholes (10).

Road Design

Road design influences the performance of the road. Poor road design will speed up the deterioration of the gravel road. The road should be designed such that more water will flow through the culverts not at the top of the road and it is easily drained from the road. If water is stagnant on the flat gravel it will soften the gravel leading to potholes and rutting. According to (6) Where the profile is flat, water tends to pond in localised depressions resulting in softening of the wearing course and the development of potholes and other deterioration. A proper gravel road design should be bulged at the centre so that water can easily flow from the road. According to (6) the road profile is rated on a five-point scale where one is very good Surface and will shed water easily, and five is very uneven road that result in accumulation of water that may cause potholes.

Road dust

Road dust is the dry solid matter consisting of clay and silt-sized particles that is entrained by wind, the wind shear forces created by vehicles and the interaction of vehicle tyres with the road and which disperses and remains in suspension for a period before eventually falling back to the earth's surface (5). Dust is a result of moving vehicles on a road with less moisture content and too much finer materials. The quality of the aggregate and the amount of vehicles using the road affect the amount of dust. Dust reduces the visibility on the road, increases gravel loss due to loss of fine material, poses health threads and also affect the surrounding vegetation (5) . Dust from the road can be controlled by watering of the gravel during dry periods which will increase the expenses on the maintenance of gravel.

Stoniness of the Road

Stoniness is the relative percentage of material embedded in the road that is larger than a recommended maximum size (usually 37.5 mm) (7). Stoniness occurs when most of the material used contains the materials that are larger (the cobbles and pebbles). The finer particles will be carried away leaving behind the rocky, bumpy or uneven surface. As such it is important to use the recommended gravel material for gravel roads. According to (6) .Stoniness leads to rough roads, poor compaction in areas with large rocks, difficulties during maintenance, development of corrugations.

Corrugation/washboard

According to (10) Corrugation or washboard refers to the series of evenly spaced bumps that make a vehicle chatter rather than bounce around like potholes. Corrugation/ washboard of gravel is when the gravel material is carried and deposited on certain intervals creating crest and troughs in the gravel road creating a bumpy rough road. corrugation is caused by the action of passing vehicles. According to (11)There are four primary causes of corrugation/ washboarding which are the driving habits of people, lack of moisture, poor quality of gravel, lack of crown on the surface

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METHODOLOGY

The samples that were tested was collected from Maope Quarry (Stockpile 1) in Palapye. The sample were tested check if it complies with the Bobs standard for G6 material. The tests carried out were the Sieve analysis, Atterberg limits, and the maximum dry density and optimum moisture content were also determined from a graph.

Sieve Analysis

The sample was passed through the stack of sieves of aperture indicated in the table below and the percentage retained, mass retained and percentage passing were calculated. The details are as follows:

Sieve Analysis of Aggregate

Date: 19/05/2017

Project: BIUST Access Roads

Client: BIUST

Source: Maope Quarry

Location: Maope Sample No: 2

Mass After Washing: 2240

Mass Before Washing: 2529

Grading Modules: 2.23

Dust Content:289

Table 1: Sieve Analysis of Aggregate

SIEVE APERTURE	MASS RETAINED	% RETAINED	% PASSING
75			
53			
37.5			100.1
25.5	47	1.9	98.2
19	149	5.9	92.3
13.2	123	4.9	87.4
9.5	145	5.7	81.7
6.7	184	7.3	74.4
4.75	208	8.2	66.2
2.36	527	20.8	45.4
1.18	278	11	34.4
0.6	257	10.2	24.2
0.425	93	3.7	20.5
0.3	75	3	17.5
0.15	114	4.5	13
0.075	38	1.5	11.5
<0.075	2+289	11.5	
	2529	100.1	

Atterberg limit tests

The plastic limit, liquid limit and plastic index of the sample were tested using the soil sample that passes through sieve no 425. The results were as follows.

Table 2: Atterberg Limits

Description of material	MOISTURE CONTENT		PLASTIC LIMIT	LL, PL & PI
Tin no	A1	E2	68	LL =23.7
Mass Tin & Wet Material	18.15	18.05	18	PL = 17.0
Mass Tin & Dry Material	16.2	16.05	16.5	
Mass Tin	7.7	7.7	7.7	PI=6.7
Mass Moisture	2	2	1.5	
Mass Dry Material	8.5	8.4	8.8	
% Moisture	23.5	23.8	17	
Number of Taps	23	23		
SHRINKAGE				
LINEAR SHRINKAGE = 3.3%				

Maximum dry density and optimum moisture

The maximum dry density and optimum moisture were determined using the graph of dry density and moisture content. They were determined to be 2146kg/m and 7.3%. The table for the maximum dry density and optimum moisture content and the graph of dry density versus moisture content are shown below.

Table 3: Determination of maximum dry density and optimum moisture content

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MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT					
PROJECT: BIUST ACCESS ROAD					
SAMPLE NO:2				DATE: 24/05/2014	
LOCATION: MAOPE QUARRY STOCK PILE 1				TECHNICIAN: PATRICK	
SAMPLE DISCRIPTION				CLIENT: BIUST	
Hygroscopic		0.6	0.8	0.7	Ave=0.7
% Added		4%	6%	8%	10%
ml		280	420	560	700
Mould no		B22	B22	B22	B22
Mould factor		4456	4456	4456	4456
Wt.Mould + Wet Soil		9564	9836	9856	9790
Wt.Mould		4701	4701	4701	4701
Wt. Wet Soil		4863	5135	5155	5089
Wet Density (kg/m)		2176	2288	2297	2268
Container no:		A1	A9	A4	A7
Wt. Con + Wet Soil		500	500	500	500
Wt. Con + Dry Soil		478	468	460	452
Wt. Water		22	32	40	48
Wt.Dry Soil					
Moisture Content (%)		4.6	6.8	8.7	10.6
Dry Density (kg/m)		2050	2142	2113	2051
	M.D.D: 2146		O.M.C: 7.3		

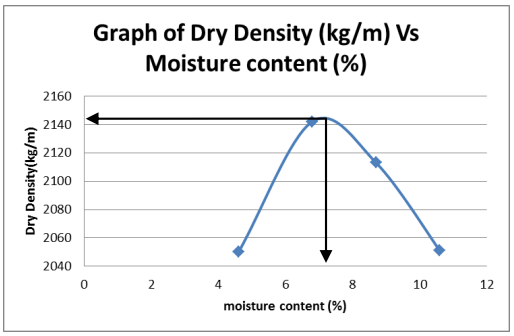

Figure 1: Graph of dry density (kg/m) Vs Moisture Content

Results Analysis

According to the Botswana Bureau of Standards (BOBS) Civil engineering Part 32 Roads specification the G6 material shall have a Plastic Index of less than 12, Linear Shrinkage of less than 5% and the product of the percentage passing the 0.425mm sieve does not exceed 320. In comparison with our results the plastic is 6.7, the linear shrinkage is 3.3% hence the gravel material at Maope Quarry is correctly classified as G6.

CONCLUSION

The results of the tests carried out so far confirmed that the quality of the borrow pits material around Palapye are in the range of gravel G5 and G6 materials used for road construction which complied with the BOBS standards. The Maope Quarry is G6 material hence it can be used as a fill or subbase material according to the BOBS standards.

REFERENCES

I. Works Cited

[1]Das, B. (2014). Advanced Soil Mechanics. Broken Sound Parkway NW: CRC Press.

[2]Fratta, D., Aguettant, J., & Smith, L. (2007). Introduction to Soil Mechanics Laboratory Testing. Broken Sound Parkway NW: CRC Press.

[3]Henning, T., Kadar, P., & Bennett, C. (2006). Surfacing Alternatives for Unsealed Rural Roads. Transport Notes, 5.

[4]Jenkins, K. (n.d.). Hitchhiker's guide to pavement engineering.

[5]Jones, D., & Green, P. (2000). Draft TMH12. Pretoria: CSIR Transportek.

[6]Jones, D., & Paige-Green, P. (2000). Draft TMH12:. Pretoria: Department of Transport Officials.

[7]Kassa, G. (2015). Modeling of Gravel Loss for Unsealed Roads. Addis Ababa.

[8]Kaufmann, F. (2012). Gravel. New World Encyclopedia.

[9]King, H. (2005). Rocks. Retrieved March 09, 2017, from Geology.com: http://geology.com/rocks/granite.shtml

[10]Lanoie, R. (2007). Gravel Road troubleshooting guide. Rural Technology.

[11]Mark, S., Rafiq, D., Hamilton, D., Megan, C., Jason, H., Bemie, K., et al. (2015). Gravel Roads Construction & Maintenance Manual. South Dakota: Federal Highway Administration.

[12]Road Management Guidelines & Road Maintenance Plan. (2006). Virginia: Virginia City Highlands Property Owners' Association.

[13]Theuns Henning, P. K. (2006). Surfacing Alternatives for Unsealed Rural Roads. Washington DC: The World Bank.

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Data Science Orientation for Engineering Students

Teaching with Open Source Software- R

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***Abstract*— This paper highlights uses of R, an open source data analysis software and programming language, in teaching an engineering module (Quality Control and Management). The main objective is to orient engineering students to the booming and lucrative data science career. Data science in engineering is mainly motivated by the need for operations improvement, supply chain management, and personalised production (a.k.a mass customization). The use of R in the mentioned module was therefore very appropriate since the learning objectives are mainly centred on the three areas of data science applications in engineering. The main achievements realised in the module were a 100% semester pass rate. Students were given an online survey questionnaire to solicit data pertaining to their views in using R as platform for introducing data science training. The responses generally indicated average to high satisfaction, practical exposure to statistical quality control tools and data analysis. Students also recorded a relatively high ease of learning of the R system and readiness to tackle practical industry problems. The results of the pilot project inspired future research into industry based applications of R for quality control and management as well as other data analytics demands. The lab sessions during the semester were mainly based on command prompt programming, but industrialists mainly find comfort in graphical based tools and real-time integration with factory floor operations.**

Keywords—Big Data; Internet of Things; Data Analytics; Data Science; R Software.

I. INTRODUCTION

Business analytics on demand has become mandatory practice of the modern day corporate world. This has significantly increased the demand for accurate data collection from baseline operations in any business setup. Data and information has long became a central productive and strategic asset, and the success of the organization depends on its ability to gather, produce, maintain and disseminate this information for its benefit and those in its value chain. The engineering field collects huge volumes of data (Big Data) through RFID readers, tags and sensors, and the trend continues to grow explosively as technology advances. The integrated technologies for collecting data are generally called Internet of Things (IoT). Most powerful applications of Big Data and Data science will likely emerge when data from multiple sources is integrated, e.g., material, process, manufacturing, and business data. The best quality data is usually generated by sensors, which are often arranged in networks. Sensors and Sensor Networks – Sensors resonate in a twofold manner within the areas of research and practice in the field of engineering, particularly mechanical. Many products and systems designed by engineers utilize sensors. Markets call for products and solutions that are more reliable, safer, and more dependable. This in turn creates demand for new and more accurate sensors, which measure parameters that only a few years ago were merely dreamed about. Progress in computing and data science is another factor fueling progress in sensor technology, as the data generated by sensors adds value to products. Engineering training, as well as other scientific disciplines have been emphasising fundamental technical concepts that form the body of knowledge of the specific professional fields. The emanating missing link is now the disparity between technological advancement to collect data about things versus exploitation of the available data to derive value or meaningful information. Data Science skills have since become a mandatory part of the modern day engineering curriculum. The skills are of a multi-disciplinary domain, anchored on computer science, mathematics, human-technology interaction, and business models and operations management. Most of the skills are already incorporated in the traditional curriculum except state-of-the-art machine learning and data analytics.

II. LITERTURE

A. Data Science

Data science is defined as the study of the generalizable extraction of knowledge from data. More people now consider a data scientist as a job role in the big data realm and is different from a statistician or other job roles [1, 2]. Data scientists are also among the most critical skills of the 21st century. Data science is different for conventional science in the sense that "science" extracts knowledge from experiment data whereas data science. Today's data is mainly in the form of digital traces produced in the regular course of work or play (i.e., data generated or managed by operational support (OS) tools) and is known as operational data (OD). Operational data

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has no carefully designed measurement systems. OD exhibits the following attributes;

- Prevalent
  - Massive data from software development
  - Increasingly used in practice
  - Many activities transitioning to a digital domain
- Treacherous - unlike experimental data
  - Multiple contexts
  - Missing events
  - Incorrect, filtered, or tampered with
- Continuously changing
  - OS systems and practices are evolving
  - New OS tools are being introduced in SE and beyond
  - Other domains are introducing similar tools

B. Big Data

Big Data refers to data sets with sizes beyond the ability of commonly used software tools to capture, curate, manage, and process the data within a reasonable time. Another definition refers to Big Data as the tools, processes and procedures allowing an organization to create, manipulate, and manage very large data sets and storage facilities – according to zdnet.com. Big data is not just about size. It finds insights from complex, noisy, heterogeneous, longitudinal, and voluminous data. It aims to answer questions that were previously unanswered. Big data analytics (BDA) is defined as a holistic approach to manage, process and analyze the "5 Vs" data-related dimensions (i.e., volume, variety, velocity, veracity and value) in order to create actionable insights for sustained value delivery, measuring performance and establishing competitive advantages [3]. It has recently emerged as "the next big thing" in management. Some scholars and practitioners even suggest that BDA is the "fourth paradigm of science" [4, p.34], or even "the next frontier for innovation, competition, and productivity" [5, p.1], or the "new paradigm of knowledge assets" [6, p. 2]. These statements are mainly driven by the pervasive adoption and use of various tools and technologies, including social media (e.g., Facebook, Twitter), mobile devices (e.g., laptops, smartphones), automatic identification technologies enabling the Internet of Things (IoT) (e.g., radio frequency identification (RFID), Bluetooth), and cloud-enabled platforms to support intra- and inter-organizational business processes and achieve a competitive advantage. Some analysts estimate that Twitter users generate more than 250 million tweets per day, while about 50 hours of video are uploaded each minute on YouTube from around the world. The same analysts estimate that Facebook now holds more than 90 billion photos, with over 200 million photos uploaded per day [7].

C. Tools for Big Data and Data Scienc

Python

Python is a powerful, flexible, open-source language that is easy to learn, easy to use, and has powerful libraries for data manipulation and analysis. Its simple syntax is very accessible to programming novices, and will look familiar to anyone with experience in Mat lab, C/C++, Java, or Visual Basic. For over a decade, Python has been used in scientific computing and highly quantitative domains such as finance, oil and gas, physics, and signal processing. Python is one of the most popular programming languages in the world, ranking higher than Perl, Ruby, and JavaScript by a wide margin. Among modern languages, its agility and the productivity of Python-based solutions are legendary. The future of python depends on how many service providers allow for SDKs in python and also the extent to which python modules expand the portfolio of python apps.

R

R is an open source programming language and software environment for statistical computing and graphics. The R language is widely used among statisticians for developing statistical software and data analysis. According to a survey in 2010, R was the data mining tool used by more data miners (43%) than any other. The S language is often the vehicle of choice for research in statistical methodology, and R provides an open source route to participation in that activity. R is emerging as a defacto standard for computational statistics and predictive analytics. R provides a wide variety of statistical and graphical techniques, including linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering, and others. R is an integrated suite of software facilities for data manipulation, calculation and graphical display. It includes:

- An effective data handling and storage facility.
- A suite of operators for calculations on arrays, in particular matrices.
- A large, coherent, integrated collection of intermediate tools for data analysis.
- Graphical facilities for data analysis and display either on-screen or on hardcopy.
- A well-developed, simple and effective programming language which includes conditionals, loops, user-defined recursive functions and input and output facilities.

Hadoop

The name Hadoop has become synonymous with big data. It's an open-source software framework for distributed storage of very large datasets on computer clusters.

Currently Hadoop is the standard of many organization in dealing with Big Data [11]. As several technologies associated to Big Data are open source, vendors are showing their interest in integrating these tools with their own products [12]. The Apache Hadoop, an open source framework designed to support distributed parallel processing of large amount of data sets across clusters of computers using simple programming models. It is written in java. It can run on commodity hardware, scaling up from single nodes to thousands of computer, thus forming cluster. Each node in the cluster offers local computation and storage. Hadoop promise high availability to end user. Instead of depending on hardware to

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deliver high-availability, its framework itself can identify and figure out single point of failures at the application layer, thus providing a high availability service to its user [8].It has a number of commercially supported distributions from companies such as Map Technologies, Hortonworks, Cloudera, etc [9].

D. Education and Training Trends in Data Science

There are a wide range of knowledge and skills, or the so called "data scientist's tool box," being recognized as essential for the field. A variety of requirements range from statistics, computer science [5, 7], and business knowledge to creativity, passion [10], and patience.

A poll, conducted by Gallup for the Business-Higher Education Forum in America, revealed that by 2021, 69% of employers expect candidates with data science analytics (DSA) skills to get preference for jobs in their organizations. Yet only 23% of college and university leaders say their graduates will have those skills. Digital infrastructure is being built out in public and private spaces across the US. With it, our capacity to generate and transmit data from and across devices, entities, systems, and sensor networks (embedded in the Internet of Things) is growing exponentially. Capacity, however, is only one of the essential enablers of digitization. Capability is essential, too, and that resides in the skills of people. The market for DSA skills is hot, but it's full of mismatches. There is a growing number of DSA degrees and credentials—since 2010, 303 new accredited DSA programs were launched in the US, a 52% increase overall [13].

There is a far deeper pool of STEM talent, but here, too, it's often unclear how well prepared these job candidates are to use data science and analytics in business pursuits. Meanwhile, business schools have very few programs that include DSA coursework.

DSA is a catalyst for change and innovation within universities not just because it is creating new professional disciplines, but also because it is altering so many established disciplines. As such, DSA can be seen as part of a broader set of trends that are challenging colleges and universities to:

- Change curriculums to meet skill needs
- Structure degrees and credentials for individual paths
- Provide a high-quality education at a reasonable cost
- Partner more frequently with employers
- Invest in their reputations for applied research

Some common trends to curb DSA skills shortage undertaken in the education sector include University-branded MOOCs, bootcamps, and hackathons. These help universities meet some of the challenges,

III. METHODOLOGY

Fundamentals of data science were first incorporated into an already existing semester module for Quality control and management- INDE 312. A course satisfaction survey was then conducted at the end of the semester among all the students who took the module. R platform was chosen as the data science tool throughout the semester. The survey was aimed at assessing individual perspectives on using R for data science and the actual learning impact on the module.

A. Learning in SPC with R

The survey question sought to gather the depth of understanding on the students on various statistical process control (SPC) tools. The students were asked to rate their understanding on a scale of 1 (not at all) – 5(very well), due to the use R during lab sessions. The SPC tools that students were exposed to during the semester are;

a. histogram or stem-and-leaf plot
b. pareto chart
c. cause-and-effect diagram
d. scatter diagram
e. variables control charts
f. attributes control charts
g. process capability analysis

85% of the students revealed a "moderate to very well" understanding of the concepts, enhanced by using R during lab sessions.

B. Data analysis and programming

This inquiry sought to understand the level of data analysis and programming skills that students acquired during the course of the semester as a result of using R. The ranking scale is in the range of 1(nothing) – 5(great deal).The following specific questions follow under this category.

a. solving quality control problems
b. writing quality data analysis reports
c. writing R code to analyse statistical data
d. working effectively with others

70% responses indicated a moderate to great deal of data analysis and programming skills gained in using R during the course of the semester.

C. Understanging the R Data Science Tool

The survey question sought to evaluate the students' overall understanding and mastery of R. The ranking scale is between 1 (not at all) - 5 (great deal). The category of the survey has many part questions as follows;

a. good understanding of the main concepts of R and its applications in SPC
b. understanding the relationship between SPC concepts
d. understanding of the relevance of R package to real world quality control issues
e. understanding of the nature of SPC
f. appreciation of the methods of SPC
g. ability to think through a problem or argument
h. confidence in your ability to do statistical process control
i. feeling comfortable with complex problems
j. enthusiasm for statistical process control (SPC)

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D. Industry Relevance

Students were asked, "How much of what you learned in this class (i.e., knowledge, skills, and other gains) do you think you will REMEMBER and CARRY WITH YOU into other classes or other aspects of your life?" The scale for rating ranged from 1 (nothing) – 5 (great deal). 80% of the class had responses from moderate and great deal, whereas 20% indicated that little of the learned aspects will be passed on to real life situations.

Generally students proved that they gained a great deal of knowledge about data science practice, using R. They showed readiness to take the skills acquired to industry practice.

IV. CONCLUSION

Data science skills are becoming more prominent in the modern day industry practice and the business fraternity. There is a call upon education institutions to be pragmatic in promoting data science oriented curriculum. The good news is that most platforms for data science and analytics are open source, which takes off the huge investment burden on education institutions. The main role demanded now is to invest in curriculum review in order to stay industry relevant. The pilot implementation of fundamental data science skills into an existing module proved to be very relevant and welcome by students. Using R during lab sessions drew interest and continuous engagement upon students, which is a very positive development in linking education and industry practice. Other strategies are needed to further reduce the gap between traditional qualifications oriented education and acquiring skills for industry job practice.

REFERENCES

[1] Eckerson, W. (2011) "BigDataAnalytics: Profiling the Use of Analytical Platforms in User Organizations," TDWI, September. Available at http://tdwi.org/login/default-login.aspx?src=%7bC26074AC-998F-431B-BC994C39EA400F4F%7d&qstring=tc%3dassetpg

[2] "Research in Big Data and Analytics: An Overview" International Journal of Computer Applications (0975 –8887) Volume 108 –No 14, December 2014

[3] Fosso Wamba, S., et al., How 'big data' can make big impact: Findings from a systematic review and a longitudinal case study. International Journal of Production Economics, 2015. 0(0): p. xx-xx.

[4] Strawn, G.O., Scientific Research: How Many Paradigms? EDUCAUSE Review, 2012. 47(3): p. 26.

[5] Manyika, J., et al., Big data: the next frontier for innovation, competition and productivity, 2011, McKinsey Global Institute.

[6] Hagstrom, M., High-performance analytics fuels innovation and inclusive growth: Use big data, hyperconnectivity and speed to intelligence to get true value in the digital economy. Journal of Advanced Analytics, 2012(2): p. 3-4.

[7] Sethuraman, M.S., Big Data's Impact on the Data Supply Chain, in Cognizant 20-20 Insights2012, Cognizant: New Jersey.

[8] Douglas, Laney. "The Importance of 'Big Data': A Definition". Gartner. Retrieved 21 June 2012.

[9] D. Fisher, R. DeLine, M. Czerwinski, and S. Drucker, "Interactions with big data analytics," interactions, vol. 19, no. 3, pp. 50–59, May 2012

[10] Ari Banerjee senior analyst, heavy reading, "Big data and advanced analytics in Telecom: A Multi-Billion-Dollar Revenue Opportunity," December 2013.

[11] Hadoop Wiki,"Apache Hadoop", Accessed : http://wiki.apache.org/hadoop

[12] Sheikh Ikhlaq and Dr. Bright Keswani," Computation of Big Data in Hadoop and Cloud Environment ",IOSR Journal of Engineering (IOSRJEN), Vol. 06, Issue 01 (January. 2016)

[13] Tableau, The State of Data Education 2016 (November 2016

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Pyrolysis of plastic waste into fuel and other products

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Abstract

In this article, we propose, design and implement a sustainable process technology that converts plastic waste into useful products. The nature of the raw material for our process (plastic waste) make our proposed technology serve a dual purpose of not only taking care of the solid waste management problem, but also producing cheaper, safer and more easily accessible products for the rural communities. The envisaged outcomes of our research outputs are an improvement in the general lifestyle of our people living in less advantaged communities as well as an opportunity for employment creation of the local youth if our process is scaled up into an industrial plant.

Keywords: Pyrolysis, Waste plastics, Fuel, By-products,

1. Introduction

Domestic and Industrial solid waste collection and disposal systems in Botswana are not as efficient as those in other developing African countries. Specifically, the mode of disposal of domestic plastic waste in smaller cities and villages in Botswana is a major concern. In big cities, the current waste management systems mostly entail use of dumping sites and landfills, where the majority of the waste has been identified to be plastics from different sources such as clinical, industrial and domestic waste. Although the rate of reaction associated with the degradation process of plastic waste is said to be slow that it is kinetically approximated not to be taking place, it is however thermodynamically feasible. Some chemical engineering reaction based researchers have argued that plastics can be broken down by acidic leachates under certain harsh conditions of temperature and pressure to give products that are both deleterious and obnoxious to the environment and to the underground water sources which in some areas serve as drinking water for livestock, wildlife and even the rural folk.

The composition of different forms and types of plastics is such that it is made up of different elements, with some of them having an adverse effect on the environment upon pollution. Despite these stated numerous plastic waste issues, the Botswana Government has only responded to this societal challenge by implementing some policies and inviting some NGOs and private companies on-board in assisting to combat this waste situation. But this approach has only been useful mostly in urban areas while no progress has been reported in villages like Palapye and smaller towns like Serowe. In these parts of the country, plastic waste will continue to increase with negative implications on the local economies and environment.

In this research article, we focus on designing and implementing a sustainable process that uses the plastic waste as its raw material in producing useful chemical products.

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We will demonstrate the feasibility of our process by first producing a measureable quantity of liquid fuel in the form of paraffin. Our technology will not only solve the plastic waste disposal problems and reduce landfill challenges, but will also produce products that are of economic value to the rural populace thereby improving their livelihood. We will also use the attainable region optimization technique to improve the efficiency of our process.

2. Theoretical background

2.1 The pyrolysis process

Traditionally, the production of liquid fuels, high and low molecular chain hydrocarbons (organic chemicals) as well as energy, has relied heavily on the gasification of coal, distillation of crude oil and hydro-power. As our natural resources have become depleted, and continue to do so due to the exponential growth of world population, the need to look elsewhere for sources of raw materials and alternative processes is imperative. The pyrolysis method of synthesizing useful products uses techniques that are the opposite of the Fischer-Tropsh (F-T) process. In the F-T process, carbonaceous material e.g. coal, is combusted in order to give syngas ($CO + H_2$). The syngas is then synthesized into targeted higher molecular chain hydrocarbons e.g. petrol, diesel and paraffin. The pyrolysis process starts with higher molecular chain hydrocarbons (plastic), then break it down (cracking) using either heat, a catalyst or hydro-energy into targeted smaller chain hydro-carbons e.g. liquid fuels.

2.2 The Attainable Region Approach.

In this article, we will apply the Attainable Region (AR) optimization technique to optimize the objective function by way of manipulating the input variables to result in maximum process outputs. The AR method is a modern day geometric optimization technique that has been applied successfully in the different disciplines of chemical engineering. This approach owes its origins to the field of chemical reaction engineering where Hildebrandt and Glasser (1990) tested it in choosing optimal reactor configurations. Over the years, different researchers have used this optimization method on their laboratory scale data with the aim of either minimizing an experimental manipulated variable or maximizing an associated process variable. Since one of the objectives of operating any process is to make profit, the AR technique assists in this regard by way of specifying optimal experimental parameters that will result in either a maximum or minimum condition of the objective function. The greatest advantage of the AR method is its versatility. The versatility of the approach lies in that it is generic across the field of chemical engineering and a researcher can apply this technique on any process parameter of choice. Smith and Malone (1997) also applied the technique in organic industrial chemistry where they optimized the molecular weights, monomer conversions and residence time in isothermal polymerization systems. In 1998, McGregor et al. went on to use the geometric ideas of the AR method in process synthesis in which they optimized a reactor-separator-recycle system. Godorr et al. (1999) extended the application of the technique in selecting optimal control and operating policies to situations where the rate vector depends on a control parameter. In the year 2000, Book and Challagulla used the technique in order to obtain

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optimal design and operating conditions for the adiabatic oxidation of sulfur dioxide to sulfur trioxide. Nicol et al. (2001) applied the technique in order to find an optimum process design for an exothermic reversible reaction system where provision was made for an external heating and cooling source. Over the years, the technique has been further modified and employed in various fields of chemical.

3. Experimental procedure

Group plastics into their seven classification categories using plastic numbers (low density polyethylene, polypropylene, polystyrene etc.), this classification makes it easy to separate the fuel into different elements unlike when different types of plastics are used. The different plastic types are then taken through a process of size reduction to increase the surface area for heat to act on them. Size reduction also enhances packing within the reactor. The reduced material is introduced into the reactor for heating under a certain pressure and temperature, initially the opening in the reactor leading to the delivery pipe is closed so that no vapour should escape until a certain period of time. The molecular vibrations are directly proportional to temperature therefore at higher temperatures the molecular vibrations are increased. The increase in molecular vibrations causes the bonds holding the molecules to break into smaller molecules (solid to liquid then vapour state). After a period of time succeeding the start of the reverse polymerisation process, the pipe is open to allow the flow of vapour through to the condenser where it is condensed to liquid and collected. The analysis of the condensate for chemical compositions is then carried out in either gas chromatography or liquid mass chromatography. Interpretation and analysis is made on the results to know the elements that are in high quantities and make a background research on them. The last step is to extract the elements through separation processes that are suitable for each molecule or element.

4. Results and discussion

Structural analysis of the results from pyrolysis is important since it helps in understanding of the results so that better ways of optimization can be identified with ease. The documents attached with this article shows the gas chromatography pyrolysis results for the sample which indicates about two hundred and thirty nine (239) different components that where present in the sample. The high number of components could have resulted from the fact that different types of plastics where put into the reactor at the same time. The other reason for the high number of components could have been because the sample was heated to higher temperatures, high temperatures enhance the bond breaking in compounds therefore favouring the formation of more of the smaller components. High temperatures also ensure that more gaseous components are formed than liquid components. The large number of components made the analysis of the results much difficult, more time is neded to analyse the whole batch of sample so as a result wasting more time, resources. Ways of reducing the number of components should be implemented to make analysis more easy and efficient. The mass spectra that also include the retention times of the different components is shown also below. The fuel obtained can be used as a multifuel (diesel and gasoline engines), the fact that it can work on both the diesel and gasoline engines have not been verified through tests in

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those particular engines. The type of plastic used matters a lot in the type of fuel that can be obtained because literature has shown that if polyethylene (all kinds of flexible non break plastics) is used, the liquid fuel that solidifies as it cools into paraffin will be obtained. If polypropylene is used no paraffin will be formed but only liquid fuel will be obtained. This shows that it should be considered very well on which plastics to be used depending on the desired product output.

169	PR1:4	1,2-Di(prop-2-ynyl)cyclohexane	14274083
244	PR1:4	Cyclopentanecarboxylic acid, 2-amino-, cis-	3738403
76	PR1:4	Decane, 2,2,3-trimethyl-	7823160
203	1	2-Octene, 2-methyl-6-methylene-	12541919
274	PR1:4	Oxalic acid, hexyl octadecyl ester	11877995
32	PR1:4	Dodecylcyclohexane	915348
113	PR1:4	2-Heptyne-4-one	11015356
27	PR1:4	1-Octyn-3-ol, 3-methyl-	837606
37	PR1:4	Cyclobutene, 3,3-dimethyl-	26120068
213	PR1:4	7-Heptadecyne, 17-chloro-	6506185
38	PR1:4	Cyanic acid, 2-methylpropyl ester	4255647
171	PR1:4	Fumaric acid, 3-phenylpropyl tridec-2-yn-1-yl ester	2462827
30	PR1:4	4-t-Butylcyclohexylamine	903240
153	PR1:4	4-Benzoyloxy-1-morpholinocyclohexene	3556517
47	PR1:4	2-Butyn-1-ol	1268880
70	PR1:4	Spiro[2.5]octane	6204544
114	PR1:4	2-Propenoic acid, 2-methyl-, oxiranylmethyl ester	23644763
231	PR1:4	Cyclohexane, 1-bromo-2-methyl-	7511464
178	PR1:4	Glycine, furfuryl ester	18481423
5	PR1:4	2-Propenoic acid, oxiranylmethyl ester	7897995
191	PR1:4	2,7-Octadiene-1,6-diol, 2,6-dimethyl-, (E)-	5914992
192	PR1:4	2-Pentene, 4-bromo-	2234377
44	PR1:4	2-Butanone, 1-(2-furanyl)-3-methyl-	4524799

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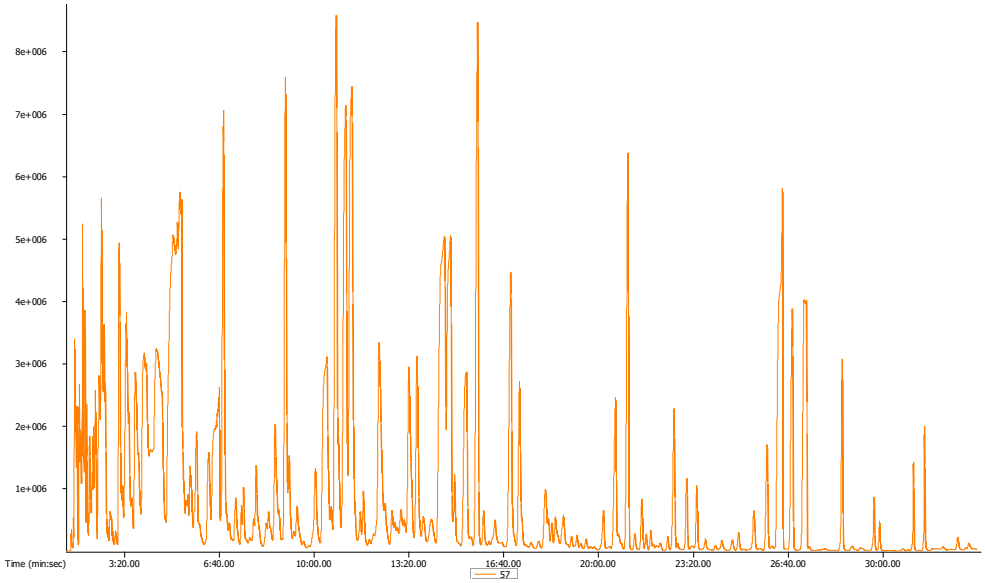

Figure 1:GC PROFILING DATA

Peak #	Sample	Area %	Name	Area	Group	R.T. (min:sec)	Weight	Similarity		
	UniqueMass		S/N							
218	PR1:4 171521	5.9689	Undecane	471030499	>0.08%	15:45.10	156	873	57	
95	PR1:4 249531	5.9301	Ethylbenzene	467973040	>0.08%	5:40.00	106	949	91	
124	PR1:4 82	5.1836	3-Hexen-1-ol, formate, (Z)-	409062963	>0.08%	7:09.90	128	773		
		188113								
165	PR1:4 62018	4.4147	1-Decene	348384460	>0.08%	10:26.60	140	937	57	
247	PR1:4 72250	4.3707	1-Dodecene	344911284	>0.08%	20:36.10	168	934	43	
23	PR1:4 56	4.2684	Aziridine, 1-(2-buten-2-yl)-	336840093	>0.08%	1:54.70	97	858		
		308327								
252	PR1:4 129901	3.8394	Tridecane	302981856	>0.08%	21:02.00	184	884	57	
228	PR1:4 210	3.7202	2,4,6,8-Tetramethyl-1-undecene	293579323	>0.08%	17:13.40				
		876	43	67253						

5. Conclusion and Recommendation

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The extraction of fuel and different other components have been carried out through the pyrolysis of plastic waste, the objective of the pyrolysis was achieved since fuel was obtained at the end and analysed for its chemical composition. The conclusions that follow were observed; the different types of plastics displayed the presence of many different components within their structure, the number of components that can be observed from the degradation process also shown to be dependent on the intensity of the heat. Even though the experiment was successful there are possible areas of improvement so as to optimize the process. First of all, a catalyst should be used to improve the degradation process and lower the degradation temperature, similar types of plastics should be heated per batch in order to reduce the variability of components per sample, lastly the temperature should be kept consistent at about 350-400 degrees to influence liberation of common type of fuel.

References

1. Amte, V. Nistala, S. Mahajani, S.M. Malik, R.K. Optimization based conceptual design of reactive distillation for selectivity engineering, Computer Aided Chemical Engineering 28 (2010) 1237-1242.
2. Asiedu, N. Hildebrandt, D. Glasser, D. Experimental simulation of a two-dimensional attainable region and its application in the optimization of production rate and process time of an adiabatic batch reactor, Industrial and Engineering Chemistry Research, 53 (2014) 13308-13319.
3. Beneke, D.A. Abbas, R. Hildebrandt, D. Glasser, D. Design and analysis of multiple thermally coupled configurations using column profile maps, 2011 AIChE Spring Meeting and 7th Global Congress on Process Safety, 11AIChE; Chicago, IL; United States; 13 March 2011 through 17 March 2011.
4. Book, N.L. Challagulla, V.U.B. Inherently safer analysis of the attainable region process for the adiabatic oxidation of sulfur dioxide Computers and Chemical Engineering, 24 (2000) 1421-1427.
5. Chimwani, N. Mulenga, F.K. Hildebrandt, D. Glasser, D. Bwalya, M.M. Use of the attainable region method to simulate a full-scale ball mill with a realistic transport model, Minerals Engineering, 73 (2015) 116-123.
6. Danha, G. Hildebrandt, D. Glasser, D. Bhondayi, C. A laboratory scale application of the attainable region technique on a platinum ore, Powder Technology, 274 (2015) 14-19.
7. Godorr, S. Hildebrandt, D. Glasser, D. McGregor, C. Choosing optimal control policies using the attainable region approach, Industrial and Engineering Chemistry Research, 38 (1999) 639-651.
8. Hamid, M.K.A. Sin, G. Gani, R. A New Model-Based Methodology for Simultaneous Design and Control of Reaction-Separation System with Recycle, Computer Aided Chemical Engineering, 26 (2009) 839-845.
9. Hlabangana, N. Danha, G. Hildebrandt, D. Glasser, D. Use of the attainable region approach to determine major trends and optimize particle breakage in a laboratory mill, Powder Technology, 291 (2016) 414-419.
10. Hildebrandt, D. Glasser, D. The attainable region and optimal reactor structures, *Chemical Engineering Science*, 45 (1990) 2161-2168.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

11. Hogg, R. Fuerstenau, D.W. Power Relations for tumbling Mills, Trans, SMEAIME, 252 (1970) 418-432.
12. Kauchali, S. Rooney, W.C. Biegler, L.T. Glasser, D. Hildebrandt, D, Linear programming formulations for attainable region analysis, Chemical Engineering Science, 57 (2002) 2015-2028.
13. Kauchali, S. Hausberger, B. Hildebrandt, D. Glasser, D. Biegler, L.T. Automating reactor network synthesis: Finding a candidate attainable region for the water-gas shift (WGS) reaction,

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Automatic channel allocation using cognitive radio

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***Abstract*— Due to the high demand of free channels and lack of channel regulation policies unlike in the licensed spectrum, users do not sufficiently utilise the open band and cause interference. As a result, conventional and traditional radios proven not to be sufficient. The present paper proposes a channel allocation method based on cognitive radio to automatically assign a user to the best available channel in the 2.4GHz spectrum. The approach used here studies the BIUST radio spectrum to measure the different power levels which also communicates the traffic distribution. Based on this information, a channel with less power is the best channel to allocate a user without causing interference to other users. It is evident that the proposed method gives better connectivity as shown by the even distribution of power signals across all channels in the power-channel graphs. This is in comparison with the static approach where some channels are centralised while there are free channels. Without a need for the radio equipment to be configured, it is able to sense, measure and allocate itself using its software based environment unlike the conventional radio technology.**

Keywords*— *cognitive radio, channels selection, unlicensed band, avoiding interference.

I. INTRODUCTION

In wireless radio network, the unlicensed spectrum was assumed to be free of interference and use of conventional radios was not a problem at first as there were very few devices using it until the introduction of the Internet of Things (IoT) [2]. This presented an opportunity for fast, cordless file transfer capabilities such as Device to Device (D2D) communications.

A computer scientist one day had an idea of implementing a cognitive program into the software defined radio (SDR) to enable it to automatically switch from one channel to another giving birth to the current Cognitive radio technology being used by engineers (**cite**). Cognitive Network (CN) became a very important concept as the saturation of spectrum became problematic, with this technology incorporated in to receivers, it enabled them to intelligently depict which channels are occupied and which are not. By instantly switching and avoiding occupied ones reduces channel interference.[2][3]

A. Motivation

Wi-Fi technology has become more than just a means to access internet, download, upload and browse. Sharing technology (e.g. mobile hotspots) has made devices dependent on each other and continuously sharing data and all this is done with in the limited free license spectrum and Wi-Fi is mostly considered convenient way to link devices causing an increase in demand for this unlicensed spectrum. Whenever increasing is not an option, we resort to maximizing efficiency. In this instance, this work intend to find techniques to identify the best available channel with minimal interference. Cognitive radios have some level of intelligence unlike conventional radios which are made with the assumption that there is no interference in their operating spectrum, cognitive radios have already made it possible for devices to allocate themselves channels without clear distinction of the best available channel.

B. Research Obectives

1. To measure the amount of traffic/noise/interference in each band

2. To select the least utilized band with minimal interference

3. Radio should be able to re-assign itself the next best available channel if interference is detected

C. Scope of work

The radio physical layer involves greater performance frequency circuitry. We need to play around and control the hardware to achieve new techniques and flexibility. Once we have input the signals using a transducer module out of the analog domain via the USB dongle, we need to receive and also process communication signals. After that, it is crucial that we limit the bandwidth, be efficient in our utilization of radio frequency spectrum and here our focus is on the unlicensed one, address whatever differences between the transmitter and the receiver. Also handle radios which are in motion, adapt for the physical communications from the transmitter to the receiver, allocate radio software and hardware resources for efficient communications, adaptation by learning how and when to share information, re-route network traffic as links disconnect and reconnect, and know how to adapt to the current situation in this complex and congested radio communications environment. Wireless networks are challenging systems because of the complex and unstable nature of signal propagation. At the end of the research this

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subject should be fully covered and addressed, and at the end of this paper the spectrum sensing and channel allocation problem will be addressed.

D. Report Structure

This report starts off with looking into the works of other engineers and researchers, their definitions and understanding of concepts, backgrounds and what they say about the variables/topics. By looking into the different works and connecting the ideas/variable helps in coming up with a possible solution to achieve the project objectives. Focus will be governed by IEEE802.11 regulations based upon: Cognitive Radio Technology, Wi-Fi access point and Software Development Radio environment.

II. Cognitive Radio Prototype Construct

A cognitive radio prototype system is built in MATLAB/Simulink and interfaced with two universal software radio peripherals to run in parallel. Besides a ready built Software Defined Radio ready-made software, MATLAB has a rich family of toolboxes that allows building software-defined and cognitive radio to explore various spectrum analyzing, prediction and management techniques [2]. All this will be built on the basis of. All waveform analysis such as sensing, cognition and management are done on the software host computer to be later employed on a microcontroller. The overall purposes such as high-speed operations of digital down and up interpolation and decimation inside the RDL-STR (Universal Software Radio Peripheral) [2][1]. At the end of this design chapter we should have a system design technology with aspects such as spectrum sensing, MIMO adaptabilities and spectral efficiency.

$$Y(t) = \begin{cases} n(t) \ldots\ldots\ldots\ldots\ldots \dot{H}_0 \\ h \cdot y(t) + n(t) \ldots\ldots H_1 \end{cases} \quad CharacteristicEquation$$

Equation 1

From equation one, an analysis of a spectral density function Y(t) can yield two outcomes. One being the null hypothesis H_0 and the other the alternative hypothesis H_1. The null hypothesis refers to areas of the spectral density distribution which only have additive white Gaussian noise only (AWGN), n(t) signifying that there are currently no active users. On the other hand the alternative hypothesis signifies that there is an active user y(t) with a gain factor h currently active.[4]

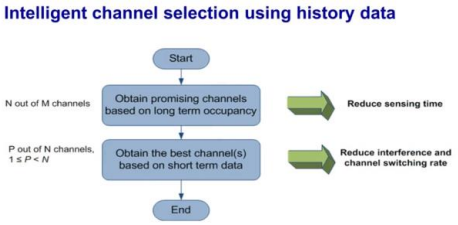

Fig 1: Algorithm flow

The method used to estimate the power spectral density is called the Periodogram which is calculated in units of power per radians per sample [2]. It also known as the Welch's method [4].

1. Cognitive Radio in MATLAB/Simulink implementation

In order to get an idea and better understanding of the concept of cognitive radio and its channel selection capabilities so we come up with techniques to better it. A basic MATLAB R2008a system with spectral efficiency algorithm is created to simulate the cognitive radio operations running the algorithm in figure 1 using the periodogram function.

2. Software-defined radio is a

communications structure where components that have been traditionally implemented in hardware (e.g. amplifiers, mixers, detectors, filters, modulators/demodulators, etc.) are instead implemented by means of software on a personal computer or finally on an embedded system. Using a device such as the one on figure 2, it acts as a transducer and an input into a computer's SDR platform where the signal manipulations will take place. [2]

Fig 2: RTL-SDR Radio

Possible Applications: CR channel selections have many ideal applications. This can be multimedia wireless networking such as in homes (e.g. casting, SHAREit app), emergency high data rate communications such as in the combat field (e.g. SSG tactical situation video), broadband

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wireless networking in case of localized wireless network such as "hotspots".

III. Results

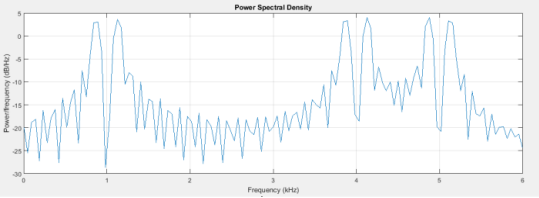

Fig 3: Initial PSD

For this research, five channels are being used for the tests rather than the actual 13 channels commonly available. From the results shown in figure 3, channels 1, 4 and 5 are currently occupied by networks which are referred to as primary users (PU's). These could be mobile hotspots, Wi-Fi networks, Bluetooth connections etc.

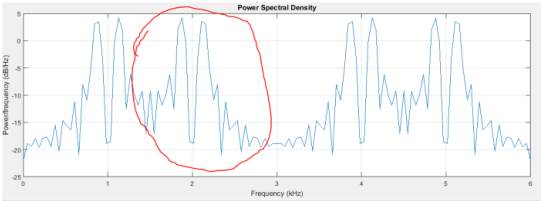

Fig 4: Final PSD

Initially we had 3 primary users operating in the unlicensed band. In order to an additional user, the forth user, which will be the secondary user (SU) with the cognitive radio program. It will run the cognitive radio algorithm embedded in it and eventually come to a decision on the best channel to assign to having considered all factors. In this instance, form just visual observation of figure 3 we can conclude that channels 2 and 3 were the best choice because of their minimal network traffic. Through the Welch method the SU was assigned to channel 2 which was the best alternative as well as channel 3.

What makes cognitive radio using the Welch method most impressive is the ability to initially scan the different channels and assign a new user such as in figure 4. Channels with traffic cannot be confused with AWGN because of the huge difference between the two energy levels.

Conclusion

Traditional wireless technology devices have limited coexistence and spectrum sharing mechanisms as compared to cognitive radio which is an adaptive system. Cognitive radio would offer greater Wi-Fi network synchronicity mechanisms currently using the advanced cognition. And eventually after further developments, forecasting techniques for various wireless communication systems. Secondly, we developed a prototype environment (testbed) for manipulation, experimenting and emulating the cognitive radios on-top-of software defined radios built in MATLAB/- Simulink and interfaced with an RTL-SDR Radio dongle from Adafruit. The research challenges of cognitive radios are also briefly considered.

References

[1] Kapoor, Shipra, S. V. R. K. Rao, and Ghanshyam Singh. "Opportunistic spectrum sensing by employing matched filter in cognitive radio network." *Communication Systems and Network Technologies (CSNT), 2011 International Conference on*. IEEE, 2011.

[2] Tabassam, A. A., Ali, F. A., Kalsait, S., & Suleman, M. U. (2011, March). Building software-defined radios in MATLAB Simulink-a step towards cognitive radios. In *Computer Modelling and Simulation (UKSim), 2011 UkSim 13th International Conference on* (pp. 492-497). IEEE.

[3] Di Benedetto, M., Ferrante, A., & De Nardis, L. (2012, October). Cognitive radio and networking for cooperative coexistence of heterogeneous wireless networks. In *Satellite Telecommunications (ESTEL), 2012 IEEE First AESS European Conference on* (pp. 1-6). IEEE.

[4] Faridi, M. H., Jafari, A., & Dehghani, E. (2016). An Efficient Distributed Power Control in Cognitive Radio Networks. *International Journal of Information Technology and Computer Science (IJITCS)*, *8*(1), 48.

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Simultaneous determination of nitrate, nitrite and phosphate in environmental samples by high performance liquid chromatography with UV detection

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***Abstract*—An HPLC method using an UV detector was developed for the simultaneous determination of nitrites, nitrates and phosphates for environmental samples. Chromatographic separation was achieved on a Phenomenex Synergi Polar-RP LC column using acetonitrile and acidified water (pH 2.7) at 60:40 v/v as mobile phase, isocratically at a flow rate of 0.800 mL/min. Baseline resolution of all the three analytes was achieved within 3 min. The calibration curves for nitrite, nitrate and phosphate in the range of 1.0 – 50.0 ppm were linear with correlation coefficients of more than 0.999 for all the analytes. The developed method was applied to water samples obtained from the wastewater treatment plant in Gaborone, Botswana. The use of HPLC technique in this study demonstrated its ability to carry out a simultaneous determination of nitrite, nitrate and phosphate in water samples. The treatment plant was found to be functioning within expectations, as it led to the removal of 97.6% nitrite, 88.0% nitrate and 90.9% phosphate from the received wastewater. Nevertheless, the concentrations of the analytes in the effluent tank were found to exceed the limits set by the Water Utilities Corporation. Results of the developed method were comparable with those of the traditional Ion chromatography method, showing accuracy values between 95.22% – 98.04%. The precision of the method for the determination of all analytes was determined by RSD values, all of which were lower than 5%. The method is of low cost, fast, has an easy procedure and avoids the use of many reagents – some of which may be hazardous.**

Keywords—simultaneous determination; environmental samples; baseline resolution; nitrite; nitrate; phosphate; wastewater treatment; HPLC; Ion chromatography; low cost method

I. INTRODUCTION

Nitrogen is a vital nutrient for both plants and animals [1]. In the environment, it exists as nitric oxide (NO), nitrite (NO_2^-) and nitrate (NO_3^-). These are ubiquitous within biological, food and environmental samples [2]. In water, NO_3^- occurs both naturally and through external inputs which may include run-off from agricultural soils, soil organic matter as well as livestock and human faecal material [3]. Contamination of groundwater resources by nitrate is mainly a consequence of anthropogenic activities and uncontrolled discharges from industries, agricultural activities, sewage treatment plants and pit latrines [4].

Contamination of water and food sources by nitrate is a concern as it may result in methemoglobinaemia [5], which may eventually lead to mental retardation [6]. Nitrite may react with amines in human bodies to form nitrosamines, which are said to be carcinogenic [1]. In surface waters, excess nitrates and nitrites lead to algal blooms, resulting in lowered levels of oxygen in the water, leading to eutrophication [7].

Phosphates are of great importance in numerous fields such as in the manufacturing of fertilizers, detergents, beverages and semiconductors [8-10]. However, excessive phosphorus concentration in waters leads to over growth of aquatic plants and algal bloom formation, which ultimately result in the depletion of dissolved oxygen in water. This is then followed by the death and decay of aquatic life and degradation of the water quality [11-13].

It is for the above-mentioned reasons that a simple and sensitive analytical method is desirable for the monitoring and routine analysis of nitrates, nitrites and phosphates, both in water and soil samples.

Several analytical techniques such as electrophoresis [14], potentiometry [15], gas chromatography (GC) [2], ion exchange chromatography (IC) [16], and high-performance liquid chromatography (HPLC) [2], have been applied in the determination of NO_2^-, NO_3^- and PO_4^{3-} in different samples. Many of these techniques (e.g. electrophoresis) suffer from drawbacks such as interferences caused sample matrix [17] and/or lack of reproducibility of migration times which can cause errors in peak identification [18]. Although electroanalytical techniques such as potentiometry, amperometry, voltammetry and polarography do not suffer from interferences and do not require extensive pre-treatments [19], they however tend to suffer from poor reproducibility upon reuse [15] due to poisoning of the biosensor films used in

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them. GC cannot be used in the determination of PO_4^{3-} due to its requirement that the sample be highly volatile [20,21].

IC is normally the method of choice for the determination of these nutrients. Examples include the analysis of water (natural, waste and seawater) [16], sediments [22], fertilizers and soils [23], foodstuffs [23], dairy products [24] and clinical fluids [25]. Although IC is characterized by high sensitivity, it is prone to temperature variations and matrix effects – particularly in the determination of nitrate in the presence of chlorides (Cl^-), sulphate (SO_4^{2-}) and bromide (Br^-) [26,27]. Modifications to try and circumvent this problem resulted in lower sensitivities and poor resolution between the analyte and interferents peaks [28]. In order to circumvent these difficulties, extensive sample preparations and separation steps are needed, which usually lead to increased overall determination time and low sample throughput [5,24].

HPLC is a much more rapid, sensitive and selective technique than most methods of analysis, hence it is a better choice for the determination of nitrate, nitrite and phosphate in water samples. Although the determination of NO_2^-, NO_3^-, and PO_4^{3-} has been carried out using HPLC, the simultaneous determination of these analytes are limited. The objective of this study was therefore to develop a specific, sensitive, cost-effective, and reliable analytical method that can be applied in the simultaneous determination of nitrate, nitrite and phosphate. The attributes of the developed method (e.g. precision, accuracy, LOD etc.) were determined by comparing HPLC results with those obtained from the IC method.

II. Materials and Methods

All commercially available reagents and solvents (potassium dihydrogen phosphate, sodium nitrite, sodium nitrate, potassium thiocyanate, methanol, acetonitrile Dionex, seven-anion standard solution, ECG III KOH eluent generator) used in this study were of analytical-reagent grade and were used without further purification. Distilled, de-ionized water (DDW, 18 MΩ/cm) was used in all sample preparation procedures. All glassware used was soaked in 10% HCl for 24hrs, and rinsed several times with DDW prior to use.

Different mobile phase compositions in various mixture ratios using methanol (Sigma-Aldrich, Steinheim, Germany), acetonitrile (Sigma-Aldrich, Steinheim, Germany) and distilled – deionised water, were used to elute the prepared analyte standards.

A Dionex, seven-anion standard mixture (purchased from Thermo Fisher Scientific, California, USA), which contains a mixture of F (20ppm), Cl^- (100 ppm), NO_2 (100 ppm), Br^- (100 ppm), NO_3^- (100 ppm), PO_4^{3-} (200 ppm) and SO_4^{2-} (100 ppm) was used to prepare calibration mixtures for nitrate, nitrite and phosphate within a working range of 1.00 to 100.00ppm in DDW. Working standards were prepared freshly daily in 50 mL volumetric flasks.

A. Sample collection

Wastewater samples were collected from the Glenvalley Wastewater Treatment Plant (GVWTP) in Gaborone, Botswana on the 24th Feb 2015. Samples were collected from the treatment plant at the inlet, primary settlement tank, secondary settlement tank, aeration tank and final effluent. They were immediately taken to the laboratory and stored at 4ºC until further analysis.

III. Experimental

A. HPLC Method Optimisation

Analyses with HPLC-UV were performed using an Agilent Technologies HPLC-UV equipped with a diode array detector. In order to achieve the best method characteristics, the main parameters leading to a good separation in HPLC (mobile phase composition, temperature, pH, flow rate, etc) were optimized.

The stationary phase used was a Phenomenex Synergi Polar-RP LC column, with the dimensions: 150 x 4.6 mm 4 µm, 80 Å. This column showed maximized retention and selectivity for polar analytes with an improved peak shape [29]. Furthermore, it is able to withstand low pH conditions, has the highest cation selectivity [29] and is reported to be stable in 100% aqueous conditions [29-31], allowing for a wide range of mobile phase composition variation.

The wavelength of maximum absorbance for all the analytes was determined with an Evolution 201 UV-Vis spectrophotometer (Thermo Scientific, USA), set to scan peaks at λ = 190nm to 800.0nm. A mixture of standard solutions of $NaNO_3$, $NaNO_2$ and Na_3PO_4 was then made, in which the concentration of each of the analytes was 20ppm each. This mixture was also scanned using the same UV-VIS spectrophotometer at a wavelength range of 190 – 800nm. For all the analytes of interest, λ_{max} was found to be 207.4nm. This wavelength was then used for all subsequent experiments using an Agilent Technologies HPLC-UV equipped with a diode array detector.

Different mobile phase compositions in various mixture ratios using methanol, acetonitrile and DDW, were used to elute the prepared analyte standards. Experiments were carried out using methanol, acetonitrile and water at various methanol:water and acetonitrile:water ratios (from 100:0 v/v to 0:100 v/v each). A mixture of the analytes (in which the final concentration of each analyte was 20ppm) was injected at these mobile phase compositions in order to investigate and optimize the separation.

The pH of the mobile phase was altered by adding concentrated H_2SO_4 to the aqueous part of the mobile phase so as to vary the pH of the aqueous part in the range of 0.5 to 6.5, at increments of 0.5 units. A mixture of the analytes (20ppm each) was injected at each pH value in order to investigate and optimize the separation of the different analytes.

System temperature was varied from 10ºC up to 70ºC, at increments of 5ºC for experiments carried out using both methanol and acetonitrile as organic modifiers.

Optimization of the mobile phase volumetric flow rate was carried out in the range of 0.20 mL/min to 1.50 mL/min using the optimum conditions found above. The best separation conditions, hence the optimum mobile phase flow rate, was determined based on the resolution between the different

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components at each flow rate. The total analysis time was also taken into consideration.

B. *Ion Chromatography (IC) Analysis*

A Dionex ICS-2100 Ion Chromatography System and Chromeleon® Chromatography Data System software were used in this study. The chromatography system was fitted with a 2 x 250 mm IonPac AS18 Analytical column, preceded by a 2 x 50 mm IonPac AG18 Guard Column. The EGC III KOH Cartridge was used as an eluent source, set to produce an eluent of 32 mM potassium hydroxide. The column temperature was set to 30°C and the flow rate set at 0.25 mL/min. Detection was carried out using a DS6 heated conductivity cell.

IV. RESULTS AND DISCUSSION

A. *HPLC method optimisation*

Fig 1 to Fig 3 show the chromatograms which were obtained using a 20ppm mixture of nitrate, nitrite and PO_4^{3-} standards at an optimum wavelength of 210nm. Peak letters correspond to the following substances: a) NO_2^- , b) NO_3^-, c) SCN^- (internal standard) and d) PO_4^{3-}

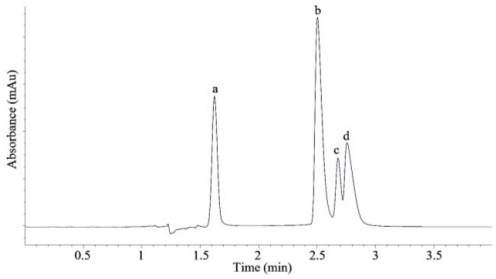

Fig. 1. Chromatogram for a mixture of NO_2^-, NO_3^-, PO_4^{3-} and SCN^- (20ppm each) standards by HPLC-UV using 100 % acetonitrile at a wavelength of 210nm.

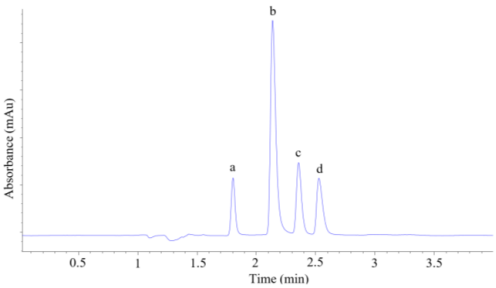

Fig. 2. Chromatogram obtained in the separation of NO_2^-, NO_3^-, KSCN and PO_4^{3-} (at a final concentration of 20ppm each) with a mobile phase composed of CH_3CN : acidified H_2O = 55:45 v/v. Peak letters correspond to the following substances: a) NO_3^- , b) NO_2, c) KSCN and d) PO_4^{3-}

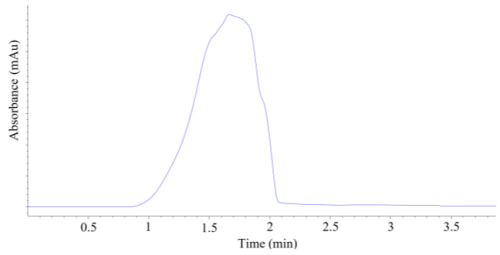

Fig. 3. Chromatogram obtained in the determination of a mixture of NO_2^-, NO_3^-, and PO_4^{3-} standards (at a final concentration of 20ppm each) by HPLC-UV using 100 % water

Elution was improved by increasing the amount of the aqueous component (CH_3CN : acidified H_2O = 55:45 v/v). This resulted in a better resolution between all the three analytes (Fig 2). An additional increase in the polarity of the mobile phase (CH_3OH : acidified H_2O = 50:50 v/v) resulted in loss of resolution even though there was a slight improvement in the shapes of some peaks. Further loss of resolution resulted when the mobile phase was made more polar (Fig 3).

Since a high throughput and productivity was also required, the time of analysis (i.e. method run-time) was also considered. A method with a short run-time saves time and expense, hence it is preferred. Baseline resolution of all the three analytes was achieved at the shortest possible time (3 min; Fig 2) using a mobile phase composition of MeCN: acidified H_2O (pH 2.7) = 55:45 v/v. This is a huge improvement when compared to the ion chromatography method, which has a total run time of more than 10 minutes (see Fig 5).

B. *Analytical parameters*

The developed HPLC method was validated by determining its figures of merit (accuracy, precision, linearity, limits of detection (LOD) and quantification (LOQ)). The results obtained from the developed method were comparable with those from the traditional IC method. Table 4 shows the numerical values of the concentrations obtained by the two methods.

The accuracy of the HPLC method was expressed through recovery calculations using wastewater samples that had previously been analysed and found to contain 33.87, 20.87 and 5.77ppm NO_2^-, NO_3^-, and PO_4^{3-} respectively. Three different concentrations of each analyte were prepared by measuring 2.5 mL of the wastewater sample in three different volumetric flasks, then spiking with different amounts of 1000 ppm stock solution (of each analyte) and making up to 10mL final volume with DDW. This formed final concentrations of 10ppm, 50ppm and 100ppm each of NO2-, NO3-, and PO43- in the different volumetric flasks. The blank was prepared by spiking DDW with the same amount of analytes to give the same final concentration in the different levels. These spiked samples were then analysed with both HPLC and Ion Chromatography. Percentage recoveries were calculated as follows:

$$\% \text{ Recovery} = \frac{\text{Determined concentration of spiked sample}}{\text{Known spike added concentration}} \times 100\% \quad (1)$$

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As shown in Table 1, the recoveries for all samples at all levels were found to be above 93.20%. The high level of accuracy, together with low RSD values (which were found to range from 1.29% (NO_2^-) to 4.92% (PO_4^{3-})) indicate that the method is accurate and precise – hence reliable and its results can be trusted.

Linearity was assessed based on a plot of the analyte peak area ratios to IS (KSCN) versus analyte concentration. The results proved to be linear and acceptable, as the correlation coefficients (R^2) were greater than 0.999 for all the analytes (Table 2).

Linear Dynamic Range (LDR) was determined over the concentration range of 0.200–200 mg/mL, which is a significant progress when compared with most methods for the analysis of nitrate and nitrite, which are linear over only very narrow concentration ranges. These wide linearity ranges enabled quantification of the analytes at different process points.

TABLE 1: RECOVERIES OF NITRITE, NITRATE AND PHOSPHATE SPIKED INTO WASTEWATER SAMPLES

Analyte	Technique	%Recovery at Concentration Level		
		5 ppm	*50 ppm*	*150 ppm*
NO_2^-	HPLC	92.08 ± 7.46	94.29 ± 0.13	100.75 ± 1.33
	Ion Chrom	98.76 ± 0.16	98.13 ± 1.12	102.03 ± 3.02
NO_3^-	HPLC	110.65 ± 2.72	92.27 ± 1.20	96.59 ± 1.22
	Ion Chrom	98.89 ± 0.69	97.65 ± 0.36	93.93 ± 0.71
PO_4^{3-}	HPLC	94.25 ± 2.39	88.47 ± 0.17	98.87 ± 0.40
	Ion Chrom	98.52 ± 0.63	93.12 ± 0.21	96.76 ± 0.20

TABLE 2: LINEARITY DATA OBTAINED IN THE ANALYSIS OF NO_2^-, NO_3^- AND PO_4^{3-} USING THE DEVELOPED HPLC-UV/DAD METHOD

Analyte	Calibration equation	R^2	LDR (ppm)
Nitrite	y = 0.0608x + 0.0050	0.9995	0.200 – 200.000
Nitrate	y = 0.3188x + 0.1280	0.9996	0.200 – 200.000
Phosphate	y = 0.0956x + 0.0269	0.9991	0.200 – 200.000

TABLE 3: LOD AND LOQ VALUES OF HPLC AND ION CHROMATOGRAPHY FOR THE ANALYTES OF INTEREST. ALL VALUES ARE GIVEN IN mg/L

Analyte	Nitrite		Nitrate		Phosphate	
Method	LOD	LOQ	LOD	LOQ	LOD	LOQ
HPLC	0.451	1.504	9.451	31.504	1.334	4.447
Ion Chrom	0.147	0.491	0.340	1.134	0.264	0.880

The calibration sensitivity, defined by IUPAC [32] as the slope of the calibration curve is also reported in Table 2. The high sensitivity values obtained for the analytes imply that low injection volumes will be adequate for detection.

The limits of detections (LODs) and Limits of quantifications (LOQ) were estimated based on the signal background noise. The level of noise was measured from chromatograms of the lowest standard at concentration of 0.01mg/L. The LODs and LOQs were calculated from equations 3 and 4 respectively.

$$LOD = y_B, + 3s_B \quad (n=7) \tag{2}$$

$$LOQ = y_B, + 10s_B \quad (n=7) \tag{3}$$

Where: y_B = blank signal, and s_B = standard deviations of the blank samples spiked with low concentration of analytes.

The LODs obtained by the HPLC-UV/DAD method are given in Table 3.

These values are considerably higher than the LODs obtained by IC and the limits established by WHO [33]. Nevertheless, they are lower than the typical concentrations of these analytes in wastewater samples, therefore the HPLC method is still valid for analysis of this type of samples.

C. Application of method to wastewater samples

Wastewater entering the GVWTP contains considerable amounts of nitrates, nitrites and phosphates due to the chemicals used in both households and industries. The purpose of the treatment plant is to reduce the amount of these analytes as the water goes through the different treatment stages.

The selectivity of the method was established by the analysis of water samples obtained from the inlet of the wastewater treatment plant. These are the dirtier samples as they have not yet undergone any treatment. No interferent peaks were observed at the retention times of NO_2^-, NO_3^- and PO_4^{3-} in any of the samples (Fig 4). A chromatogram obtained from the analysis of the same sample by Ion Chromatography is shown in Fig 5.

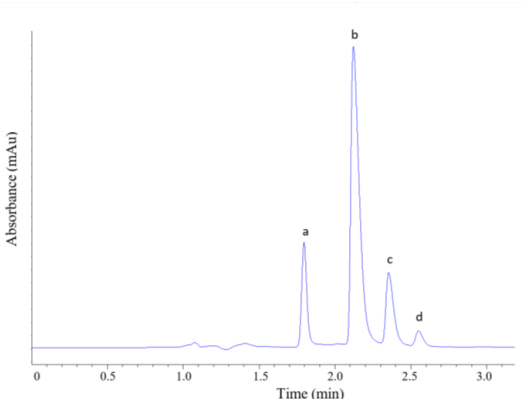

Fig. 4. HPLC-UV chromatogram of raw wastewater sample collected from the inlet of the wastewater purification plant. Peak letters correspond to the following substances: a) NO_2^- , b) NO_3^-, c) $SCN^-$and d) PO_4^{3-}

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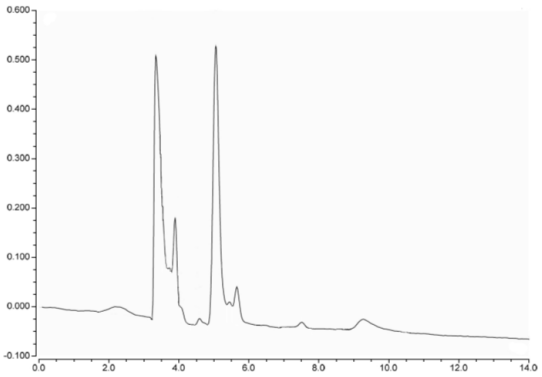

Fig. 5. Ion Chrom chromatogram of raw wastewater sample collected from the inlet of the wastewater purification plant. Peak letters correspond to the following substances: a) Fl^-, b) Cl^-, c) NO_2^-, d) Br^-, e) SO_4^{2-}, f) NO_3^- and g) PO_4^{3-}

Since Ion chromatography is not selective to the analytes of interest, it is prone to interferences which result from matrix components. More often than not, it was difficult to intergrate the nitrite peak quantitatively due to the interference caused by chloride. As a result, analysis by Ion chromatography requires more sample cleanup steps to remove the interfering species. This increases the overall analysis time and sample handling steps, which may lead to sample losses and/or the introduction of artifacts. method was validated by determining its figures of merit (accuracy, precision, linearity, limits of detection (LOD) and quantification (LOQ)). The results obtained from the developed method were comparable with those from the traditional IC method. Table 4 shows the numerical values of the concentrations obtained by the two methods.

IC was however found to be more precise than HPLC. Table 4 shows the standard deviation and %RSD values obtained in the determination of NO_2^-, NO_3^- and PO_4^{3-} in wastewater tanks. Standard deviation values and %RSD (ion chromatography) range from 0.44 – 3.62, while %RSD (HPLC) range from 1.29 – 4.85.

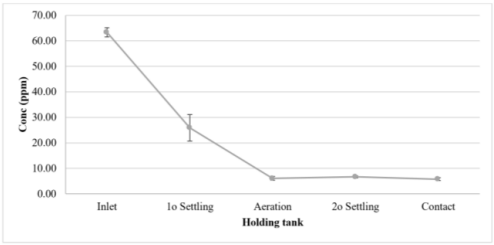

Fig 6. Concentration profile of phosphate along the different holding tanks in the GVWTP at a mobile phase composition range of MeCN:H20 = 60:40, flowrate of 0.800 mL/min and a column temperature of 30oC.

The effects of treatment process on the amount of PO_4^{3-} is shown in Fig 6.

The water obtained from the effluent tank (at the end of the treatment process) was found to have 9.11% of the amount of phosphate initially present at the inlet. This translates to a phosphate removal efficiency of 90.89%. Similar trends were observed for nitrites and nitrates, with a removal efficiency of 97.59% and 87.99% respectively (see Table 5).

The removal of nitrogen in the water occurs through nitrification – a process in which ammonia is biologically converted to nitrate according to the following equations [34, 35]:

$$NH_3 + O_2 \longrightarrow NO_2^- + 3H^+ + 2e^- \quad (4)$$

$$NO_2^- + H_2O \longrightarrow NO_3^- + 2H^+ + 2e^- \quad (5)$$

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+ \quad (6)$$

$$2NO_2^- + O_2 \longrightarrow 2NO_3^- \quad (7)$$

The production of both NO_2^- and NO_3^- in the steps above could be used to explain the trends seen in Fig 2 and Fig 3, whereby the amounts of both NO_2^- and NO_3^- increase from the inlet tank to the primary settlement tank. This process is followed by denitrification, where nitrate is reduced to nitrogen gas [36]:

TABLE 4: COMPARISON OF THE CONCENTRATION OF NO_2^-, NO_3^- AND PO_4^{3-} IN WASTEWATER SAMPLES COLLECTED FROM HOLDING TANKS USING IC AND HPLC –UV METHOD.

Analyte	Technique	Inlet		1º Settlement		Aeration		2º Settlement		Effluent	
		Conc (mg/L) ± Std Dev	*% RSD*	*Conc (mg/L) ± Std Dev*	*% RSD*	*Conc (mg/L) ± Std Dev*	*% RSD*	*Conc (mg/L) ± Std Dev*	*% RSD*	*Conc (mg/L) ± Std Dev*	*% RSD*
NO2-	HPLC	1409.06 ± 63.41	4.50	3528.52 ± 107.27	3.04	115.78 ± 3.80	3.28	143.90 ± 1.85	1.29	33.87 ± 0.76	2.24
	Ion Chrom	1315.41 ± 39.60	3.01	3763.82 ± 26.84	0.71	120.03 ± 1.02	0.85	147.11 ± 1.70	1.16	36.49 ± 1.32	3.62
NO3-	HPLC	173.75 ± 6.17	3.55	340.64 ± 11.01	3.23	21.96 ± 0.45	2.05	15.48 ± 0.63	4.07	20.87 ± 0.71	3.40
	Ion Chrom	157.89 ± 0.69	0.44	348.84 ± 11.79	3.38	23.93 ± 0.71	2.97	16.90 ± 0.24	1.42	22.50 ± 0.75	3.33
PO43-	HPLC	63.34 ± 1.79	2.83	25.93 ± 0.53	2.04	6.08 ± 0.17	2.80	6.68 ± 0.22	3.29	5.77 ± 0.28	4.85
	Ion Chrom	63.52 ± 0.63	0.99	23.12 ± 0.21	0.91	6.76 ± 0.20	2.96	6.77 ± 0.15	2.22	5.46 ± 0.10	1.83

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TABLE 5: OBTAINED AMOUNTS AND MAXIMUM LIMITS FOR WASTEWATER ENTERING AND LEAVING GVWTP

Holding tank	NO_2^- (mg/L)		NO_3^- (mg/L)		PO_4^{3-} (mg/L)	
	Obtained amount	*WUC limit*	*Obtained amount*	*WUC limit*	*Obtained amount*	*WUC limit*
Inlet	1409.06	200	173.75	100	63.34	30
Effluent (contact tank)	33.87	1.5	20.87	10	5.77	1.5
Removal Efficiency	97.59	--	87.99	--	90.89	--

$$NO_3^- \quad NO_2 \quad NO + N_2O \quad N2$$

$$2NO_3^- + 10e^- + 12H^+ \longrightarrow N_2 + 6H_2O$$

It is due to the denitrification process that the amounts of NO_2^- and NO_3^- are reduced as the water travels to the secondary settling tank, aeration tank and contact tanks.

The removal of phosphate in the wastewater is also seen to be effective since the phosphate amount decreases as the wastewater travels through the treatment process. Phosphorus in wastewater can be removed biologically by polyphosphate-accumulating organisms, which accumulate large quantities of phosphate within their cells [37,38]. Chemical removal of phosphorus in wastewater also occurs through precipitation with iron, alum or lime [39].

Although the removal efficiency of these nutrients is satisfactorily high, the amounts of the analytes in the effluent were still above the limits set by the Water Utilities Company as shown in Table 6. This is in contrast to the studies done in 2005 by Nkegbe and co workers [40], who found the effluents to be below the maximum allowable effluent levels of <1 (PO_4^{3-}) and <5 (NO_3^-), thereby implying that the wastewater treatment process is not functioning accordingly in the removal of the analytes of interest from wastewater. This water however undergoes further natural treatment as the effluent from the plant is released to maturation ponds and then discharged to the Notwane River. Some of the water is used to irrigate golf courses, lawns and crops grown under the Glen Valley irrigation project [41].

V. CONCLUSIONS

The use of HPLC technique in this study demonstrated its benefit of being able to carry out a simultaneous determination of NO_2^-, NO_3^- and PO_4^{3-} in water samples. Furthermore, HPLC is fast and does not require extensive sample preparations, which may lead to sample losses and the introduction of artifacts. It also does not require derivatization, hence avoids the use of many reagents – some of which may be hazardous. Furthermore, HPLC is efficient and economical as it requires the use of fewer amounts of reagents. A single injection in HPLC requires filling a 20 µL loop. In contrast, IC requires a sample volume of 5 mL, all of which is consumed in a single injection.

The developed method was employed to quantify nitrite, nitrate and phosphate content of water from different stages of a wastewater treatment plant. The analyte concentrations were found to be reducing at each stage of treatment, with percentage removal of 97.59% (NO_2^-), 87.99% (NO_3^-) and 90.89% (PO_4^{3-}).

Although the final effluent has not been tested for the presence/absence of pathogenic organisms, it is however environmentally friendly with regards to the analytes of interest and may be used for applications which do not require potable water (such as irrigational or industrial purposes). Although this may not directly augment existing water sources, it may provide an additional source of water supply which will assist in meeting the water needs of Botswana.

REFERENCES

[1] Chetty, A. A. & Prasad, S. 2009. Flow injection analysis of nitrate-N determination in root vegetables: Study of the effects of cooking. *Food Chemistry*, **116**:561–566.

[2] Akyüz, M. & Ata, S. 2009. Determination of low level nitrite and nitrate in biological, food and environmental samples by gas chromatography–mass spectrometry and liquid chromatography with fluorescence detection. *Talanta*, **79**:900–904.

[3] Mikuška, P. & Vecera, Z. 2003. Simultaneous determination of nitrite and nitrate in water by chemiluminescent flow-injection analysis. *Analytica Chimica Acta*, **495**:225–232.

[4] Stamatis, G., Alexakis, D., Gamvroula, D. & Migiros, G. 2011. Groundwater quality assessment in Oropos-Kalamos basin, Attica, Greece. *Environmental Earth Sciences*, **64**:973–988.

[5] Burakham, R. Oshima, M., Grudpan K. & Motomizu S. 2004. Simple flow-injection system for the simultaneous determination of nitrite and nitrate in water samples. *Talanta*, **64**:1259–1265.

[6] Cemek, M. Akkaya, L., Birdane, Y. O., Seyrek, K., Bulut, S. & Konuk, M. 2007. Nitrate and nitrite levels in fruity and natural mineral waters marketed in western Turkey. *Journal of Food Composition and Analysis*, **20**:236–240.

[7] Lyddy-Meaney, A. J., Ellis, P. S., Worsfold, P. J., Butler, E. C. V. & McKelvie, I. D. 2002. A compact flow injection analysis system for surface mapping of phosphate in marine waters. *Talanta*, **58**:1043–1053.

[8] Motomizu, S & Li, Z. H. 2005. Trace and ultratrace analysis methods for the determination of phosphorus by flow-injection techniques. *Talanta*, **66**:332–340.

[9] Hrynczyszyn, P., Jastrzębska, A. & Szłyk, E. 2010. Determination of phosphate compounds in meat products by 31-Phosphorus Nuclear Magnetic Resonance spectroscopy with methylenediphosphonic acid after alkaline extraction. *Analytica Chimica Acta*, **673**:73–78.

[10] Welz, B., Lepri, F. G., Araujo, R. G. O., Ferreira, S. L. C., Huang, M., Okruss, M. & Becker-Ross, H. 2007. Determination of phosphorus, sulfur and the halogens using high-temperature molecular absorption spectrometry in flames and furnaces – A review. *Analytica Chimica Acta*, **647**:137–148.

[11] Ejhieh, A. N. & Masoudipour, N. 2010. Application of a new potentiometric method for determination of phosphate based on a surfactant-modified zeolite carbon-paste electrode (SMZ-CPE). *Analytica Chimica Acta*, **658**:68–74.

[12] Nagendrappa, G. Mahadevaiah, M. S., Kumar, Y., Mansour, S., Galil, A., Suresha, M. S. & Sathish, M. A. 2007. A Simple Spectrophotometric Determination of Phosphate in Sugarcane Juices, Water and Detergent Samples. *E-Journal of Chemistry*, **4**:467–473.

[13] Shyla, B., Mahadevaiah & Nagendrappa, G. 2011. A simple spectrophotometric method for the determination of phosphate in soil, detergents, water, bone and food samples through the formation of

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

phosphomolybdate complex followed by its reduction with thiourea. *Spectrochimica Acta Part A*, **78**:497–502.

[14] Connolly, D. & Paull, B. 2001. Rapid determination of nitrate and nitrite in drinking water samples using ion-interaction liquid chromatography. *Analytica Chimica Acta*, **441**:53–62.

[15] Sohail, M. & Adeloju, S. B. 2008. Electroimmobilization of nitrate reductase and nicotinamide adenine dinucleotide into polypyrrole films for potentiometric detection of nitrate. *Sensors and Actuators B*, **133**:333–339.

[16] Thabano, J. R. E., Abong'o, D. & Sawula G. M. 2004. Determination of nitrate by suppressed ion chromatography after copperised-cadmium column reduction. *Journal of Chromatography A*, **1045**:153–159.

[17] Alonso, M.C.B. & Prego, R. 2000. Determination of silicate, simultaneously with other nutrients (nitrite, nitrate and phosphate), in river waters by capillary electrophoresis. *Analytica Chimica Acta*, **416**:21–27.

[18] Francois, C., Morin, Ph. & Dreux, M. 1995. Effect of the concentration of 18-crown-6 added to the electrolyte upon the separation of ammonium, alkali and alkaline-earth cations by capillary electrophoresis. *Journal of Chromatography A*, **706**:535–553.

[19] Cosnier, S., Da Silva, S., Shan, D. & Gorgy, K. 2008. Electrochemical nitrate biosensor based on poly(pyrrole–viologen) film–nitrate reductase–clay composite. *Bioelectrochemistry*, **74:**47–51.

[20] Helmke, S.M. & Duncan, M.W. Measurement of the NO metabolites, nitrite and nitrate, in human biological fluids by GC–MS. 2007. *Journal of Chromatography B*, **851**:83–92.

[21] Liu, Z. & Rochfort, S. 2013. A fast liquid chromatography–mass spectrometry (LC–MS) method for quantification of major polar metabolites in plants. *Journal of Chromatography B*, **912**:8–15.

[22] Colina, M., Ledo, H., Gutiérrez, E., Villalobos, E. & Marín, J. 1996. Determination of total phosphorus in sediments by means of high pressure bombs and ion chromatography. *Journal of Chromatography A*, **739**:223–227.

[23] Stalikas, C. D., Konidari, C. N. & Nanos, C. G. 2003. Ion chromatographic method for the simultaneous determination of nitrite and nitrate by post-column indirect fluorescence detection. *Journal of Chromatography A*, **1002**:237–241.

[24] Gapper, L. W., Fong, B. Y., Otter, D. E., Indyk, H. E. & Woollard, D. C. 2004. Determination of nitrite and nitrate in dairy products by ion exchange LC with spectrophotometric detection. *International Dairy Journal*, **14**:881–887.

[25] Helaleh, M. I. H. & Korenaga, T. 2000. Ion chromatographic method for simultaneous determination of nitrate and nitrite in human saliva. *Journal of Chromatography B*, **744**: 433–437.

[26] Ito, K., Takayama, Y. Makabea, N., Mitsui, R. & Hirokawa, T. 2005. Ion chromatography for determination of nitrite and nitrate in seawater using monolithic ODS columns. *Journal of Chromatography A*, **1083**:63–67.

[27] Dahllöf, I., Svensson, O. & Torstensson, C. 1997. Optimising the determination of nitrate and phosphate in sea water with ion chromatography using experimental design. *Journal of Chromatography A*, **771**:163–168.

[28] Rozan, T. F. & Luther III, G.W. 2002. An anion chromatography/ultraviolet detection method to determine nitrite, nitrate, and sulfide concentrations in saline (pore) waters. *Marine Chemistry*, **77**:1–6

[29] Synergi Full Range Selectivity for Reversed Phase Separation.pdf. In: https://phenomenex.blob.core.windows.net/documents/9df83c96-26ac-4df6-9b61-1c381e13cf8c.pdf. Accessed on 24 January 2015.

[30] Whelan, T. J., Gray M. J., Slonecker, P. J., Shalliker, R. A. & Wilson, M. A. 2005. Study of the selectivity of reversed-phase columns for the separation of polycarboxylic acids and polyphenol compounds. *Journal of Chromatography A*, **1097**:148–156.

[31] Orioli, M., Aldini, G. Beretta, G., Facino, R. M., Carini, M. 2005. LC–ESI-MS/MS determination of 4-hydroxy-trans-2-nonenal Michael adducts with cysteine and histidine-containing peptides as early markers of oxidative stress in excitable tissues. *Journal of Chromatography B*, **827**:109–118.

[32] Currie, L. A. 1999. Nomenclature in evaluation of analytical methods including detection and quantification capabilities[1]: (IUPAC Recommendations 1995). *Analytica Chimica Acta*, **391**:105–126.

[33] WHO 2011. Guidelines for drinking-water quality, 4th edition.World Health Organization. In http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/ Accessed on 03 March 2015

[34] EPA. 2002. Nitrification. In http://www.epa.gov/safewater/disinfection/tcr/regulation_revisions.html. Accessed on 26 Aug 2014

[35] Strous, M., Van Gerven, E., Zheng, P., Kuenen J. G. & Jetten, M.S.M. 1997. Ammonium Removal from Concentrated Waste Streams with The Anaerobic Ammonium Oxidation (Anammox) Process in Different Reactor Configurations. *Water Research* **31**:1955–1962

[36] Knowles, R. 1982. Denitrification. *Microbiological Reviews* **46**: 43–70

[37] Kishida, N., Kim, J., Tsuneda S. & Sudob, R. 2006. Anaerobic/oxic/anoxic granular sludge process as an effective nutrient removal process utilizing denitrifying polyphosphate-accumulating organisms. *Water Research*, **40**:2303–2310.

[38] Oehmen, A. Saunders A. M., Vives, T. M., Yuan, Z. & Keller J. 2006. Competition between polyphosphate and glycogen accumulating organisms in enhanced biological phosphorus removal systems with acetate and propionate as carbon sources. *Journal of Biotechnology*, **123**:22–32.

[39] de-Bashan, L.E. & Bashan, Y. 2004. Recent advances in removing phosphorus from wastewater and its future use as fertilizer (1997–2003). *Water Research*, **38**:4222–4246.

[40] Nkegbe, E., Emongor, V. and Koorapetsi, I. 2005. Assessment of Effluent Quality at Glen Valley Wastewater Treatment Plant. Journal of Applied Sciences, 5:647–650.

[41] Monyamane, Y. 2011. Risk Analysis of Wastewater Use in Crop Production: A Case of Glen Valley Irrigation Scheme, Botswana. MSc Thesis in IWRM. University of Zimbabwe. Faculty of Engineering. pp 3-10

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