A Survey on Management of Upstream Land Use and its Impact on Downstream Water Quality Parameters

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Abstract—**This paper introduces the various upstream land use activities that are major contributors of downstream water pollution. The proposed measures to reduce the pollution of downstream water bodies such as sustainable agricultural activities, systematic land allocation and management are discussed in the paper. It presents the analysis of upstream land use against the water quality parameters measured at different water management facilities to identify the most significant land use factors for optimization. Recommendations on how to optimize land use allocation and formulate policies for the purpose of protecting downstream water bodies, as well as reducing the cost associated with water purification, are mentioned.**

Keywords: **land management; water pollution; upstream activities; downstream catchment, agricultural sustainability**

I. Introduction

ANTHROPOGENIC activities are the principal threat to river water quality [1]. Without well-established management policies on land use, upstream human activities will continue to cause the deterioration of downstream water quality. Thus, it is necessary to improve the way people utilize and manage land use activities for the preservation of downstream water quality. Studies on technical interventions and policy formulation are continually being explored in an effort to reduce the pollution of water sources. [2] proposed acceleration of policy and institutional reforms to rescue the water pollution resulting from industrial activity in China. This is supported by another study [3] in which they identified policy formulation as one way of supporting the available environmental laws towards reducing water pollution from anthropogenic activities. On the technical side, the benefit of having adequate infrastructure to scale down the land use-related impacts on the downstream water quality has particularly been realised in Germany and Europe. During the last three decades fo r example, the chemical quality of many watercourses improved because of development and enhancement of sewage treatment systems [4].

There is a positive correlation between water quality and land use, land cover and type, and intensity of use [5] [6] [7] [8] [9]. For example, [10] and [8] stated that surface water quality deterioration is highly correlated with poor human practices and vegetation cover degradation. The rate at which land use dynamics are changing therefore requires proper land management and proactive land allocation planning in order to minimize the associated downstream pollution. Available literature focuses mainly on lack of policies, urbanization, poor planning, industrialization and agriculture as the leading contributors to water quality deterioration. These are discussed in the following sub-sections:

A. Policies

The lack of policies or the inadequacy of their implementation are some well-known factors that are stifling the efforts aimed towards water quality

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preservation. These resulted to the introduction of regulations aimed at protecting natural water resources [11]. In Europe, there are some documented policies that have been implemented for the preservation of water quality. Some examples are the Dutch nutrient policies for agriculture which came as a result of European environmental directives. The objective of the Nitrates Directive is to reduce water pollution resulting from agricultural activities [12]. Its implementation decreased nutrient surpluses and improved downstream water quality [13].The National Emission Ceilings Directive also resulted in the reduction of ammonia emissions, with downstream benefits of the water sources. The adoption and implementation of relevant policies could therefore benefit the downstream water sources.

B. Urbanization

In 1960, 23% of the Ghanaian population live in urban areas, which increased to about 51% in 2010 as a result of urbanization [14]. This resulted in an uncontrolled conversion of land from agricultural to residential use. Compared to Botswana, a similar trend on rural to urban migration is observed, but at a much higher rate. For the years 1971, 1981, 1991, 2001 and 2011, percentage urban population increased from 9%, 17.7%, 45.7%, 54.2% and 64.1% of the total population, respectively [15]. These values are higher than the world average population that are living in urban areas which was estimated to be 54% of the total population in 2014 [16]. [2] concluded that both population increase and industrial development in the 1950s and 1980s respectively have increased water demand despite the limited available sources. It is also found that such changes always result in high food demand and hence, more agricultural land requirements, resulting in downstream water pollution.

Some effects of urbanization on the water quality include sedimentation transport into water bodies. Altering the drainage patterns and expansion of impermeable cover through roads and pavements increases the amount of runoff, which in turn accelerates soil erosion [17]. The response to rural-urban migration is an increase in construction activities. Construction sites are known sources of water pollution [18]. From construction sites, sediments are the largest water pollutant, and they account for 10% of the sediment load to water bodies in the US [19].

C. Land Allocation and Planning

Improper land use planning and allocation accelerates non-point source pollution [20] [21]. In Ghana, traditional authorities play a lead role in the land allocation and planning process [14]. Given the challenges associated with this type of planning, poor sanitation can be expected, and hence pollution of neighbouring water sources is anticipated. To prevent this from happening, land authorities need to take the lead in land allocation and planning [22]. This can be achieved by using scientifically tested and accepted practices. These include, but are not limited to, reduction of overgrazing, overstocking, and zoning [23]. [24] observed that rational land use and its distribution can improve the consumption of water resources. This consequently reduces the chances of downstream water pollution. In an effort to minimise mismanagement of land and the associated downstream pollution effects, land allocation models have been developed to help address land allocation problems in different sectors of the economy [24]. Some sectors that have benefited from these models include agriculture and transportation [25] [26] [27].

D. Industrialization

Industrialization has been found to play a significant role in contributing to water pollution through the discharge of highly polluted wastewaters [28]. In one study [29], it was proven that industrialization has resulted in the increase of heavy metal addition into the pedoshere. A study by [30] identifies paper industry as one area that has not been significantly studied, particularly the chemical constituents of the effluent. Given the pollution potential of similar industries, and the reported chemical usage, more studies need to be conducted to quantify their contribution to downstream environments.

[2] identified the scale, intensity and speed of industrialization as one factor that led to the acceleration of water quality deterioration in China. Also identified in the study is the type of raw material and technology used in industrial processes that has a bearing on the pollution impacts downstream. In studies that seek to identify a relationship between urban land use and downstream water quality, authors found a positive correlation between the two. A study by [7] discovered out that industrial land use is next in the line after urbanization with respect to the deterioration of downstream water quality. With industrial land use, the impacts were significant within

a 100m buffer, beyond which the impact on water quality decreased [7].

E. Agriculture

Even though there are some agricultural activities that can improve water quality, the effect is far less than the rate at which it causes pollution to the downstream water sources. Most studies conclude that agricultural activities are very common non-point pollution sources [7] [31], mainly due to nutrient losses into water bodies [32]. In England and Wales, agriculture is the main source of fine sediment loss into watersheds [33]. Similarly, sediments are listed as the most common pollutant of water bodies in the United States [34], which originate from agriculture-related sources [35] [36]. With this, efforts are made through the implementation of policies aimed at reducing pollution from agricultural activities. One of the legislative policies aimed at reducing nitrogen emissions from agriculture is the Nitrates Directive [37].

II. Land use activities and their parameters

Figure 1 is a pictorial representation of some common land use activities that contribute to downstream water pollution. The different land use activities in Figure 1 have specific water quality parameters that add to the receiving water bodies. The effect of each parameter on the downstream water quality varies in magnitude and significance. Table I summarizes the land use activities, the associated parameters, as well as their respective impacts on downstream water quality.

Table I showed that even though natural activities have a contribution to water quality degradation, anthropogenic activities are dominant, and vary in complexity. Water sources that are related to human activity receive the highest pollution load [42]. Pollutants resulting from each land use activity vary significantly, and are used as water quality parameters. As shown in Table II below, these parameters are classified as physical, chemical or biological [42]. Examples of each parameters are presented in Table II. Their levels in water give an indication of whether the water is safe for consumption or not. If not, water needs to be treated to acceptable standards by reducing them to levels determined by regulatory authorities. Highly polluted water samples may require Advanced Treatment Technologies (ATTs) because conventional treatment methods may be insufficient. However, ATTs are expensive because they are energy intensive.

The most appropriate water purification method can only be determined when the raw water quality is fully understood. The choice of which water quality parameters to check before treatment has a bearing on the treatment efficiency and the quality of the final water. By checking a few parameters before treatment, the final water quality is likely to be compromised.

Fig. 1. Some common land use activities that contribute to downstream water pollution [38]

TABLE I
Findings on Land Use Activities and the Corresponding Parameters with Respect to Water Quality

Land use activity	Land use parameter	Findings	Reference (s)
Agriculture	Stocking rate	Stocking rates show a correlation in total phosphorus, ammonium and total nitrogen.	Buck et al. (2004) [5]
	Land cover/ vegetation	Watersheds with higher vegetation cover have lower turbidity. High pasture cover results in higher values of electrical conductivity (EC) and Total Nitrogen concentrations.	Gu et al. (2008) [6]; Moschini et al. (2016) [9]; Rickson (2014) [39]
	Amount of fertiliser used	Agriculture is the largest source (15% contribution) of Nitrogen in the atmosphere. Approximately 23% of it applied in watersheds is lost to river flow.	Schlesinger (2008) [40]; Billen et al. (2002) [41]
	Area of agricultural use	There is positive correlation between area cultivated and downstream pollutants	Buck et al. (2004) [5]; Meneses et al (2015) [8]
Industrialization	Distance of industrial land to water body	When distance from industrial land use increases, the correlation between water quality and industrial land use decreases.	Lin et al. (2015) [7]
	Type of industry	Effluent depends on the raw materials and technical production steps.	Bosowski et al. (2015) [30]
Urbanization	Area of urbanization	A larger area of activity increases the pollution potential to water courses.	Meneses et al. (2015) [8]
	Population density	Suspended Particle Matter (SMP), nitrogen and Dissolved Phosphorus increase with population.	Gu et al. (2008) [6]
	Availability & Effectiveness of WWTP	Addition of a WWTP elevates the Nitrogen levels in receiving water bodies downstream.	Ahearn et al. (2005) [10]

TABLE II
Common Water Quality Parameters [42]

Physical	Chemical		Biological
	Inorganic	Organic	
Colour	Ammonia	Total Organic Carbon	Total Coliform
Turbidity	Calcium	Total trihalomethanes	E-coli
Dissolved Solids	Chloride	Phenols	Thermotolerant (faecal) Coliform bacteria
Odour	Chlorine Residual	Chloroform	Faecal streptococci
Conductivity	Fluoride	Aldrin	Clostrodium perfringens
pH	Magnesium	Dieldrin	Cryptosporidium
Taste	Nitrate	Chlordane	Giardia
Temperature	Nitrite	DDT	
	Potassium	Endrin	
	Sodium	Heptachlor	
	Sulfate	Heptachlor epoxide	
	Zinc	Methoxychlor	
	etc	etc	

III. Key water quality parameters and their sources

A. Turbidity

Turbidity is a measure of the extent to which water loses its transparency as a result of the presence of suspended particles in it [44]. It is the most widely used parameter for monitoring the quality of treated water and evaluating the effectiveness of treatment process; it is used in almost all WTWs because of its low cost and easy application [45]. The suspended particles' adsorptive properties make turbidity a significant parameter to monitor because they harbour bacteria, viruses, parasites and other toxic organic compounds. [46] reports that turbidity is a suitable performance indicator for online monitoring of membrane treatment facilities' performance since it is easy to detect in a case of physical membrane damage, indicating that not only is turbidity a nuisance, but also helps in system efficiency monitoring.

Agricultural activity increases soil erosion, resulting in turbidity changes in rivers [47]. During rainy seasons, the loose top soil is transported into the main rivers through tributaries. [47] found that water turbidity is low in less turbulent waters. This is supported by studies by [48] [49] [50] which mentioned that seasons characterised by wave actions, coastal currents, and mixing-stratification of water column results in re-suspension of sediments, due to its high water turbidity. The re-suspension phenomenon of particles is explained using Stoke's Law of equilibrium, which gives the relationship between particle size and fluid turbulence as shown below [51];

$$Re_f = w_s d / \mu \quad (1)$$

where:

w_s – the fall velocity

Re_f – Reynolds number

d – particle diameter

μ – kinematic viscosity of water

Based on Equation 1, when all parameters remain constant, it requires a larger particle to settle for high velocities, thus, resulting in high Re_f values. This is consistent with settling velocities for different soil particle sizes shown in Table III.

TABLE III
Settling Velocity of Particles as a Function of Particle Size [52]

Particle size (µm)	Settling velocity *10^{-3}(m/h)
1000	600000
100	2000
10	300
1	3
0.1	0.01
0.01	0.0002

From Table III, settling velocity is observed to decrease with particle size. Therefore, this suggests that the type of soil on which agricultural activities are carried also determines the extent of turbidity in a downstream body of water. For a soil whose composition is predominantly clay, the water is likely to be more turbid because it consists mainly of fine particles which get re-suspended easily than sandy soils whose particles would settle in lower turbulent conditions. If the downstream water will be used for fish pond culture or in aquaculture system, the desirable range of turbidity is 30-80 cm for optimal fish growth [53].

B. pH

The pH of water is a measure of the acid-base equilibrium and in most natural waters, is controlled by the carbon dioxide –bicarbonate-carbonate equilibrium system [54]. Most dams are basic (alkaline) when they are newly constructed, and become acidic with time due to the build-up of carbon dioxide (CO_2) as organic material decompose. An increased CO_2 concentration lowers pH due to the formation of carbonic acid [55], whereas its decrease will cause pH to rise [54]. Temperature will affect this equilibrium [54]. pH has corrosive effects on water conveyance structures. It also has effects on human health such as eye irritation and exacerbation of skin disorders at pH levels greater than 11 [54]. Below pH 4, redness and irritation of eyes have also been reported [54]. The above dynamics on pH therefore spell out the importance of its quantification before and after water purification.

If the downstream water will be used for cultivating plants, its pH level should range from 5.5 to 7.5. If the pH of water is not within the acceptable range, plants experience nutrient deficiencies [56] [57]. For fish pond culture, the pH level of downstream water to be used should range from 6.0 to 9.0 to ensure fish growth [58] [59].

C. Temperature

Water temperature is a function of both natural and artificial activities. It is an important parameter because it affects the rate of bacterial activity in water, oxygen solubility, as well as the rate of gas exchange between the water body and the environment [60]. Temperature affects the efficiency of some treatment processes as it determines the chemical dissolution and reaction rates [60]. Treatment of water in winter requires more chemicals for efficient coagulation and flocculation than in summer [60]. This means that with respect to coagulants and flocculants, it is cheaper to purify warm water. On the other hand, warm water has also been found to increase chlorine demand because of increased reactivity and increased levels of algae and other organic matter in water [60]. Even though this parameter is not commonly used for water quality evaluation, it is very important when optimization assessments are to be made on a water purification system. Therefore, an optimum temperature ought to be determined to balance the coagulant/flocculant costs with the chlorine-related costs. If the downstream water will be used in aquaculture set-up, the acceptable values of water temperature for optimal fish growth is $16^{o}C$ to $33^{o}C$ [61] [57].

D. Nitrates

Agriculture, industrial activities, and urban development have increased nitrogen discharge in the natural water bodies over the years. Water contamination by nitrates is thus one of the most widespread threats that needs to be dealt with [62] [63]. A study by [40] which trace the fate of anthropogenic nitrogen estimates that about 150Tg ($150*10^{12}$ g) of anthropogenic nitrogen is produced annually, and about 23% of it is lost to river flow. Increased nutrient fluxes cause eutrophication, hypoxia and acidification of water bodies [64]. In their attempt to track different nitrate sources, [65] [66] recommended establishment of policies aimed at reducing the introduction of pollutants in the environment. In many countries such policies exist, but their implementation is ineffective.

Like many other pollutants, sources of nitrates in water are both natural and anthropogenic. In surface waters, they originate from natural nitrification of soil organic matter, with additional concentrations from such anthropogenic activities as wastewater discharges [64]. The breakdown of organic matter first forms ammonia, then nitrites, and finally nitrates, suggesting that a laboratory test of ammonia gives an indication of the nitrate levels in water. In groundwaters, nitrate sources are mainly nitrification of soil organic matter, and to a lesser extent, manure and septic systems [64]. Agricultural activities, such as application of nitrogen-containing fertilisers, have also been found to increase nitrate levels in water sources [5] [67]. For aquaculture activities, the acceptable range of downstream water to be used is from 0.1 to 4.5 mg/L to ensure fish growth and survival [53].

E. Chemical Pollutants-Organics

Decaying leaves, trees and weeds are the principal natural sources of organic matter in water. Anthropogenic sources include industrial compounds such as pesticides [68] [60]. The presence of organic matter causes colour, taste and odour problems in water [60]. It can also contribute to the formation of halogenated compounds when water is disinfected using chlorine [60]. The presence of organic matter in water attracts microbes. As they metabolize the organic material, they consume oxygen and eventually deplete the available oxygen [69] [60]. Other sources of organic contaminants are summarized in Table IV.

TABLE IV
Summary of Some Sources of Organic Water Pollutants [60]

Contaminant	**Sources**
Benzene	Industrial chemicals, paints, plastics, pesticides
Toluene	Industrial solvent
Vinyl Chlorine	PVC pipe
Xylene	Gasoline production, paint ink, detergent
Endrin	Insecticides
Lindane	Insecticides
Pentachlorophenol	Wood preservative
Total trihalomethanes (TTHMs)	Chloroform, drinking water chlorination by-product.

From Table IV, both industrial and agricultural activities are found to directly or indirectly contribute to the addition of organic pollutants in watersheds. For example, the furniture manufacturing process is an industrial activity which uses wood as a raw material. Wood is a product of agricultural activity, which in addition to being a source of organic matter in water, is a source of such other pollutants as nitrates.

Based on Table 4, the most common source of organic contaminants is industrial activity. Properly implemented regulatory policies could reduce downstream pollution of water bodies. An immediate method of managing the point source pollutants is pre-treatment of effluent before discharge. However, distributed sources are difficult to measure and manage because they are spread over a large area.

F. *Chemical Pollutants- Inorganics*

The inorganic load of water is affected by effluent discharges and geologic conditions and formations [60]. Natural water also dissolves rocks and minerals, which also increase the inorganics load in water [60]. Anthropogenic activities include pesticides, industrial waste, paint, etc. [60] which find their way into water bodies through various transportation media. Table V shows some common sources of the inorganic contaminants. It also confirms that industrial activity is also the leading source of inorganic pollutant sources. The downstream effects of pollutants can be reduced by appropriate management methods which include pre-treatment of effluent before discharge or any other suitable method determined by various operations. In Botswana, a notable advancement with respect to industrial waste discharge is the Trade Effluent Agreement entered into by industrial operators and the principal wastewater authority, which is the Water Utilities Corporation (WUC). In this agreement, WUC and affected industries set the limits of inorganic pollutants to be discharged into wastewater system. The discharging entities keep records of the effluent quality, and ensure that the agreed limits are not exceeded. This arrangement is important because it reduces the pollutant load downstream, thereby improving secondary effluent treatment efficiency.

TABLE V
Summary of Sources of Some Common Inorganic Contaminants [60]

Contaminant	Sources
Nitrate	Sewage, fertilisers, soil and mineral deposits
Fluoride	Geological deposits, drinking water additive, aluminium industries
Copper	Corrosion of household plumbing, natural deposits, wood preservatives
Lead	Corrosion of lead service lines and fixtures
Arsenic	Industrial waste, Geological, pesticide residues, smelter operations
Mercury	Industrial manufacturing, natural deposits, fungicides

G. *Biological Pollutants-Bacteria*

The process of testing individual pathogens takes time, and the associated costs are high [60]. Accepted practice is to test for a single species of indicator organism Escherichia coli (E.coli), whose presence in water indicates sewage contamination [70] [60].

E. coli are more prevalent in waters whose turbidity is high. This is because they attach themselves to the sediment particles which happen to be the main constituent of water turbidity. Because E-coli are used to living in the warm environment of human intestines, their counts are higher in warmer waters. On the other hand, sufficient ultraviolet rays of sunlight may kill them, thereby lowering their numbers from expected counts [71].

IV. Methods

Different water sources were identified, and the water quality parameters measured at each of the prior treatment were noted. In Botswana, the source of data was Water Utilities Corporation (WUC), which is the sole water authority tasked with management and operation of potable water sources. For other countries, data was obtained through review of related literature. This data was then used to determine the common water quality parameters, and the most significant ones for discussion.

V. Results

Table VI summarizes the different raw water parameters measured in the respective dams and treatment facilities. The data were obtained from WUC and other related literatures. A tick mark indicates that the water quality parameter is determined before purification at that particular facility.

[46] identified key bulk water quality parameters as those including pH, turbidity, chemical oxygen demand (COD), dissolved organic carbon, and biomass concentrations. These parameters must be determined in raw water samples before treatment. The individual parameters are discussed in detail in Section 4.

VI. Discussions

Water quality parameters have been found to be a result of anthropogenic activities, and to a lesser extent, naturally occurring. The prevalent anthropogenic activities are land use-related, while natural dynamics include washing off of minerals from rocks. At high concentrations, the water quality parameters become undesirable, and are therefore referred to as pollutants.

Industrial activities have a large contribution towards the addition of pollutants in water. These activities are therefore significant land use parameters affecting downstream reservoir water quality.

With respect to agriculture, many studies focus on sediment concentrations (suspended solids) and nutrients in water bodies from agricultural activities. Sediments are higher in areas of greater agricultural intensity. Their yield can be up to ten times greater in agriculture intensive locations than in catchments of mixed use for a similar storm [72].

Urbanization results in deterioration of downstream water quality [73]. Therefore, when rapid urbanization is anticipated in a locality, effective and efficient waste management facilities must be implemented. The percentage population in urban centres connected to

TABLE VI
Water Quality Parameters Measured in Different Facilities

Parameter	Facility							
	Shashe Dam*	Lotsane Dam*	Gaborone Dam*	Palapye Water Works*	Lake Mead	Hoover Dam	Randfontein Municipality**	Johannesburg Metro**
pH	✓	✓	✓	✓	✓	✓	✓	✓
Turbidity	✓	✓	✓	✓			✓	✓
Conductivity	✓	✓	✓	✓	✓	✓	✓	✓
TDS	✓	✓	✓	✓	✓	✓	✓	✓
COD	✓	✓	✓	✓				
Chlorides	✓	✓	✓	✓	✓	✓	✓	✓
Total Coliform	✓	✓	✓	✓				✓
E-coli	✓	✓	✓	✓			✓	✓
Faecal streptococci	✓	✓	✓	✓				
Nitrates	✓	✓	✓	✓	✓	✓	✓	✓
Calcium	✓	✓	✓	✓	✓	✓	✓	✓
Magnesium	✓	✓	✓	✓	✓	✓	✓	✓
Potassium	✓	✓	✓	✓	✓	✓	✓	✓
Sulphate	✓	✓	✓	✓	✓	✓	✓	✓
Silica	✓	✓	✓	✓	✓	✓		
Phosphate	✓	✓	✓	✓	✓	✓		
Mercury	✓	✓	✓	✓				

*Water Utilities Corporation

**Water resource information centre for the Vaal barrage & Vaal Dam catchment forums.

flush toilets for Botswana stood at 47.9% and 64.8% in 2001 and 2011 respectively [74]. This could have been a welcome development if treatment facilities were equally effective in treating the waste to acceptable limits. The low efficiency of such facilities makes them sources of pollutants. In this study, it was found that even though most pollutants are of significant importance given their impact on human health, turbidity stands out as the most significant parameter to monitor since it harbours viruses and bacteria, and on the other hand, it is useful for performance assessment of membrane treatment processes because it can be detected quicker than other pollutants. Other pollutants observed to be of great importance in no particular order are pH, temperature, E-coli, DO, and Nitrates. Comparing the effects of land use activities involves extensive studies on their corresponding downstream pollutants, which is beyond the scope of this paper.

To minimize pollution from agricultural land activities, soil less farming method such as hydroponics and aquaponics are recommended. In aquaponics system, water recycling and waste management are utilized to cultivate plants in hydroponic beds and raise fish in aquaculture tanks [61] [59]. The usage of minimal water exchange, organic fertilizer from fish waste and natural biofilter from plant roots reduce the operating cost of the aquaponics system, making it a cost-effective system [61] [59]. It could also minimize the pollution caused by soil farming activities. In addition to this, the harvested fish and vegetable crops from an aquaponic system are organic, healthy and safe for human consumption [61] [59] [75].

VII. Conclusion

Upstream land use parameters have a contribution to the water quality of downstream water sources. Population density, area and intensity of land use have a positive correlation with downstream pollutant loading. Distance from a pollutant source to the receiving environment has also been found to affect the pollutant concentration; some decompose during transportation, while new compounds are formed as pollutants interact with the environment. Vegetation cover reduces downstream turbidity. Raw materials and industrial technologies also determine the downstream pollution of water bodies. Adoption of best environmental practices and pre-treatment technologies before effluent discharge are proven methods of managing downstream pollution. The next study shall focus on the use of machine learning techniques to optimize land use allocation. A case study on water quality management for sustainable agriculture may be done as a future directive.

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