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CATCHMENT SCALE ASSESSMENT OF RIVER-WATER QUALITY IN AN UNGAUGED ENVIRONMENT

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ABSTRACT

This paper examines the application of coupled integrated model SWAT with emphasis on dynamic, physically-based modelling approaches that integrate the effects of different environmental processes across catchment scales in characterising and quantifying river water quality status. The plan is to address morphological and ecological impacts on streams and by extension, the creation of a link to correctly assess river water quality based on the attributes of the delineated catchment in ungauged and data-poor environments. The resultant pollutions are conditioned on the heterogeneity of the landscape features that control both hydrology and pollutant export coefficients which are variably distributed across catchment. The study area was delineated into five (5) landuse, land cover attributes: forest, cultivation, impervious, urbanisation and industrial within the following settlements, Ita-Iku, ABUAD farm, Ago-Aduloju, Igbemo, Ogbese-Ise and Ita-Ogbolu. A total of twenty-nine quality parameters were invesigated with the results indicating that the regions with with close proximity to emerging urbanisation and industrial development were most impacted. This serves as a policy guiding tool for water resource managers to incorporate different management scenarios in the surface water pollution abatement and control.

I. INTRODUCTION

Human developments in all facets and associated environmental vices have continued to exert great and diverse pressures on both the quality and quantity of water resources which in turn impact conditions fostering water-associated diseases [1]. A conformist estimate designated that 4.0% of global deaths and 5.7% of the global disease burden in disability adjusted life years – DALYs [2-3] were attributable to a small subset of water and sanitation related infectious diseases. [4] goes beyond the evaluation of damage to the ecosystem by reason of pollution sources by extending the scope to the dynamic nature of land use and persistence changes in the environmental factors as a strong influence on the non-point pollution source to streams and other water bodies. The resultant pollutions are conditioned on the heterogeneity of the landscape features that control both hydrology and pollutant export coefficients which are variably distributed across catchment. A classical example of the delineated catchment impact on a stream is represented in Figure 1.

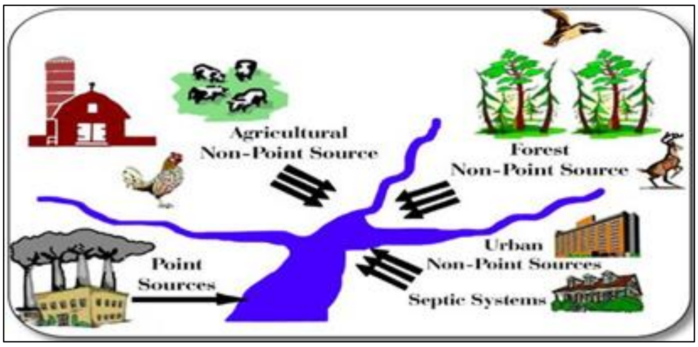


Figure 1: Schematic diagram of Non-point pollution sources in a typical catchment.
Source: [5].

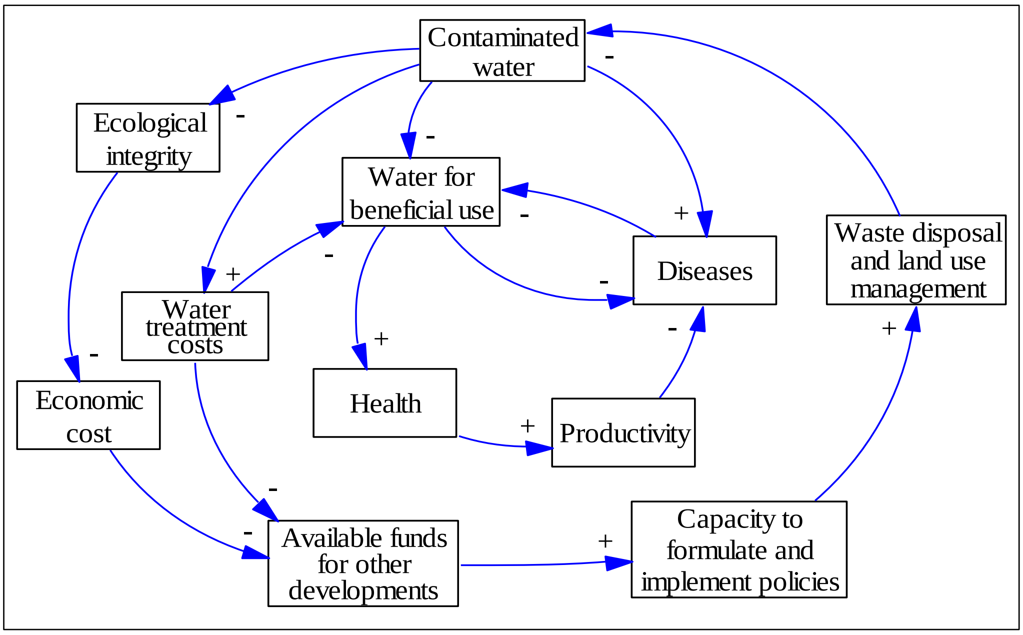
Thus, catchment scale hydrology and non-point source pollution evaluation is better addressed by a distributed-system modelling concept that accounts for all part of the catchment simultaneously and incorporates spatial and temporal variability due to the catchment attributes [1]. The concept of evaluation, by extension, consists of the methods, procedures and agents required for the transportation of pollutant from the source end to the receiving ends. Following this concept is direct to using a simulation method but as a prelude to verification of the expected result of the simulation, it is essential to make on the spot assessment of the water quality on location specifics, stemming from the delineation of the catchment at points through which the principal stream passes.

II. THEORETICAL REFERENCE

II.I THE SIGNIFICANCE OF POLLUTION

Generally, changes in biotic factors such as water nutrients and bacteria loading occasioned by anthropogenic activities, have been identified to interfere negatively with the food chain and life distribution in the water bodies which prove to be very useful for evaluating the impacts on the water status and probable effects of various measures on the environment [6]. Many environmental pollutants are hazardous to human health with the resultant effect in reducing life expectancy. This measure of life is recognised as an index to quantify the health impact of environmental pollution, especially stream pollution, in the assessment of diseases burden in larger part of today's communities. It is, therefore, relatable to note that many disease causative agents have their route and pathway in the water body at one point or the other. This informed the general framework of the diseases classification as water-borne, water-based, water-related, water-washed and water-dispersed [1]. For example, waterborne diseases, such as typhoid and cholera, are typically caused by enteric microorganisms such as Vibriocholerae, which enter water sources through faecal contamination and cause infections in humans through ingestion of contaminated water [6]. Evaluation of this pathway of transforming pollution data into disease data becomes fitting requirement on a data collection or data source and analysis of quantifying diseases burden in an ungauged environment.

Because of the level of development and poor hygiene conditions, sub-Saharan African countries is laddened with many of these water-borne problems and the consequent effects of casualties are often not recognized, reported or documented [1]. These effects and measures are captured in the health and productivity causal loop HPCL presented in Figure 2.



**The concept of adaptative sytem dynamics depicting impact of waste disposal and land management on health and economic security.*

Figure 2: Causal loop on Environmental health and Economic security.

Source: [1].

III. MATERIALS AND METHODS

III.I THE STUDY AREA

The domain of the study area with the drainage network shown in Figure 3 is a typical rainforest covering a land area of 2475 km^2 with a population density of 265 per km^2 computed based on the 2009 National population census with an assumed growth rate of 2.8 percent [1]. The catchment elevation ranges from 550 masl near the source at Igede-Ekiti (7º46'00.67"N; 5º16'00.50"E) to 307 masl at the gauge station Ayede-Ogbese (7º12'56.04"N; 5º20'51.54"E). The river is of the second order type with major tributaries at the upper and the lower courses. The upper bound of the catchment is much larger with few tributaries which may increase the downstream flow by more than twice with respect to the upstream value. The slope of the stream is more pronounced in the upper stream part of Ago Aduloju than at the middle course at Ogbese-Ise up to Ita-Ogbolu, and then increases in the final part [1]. This, together with the major tributaries located in the downstream part, makes the final part of the river much richer in flow and speed contrary to what obtains in most rivers where the upstream parts are steeper with fast flow. Nonpoint source pollution from agriculture is expected to make a measurable contribution to the river pollution. The upstream and the downstream are relatively unspoiled with densely vegetated riparian zones and sparse human settlements. In these sections, the photosynthetic action is considerable given the high nutrient content of the influent flow and attendant self-purification is very potent.

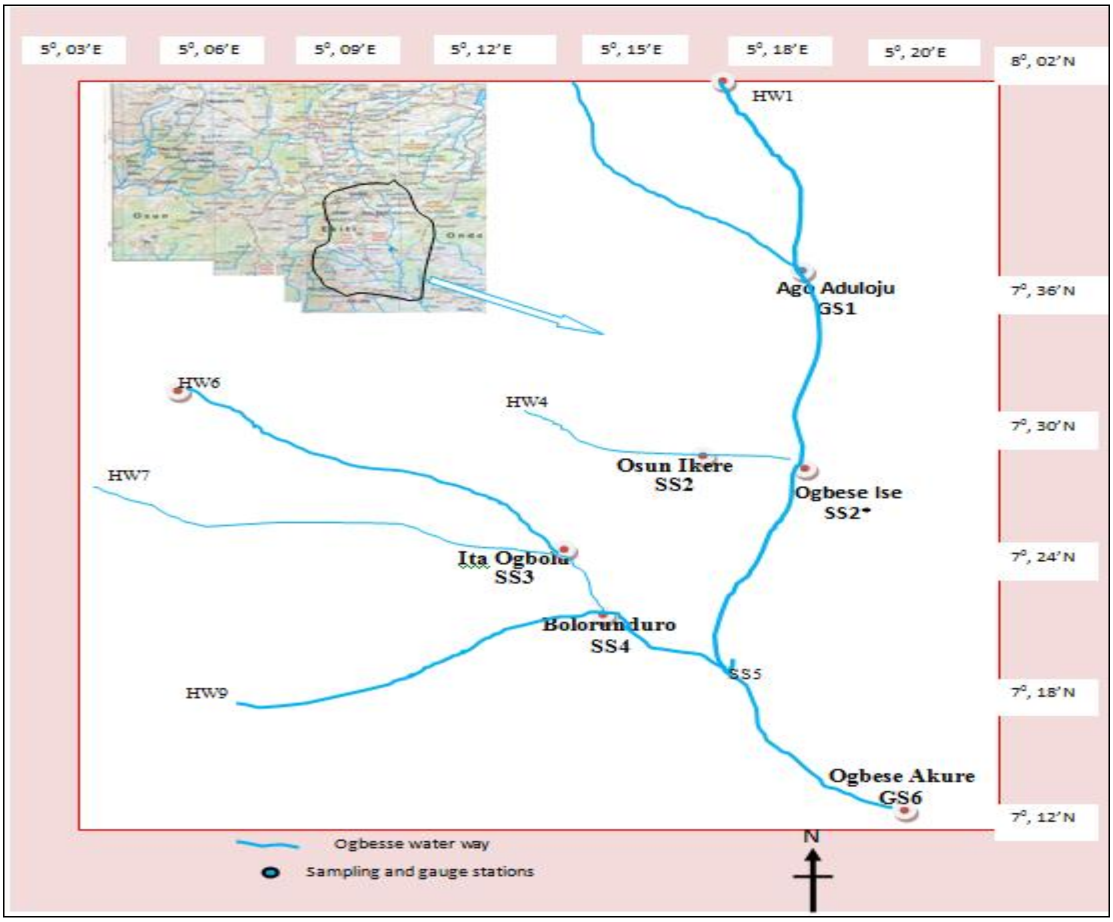


Figure 3: Extract from the Map of Nigeria showing drainage of the study área.
Source: Authors, (2021).

This paper incorporates Soil and Water Assessment Tool (SWAT), a catchment-scale model developed by [7] for the USDA Agriculture Reserve Service (ARS) primarily to predict the impact of land management and non-point source pollution on water, sediments and nutrients yield in large ungauged river catchments. The model concept framework, as expressed in Figure 4, stresses the environmental factors that impact water quality, flexibility in basin discretisation and continuous time simulation.

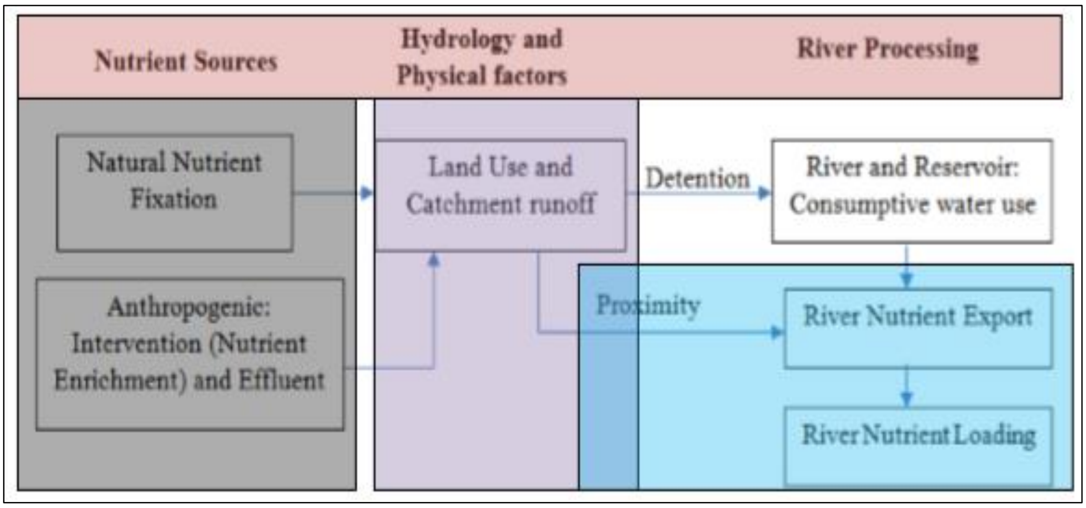


Figure 4: Catchment-Nutrient Export and Loading Scheme for Rivers: Sources and Sink.
Source: Authors, (2021).

The model integrates soil moisture replenishment, depletion and redistribution for the dynamic variation in areas contributing to direct runoff and in effect, the resulting river-water quality. Regardless though the limitation in data-feed, it provides a platform to evaluate the relationship between land use and in-stream water quality. It operates on a daily time step that allows the catchment to be subdivided into grid cells through which hydrologic components and their interaction are simulated as realistically as possible. Based on this concept, the study area was delineated into five (5) landuse sections, Table 1, for the purposes of capturing the relative contribution of each section into the stream load.

Table 1: Descriptive information of LULC for hydraulic load.

Sub-catchment code	Area (Km^2)	% Forest	% Cultivation	% Impervious	% Urbanisation	% Industrial	Reach Length (km)
1	446	41	45	1.75	12.5	0.05	18.700
2	403	30	57	3	9	1	20.320
3	220	25	42	5	25	3	15.230
4	144	12	52	7.5	27	1.5	13.720
5	378	25	60	5	10	0	25.610
6	226	20	50	22	8	0	17.800
7	125	15	62	15	8	0	14.600
8	56	15	62.5	10	12	0.5	11.180
9	195	21	52	10	15	2	22.720
10	125	22	45	5	25	3	8.810
11	157	20	28	10	37	5	12.820

Source: Authors, (2021).

III.2 SAMPLE COLLECTION AND ANALYSIS CAMPAIGN

III.2.1 Selection of the Sampling Point

The consideration for selecting the sampling points were based on the catchment delineation and the landuse landcover of the catchment area. Therefore it was important to see the water quality as a reflection of this delineation, especially where the rivers are flowing through the regions of special activities or have a close proximity to such areas. Therefore, six different locations along the course of Ogbese river were chosen based on designed criteria. These areas are Ita-Iku, ABUAD farm, Ago-Aduloju, Igbemo, Ogbese-Ise and Ita-Ogbolu.

III.2.2 In-situ Analysis

Representative water sampling was carried out from each location during the dry and rainy seasons of the year 2020 within the constraint of COVID-19 protocols. For in-situ water quality parameters, samples were collected in accordance with (SOP: 1040R01 Water Sampling.doc) and analysed in duplicates. The average values of the samples were used for graphical illustration. In-situ collection and analysis follows the standard protocols and methods of American Public Health Organization (APHA) [8] and American Society for Testing and Materials (ASTM) using different calibrated standard instruments [9]. Variables analysed are chemical components of collected water samples, dissolved oxygen (DO), pH, total suspended solids (TSS), total dissolved solids (TDS), turbidity, and electrical conductivity. The pH of the water samples was measured by using a pH meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd). The temperature ranges between 27°C and 33°C for the duration of the water sampling seasons of the year. This region has been known for a marginal difference in seasonal temperatures over the years. Each of the duplicate samples were analysed for a number of parameters in the laboratory to determine their overall compliant with the WHO standard and the local regulating unit. Conductivity meter, model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd was used to assess the conductivity of the samples with its probe calibrated using a standard solution of a known conductivity. Care was taken to prevent cross contamination among different samples by rinsing the probe with deionized water at the close of each sampling. The water sample turbidity was measured using a turbidity meter (model 2100P Turbidimeter HACH, Colombia, USA, Arachem (M) Sdn. Bhd.).

III.2.3 Laboratory Analysis

The measurements of the laboratory-based water quality parameters, mainly the chemical and some of the physical parameters, were carried by using DT–3900 Multi-parameters Water Quality Analyser with accuracy to determine turbidity and suspended solids in accordance with DIN EN ISO. The instrument uses the infrared duo scattered light method Solitax sc to provide a unique colour independent measurement of solids and a reliable sludge analysis. A blank water sample is normally set as a standard to calibrate the machine prior to and a water sample to be tested according to the experimental procedure attached to the reagent manual corresponding to the item. When the instrument is working, the absorbance of the sample liquid and the standard solution/control liquid are first deected, and then the state of the substance to be tested in the sample liquid is determined through the analysis and calculation. The instrument is used together with with the water quality testing reagents, and the water sample is quantitively determined by photoelectric colorimetry. The results were recorded automatically on the machine visual display unit. Values of the parameters are presented in Table 2.

Table 2: Quality Parameters of selected locations along the River course.

No	Parameters	ITA-IKU	ABUAD FARM	AGO ADULOJU	ITAOGBOLU	OGBESE ISE	IGBEMO
1	Colour	Whitish	Brownish	Brownish	Greenish	Brownish	Brownish
2	Temperature	27ºC	27ºC	27ºC	27ºC	27ºC	27ºC
3	Turbidity	6NTU	45NTU	22NTU	8NTU	15NTU	18NTU
4	DO	5.7 mg/L	3.4 mg/L	3.9 mg/L	4.6 mg/L	4.3 mg/L	4.1 mg/L
5	TSS	180 mg/L	530 mg/L	450 mg/L	230 mg/L	310 mg/L	360 mg/L
6	TS	240 mg/L	710 mg/L	560 mg/L	360 mg/L	420 mg/L	480 mg/L
7	TOC	6.45 mg/L	11.6 mg/L	13.55 mg/L	12.3 mg/L	7.1 mg/L	11 mg/L
8	Calcium	2 mg/L	12 mg/L	10 mg/L	8 mg/L	10 mg/L	9 mg/L
9	Org. Nitrogen	0.6 mg/L	2.8 mg/L	1.9 mg/L	1.2 mg/L	2.1 mg/L	1.7 mg/L
10	PH	7.29	7.10	6.92	6.84	7.02	6.93

No	Parameters	ITA-IKU	ABUAD FARM	AGO ADULOJU	ITAOGBOLU	OGBESE ISE	IGBEMO
11	Acidity	16.81 mg/L	18.4 mg/L	20mg/L	8.81 mg/L	23.2 mg/L	18.4 mg/L
12	Alkalinity	10 mg/L	160 mg/L	95 mg/L	45 mg/L	75 mg/L	70 mg/L
13	Ammonia	0.9 mg/L	16.0 mg/L	10.6 mg/L	4.0 mg/L	9.1 mg/L	8.6 mg/L
14	Nitrogen	1.6 mg/L	9.0 mg/L	4.1 mg/L	2.2 mg/L	4.2 mg/L	3.7 mg/L
15	Phosphate	2.4 mg/L	64.5 mg/L	18.7 mg/L	5.6 mg/L	18.2 mg/L	14.3 mg/L
16	Sulphate	8 mg/L	35 mg/L	17 mg/L	13 mg/L	20 mg/L	18 mg/L
17	Zinc	0.4 mg/L	7.4 mg/L	4.8 mg/L	0.6 mg/L	2.6 mg/L	0.6 mg/L
18	Magnesium	4.01 mg/L	20 mg/L	13 mg/L	3 mg/L	7 mg/L	3 mg/L
19	Hardness	9 mg/L	38 mg/L	27 mg/L	6 mg/L	15 mg/L	5 mg/L
20	Lead	0.017 mg/L	0.02 mg/L	0.02 mg/L	0.02 mg/L	0.02 mg/L	0.02 mg/L
21	Iron	0.25 mg/L	1.80 mg/L	0.89 mg/L	0.30 mg/L	0.75 mg/L	0.55 mg/L
22	Oil & Grease	54.7 mg/L	75.3 mg/L	66 mg/L	57.3 mg/L	60.7 mg/L	63.3 mg/L
23	BOD	8.6 mg/L	11.8 mg/L	17.6 mg/L	14.7 mg/L	8.9 mg/L	11.8 mg/L
24	COD	20 mg/L	36 mg/L	42 mg/L	38 mg/L	22 mg/L	34 mg/L
25	EC	256 us/cm	138.9 us/cm	114.6 us/cm	55.5 us/cm	106.8 us/cm	86.1 us/cm
26	TVC	6	57	43	28	47	34
27	TCC	0	15	10	5	12	8
28	E.coli	0	4	2	0	3	2
29	MPN	0	18	14	6	16	10

**Note: TVC = total variable count: TCC = total coliform: MPN = most probable number.*

Source: Authors, (2021).

Table 4: Correlation coefficient of some of the water quality parameters in the study.

	Temperature	Turbidity	Do	PH	Hardness	Zinc	Discharge	TDS	BOD	COD	E coli
Temperature	1										
Turbidity	0.81	1									
Do	-0.77	-0.83	1								
PH	-0.31	0.02	0.49	1							
Hardness	0.61	0.88	-0.67	0.14	1						
Zinc	0.66	0.91	-0.76	0.04	0.99	1					
Discharge	0.19	0.45	-0.49	-0.10	0.43	0.49	1				
TDS	0.88	0.82	-0.86	-0.39	0.60	0.68	0.61	1			
BOD	0.50	0.15	-0.44	-0.70	0.25	0.27	-0.22	0.29	1		
COD	0.77	0.41	-0.65	-0.71	0.35	0.40	-0.08	0.58	0.92	1	
E coli	-0.37	-0.10	0.59	0.95	0.08	-0.02	-0.34	-0.55	-0.52	-0.62	1

Source: Authors, (2021).

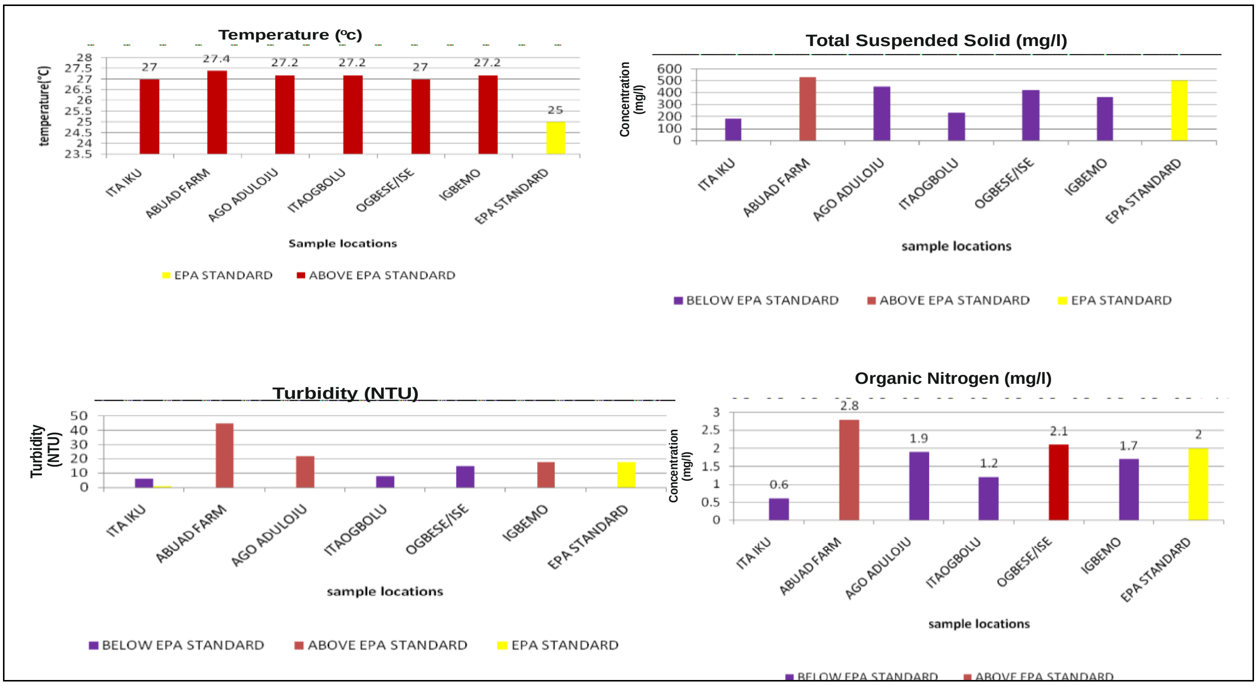


Figure 5: Some water quality parameters concentrations at various sites and in comparison with EPA standard.

Source: Authors, (2021).

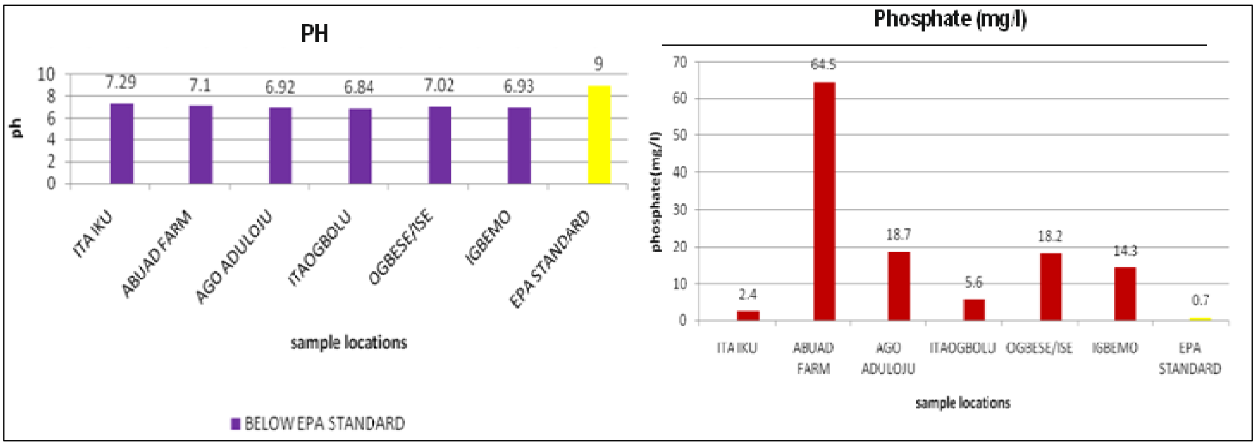


Figure 6: pH and Phosphate concentrations at various sites and in comparison with EPA standard.
Source: Authors, (2021).

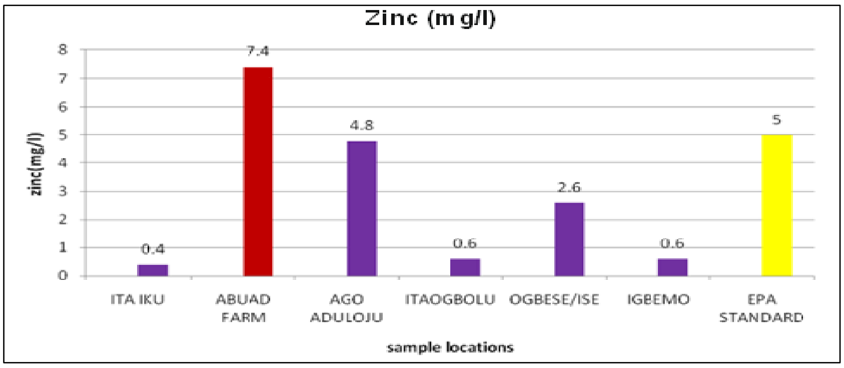


Figure 7: Zinc concentrations at various sites and in comparison with EPA standard.
Source: Authors, (2021).

IV. RESULTS AND DISCUSSIONS

IV.1 PH

The pH ranged between 6.93 and 7.29 with with Ita-Iku and ABUAD having the highest values 7.29 and 7.10 respectively There were no significant differences in the values of the pH although the values are, however, within the acceptable limits of the WHO. This is acceptable because the water would unlikely cause ailments such as acidosis. The pH is an indicator of the presence of microorganisms as it controls.

IV.2 TURBIDITY

The turbidity ranged between 6.0 to 45 NTU with ABUAD farm and Igbemo axis of the water stretch leading. There were significant differences in the values of turbidity as a reflection of development and farming activities around the river course where the samples were taken. This is understandable and acceptable because the water would likelybe imparted by the debries carried by the runoff from these riparian zones.

IV.3 ELECTRICAL CONDUCTIVITY (EC)

This is a measure of the dissolved ionic component and total dissolved substitution in water [10]. There were significant differences in the values of the electrical conductivity, although the samples were within the permissible limits of 1000 µs/cm of WHO maximum permissible limits for conductivity. The values of the electrical conductivity ranged between 86.1 us/cm and 256 µs/cm with Ita-Iku and ABUAD farm having the largest concentrations. The results indicated that the water samples are not salty as the concentration of salts dissolved in the water is as little as possible. The consumption of the water, which has values above the permissible limits over a period of time, has harmful effects on the health of man as it can defect the endocrine functions and cause total brain damage [11].

IV.4 TOTAL SUSPENDED SOLIDS (TSS)

The total dissolved solids ranged between 180 and 530 mg/L with the highest value coming from the water from ABUAD and Ago-Aduloju. These are the mid upstream sections of the river respectively where scouring and erosive actions are prominent owing to the steep topograhy coupled with the anthropogenic activities within the area. The soil layer in this region has for ages been disturbed by deforestation occasioned by cut and slash in farming process. The portion is often overgrazed by the cattle herders. Although, there were noted significant differences in the values of the TSS of the water samples they fall within the permissible l.

IV.5 CALCIUM

The value for the calcium ranged between 2 and 10mg/L with the water samples from ABUAD farm having the highest value of 12 mg/L and the least from Ita-Iku. There were significant differences in the values although the values were within the WHO permissible limits of 75 mg/L. imits of 500 mg/L.

IV.6 TOTAL HARDNESS

From the values obtained from the analysis, the total hardness ranged between 6.0and 38.0 mg/L higher at the region around the ABUAD farm and a downward trend towards the downstream of the river. All the values were within the limits of the WHO permissible limits of 150 mg/L. There was no significant difference in the value of total hardness for all the samples; therefore, the total hardness could not have been said to pose any danger to the health of the populace who live around the area.

IV.7 CHEMICAL OXIDATION DEMAND (COD) AND BIOLOGICAL OXIDATION DEMAND (BOD)

The value for the COD ranged between 20 and 36 mg/L The values were at close proximity with each other indicating the presence of chemical oxidants in the water or better still, the self purification capacity of the water owing to its velocity of flow, the cross-sectonal area of the river and the veetation cover within ghe riparian zone. The BOD is an index of oxygen required for the biotic degradation of organic matter in bodies of water. The value for the BOD follows the same trend ranging between 8.6 and 17.6 mg/L showing a close proximity in the environmental impact on the water.

IV.8 SULPHATE

The value for the sulphate ranged between 8and 35 mg/L with the water There were significant differences in the values of the sulphate between the study locations although it has been reported that there is no guideline value based on human health; however, the recommendation of WHO is that any concentration higher than the permissible limits of 100 mg/L is termed un-hygienic [11].

IV.9 MAGNESIUM

Magnesium is a nutritional component for human beings, one of the micro-elements which is accountable for functioning of the membrane, stimulation for the transmission of nerves, construction of muscles and DNA duplication [12]. Values were within the WHO permissible limits of 50 mg/L with the range between 3.0 mg/Land 13.0 mg/. There were significant differences in the values of the magnesium in the sample; it has been reported that high values of magnesium could result in the hardness of water [13]. Nigerian Standard for Drinking Water Quality (NIS 554:2007) recommended magnesium concentration of 0.2 mg/L in drinking water.

IV.10 ZINC

The value for the detected zinc ranged between. Although the values fall within the WHO permissible limits of 3.0 mg/L, there were significant differences in the values of the zinc between the study areas. Zinc may have accumulated in the river from the environment from both natural processes e.g. weathering and erosion. It has been shown that acute zinc effect on people includes nausea, lack of moisture, tiredness, weariness, abdominal pain, inability to coordinate the muscles, and kidney failure. Chronic doses of zinc increase the risk of developing deformation of blood cells and could also damage the pancreas [14].

IV.11 IRON

The value for the copper ranged between 0.25 and 1.80mg/L with the water samples from ABUAD Farm region having the highest value of 1.8 mg/L.

IV.12 LEAD

The average values for the lead ranged between 0.01 and 0.02mg/L. The values were above the WHO permissible limits of 0.015 mg/L. Lead as a contaminant is a well-documented issue. It accrues with time in bones, blood vessels and other internal organs. It can access the human body through the consumption of food, water and air [15]. Lead, aside being a carcinogen, also impacts the central nervous system of the exposed individual and could lead to delayed mental and physical growth in children and could affect the attention span and learning abilities of children [16].

IV.13 AMMONIA

The presence of ammonia at higher than geogenic levels is an important indicator of faecal pollution. Ammonia is the most common forms of nitrogen in aquatic systems. It often occurs as a component of Nitrate which predominates in unpolluted waters. Nitrogen can be an important factor controlling algal growth when other nutrients, such as phosphate, are abundant. If phosphate is not abundant it may limit algal growth rather than nitrogen. Ammonia is excreted by animals and produced during decomposition of plants and animals, thus returning nitrogen to the aquatic system. There is highest concentration of 16 mg/L at ABUAD farm section with a corresponding 35 mg/L of sulphate and 64.5 mg/L of Phosphate concentrations. The detection can undoubtedly be the practicing of mechanized farming, the effluent of which is washed to the stream.

Zinc salts cause a milky turbidity in **water** in higher concentrations. In higher concentration about 2 mg / L, it may add an unwanted flavour to **water.** Solubility of **zinc** and **zinc** compounds. The solubility of **zinc** depends on temperature and pH of the **water** in question. At a fairly neutral pH, **zinc** in **water** insoluble. It is noted that the higher doses of Fe ranging from 25 to 75 mg inhibits the uptake of zink-sulphate [ZnSO4] in the human plasma. Elementary zink does not constitute health hazard but some zinc compounds, such as zinc arsenate and zinc cyanide, may be extremely hazardous.

IV.14 MICROBIAL ANALYSIS OF WATER SAMPLES

The value for total coliform as shown in Table 3.1ranged between 6 and 18cfu/mL with the water samples from ABUAD having the highest value while Ita-Ogbolu had a record for the lowest value. The presence of coliform indicates growth and possible biofilm contamination which usually occurs when there is contact with sewage and natural wastes from human and animal feces [17] The values were all above the WHO value of zero.

V. CONCLUSIONS

This paper is able to present a unique new technical model that captures the main features of real situation for river water quality assessment. The developed framework is capable of predicting at a whole catchment scale and over a long term span, the effect of LULC on the quality of the river. Moreover, the framework is capable of characterising water quality under the different catchment scale. The author is able to develop methods for collecting and assessing input data, including LULC for data-poor and ungauged regions and to demonstrate this approach with reference to a specific catchment. He is equally able to demonstrate how the data collection can serve as a tool for water resource managers by incorporating different management scenarios in the surface water model.

VI. AUTHORS'S CONTRIBUTION

Conceptualization: Toyin Omotoso.
Methodology: Toyin Omotoso.
Investigation: Toyin Omotoso and Justina Nwaeze Falana.
Discussion of results: Toyin Omotoso.
Writing – Original Draft: Toyin Omotoso.
Writing – Review and Editing: Toyin Omotoso and Justina Nwaeze Falana.
Resources: Toyin Omotoso and Justina Nwaeze Falana.
Supervision: Toyin Omotoso.
Approval of the final text: Toyin Omotoso.

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