Downstream variation in the surface water quality of an urbanizing sub-catchment in Ibadan, Nigeria

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Abstract

Contamination of surface water bodies from various human activities significantly impairs environmental health and the well-being of humans, plants and animals. This study seeks to assess the variation downstream in surface water characteristics in a small urbanizing sub-catchment in Ibadan, Nigeria. Water sampling was carried out on the 14 first-order, 4 second-order and 5 third-order stream networks of the sub-catchment. The concentration of pH, total dissolved solids (TDS), alkalinity, total hardness, calcium and magnesium were determined in relation to stream order and increased distance downstream. The values range considerably across the sub-catchment; pH (3.8-7.5), TDS (70-1095 ppm), alkalinity (0.65-4.65 ml), total hardness (2.35-36.95 ml), calcium (1.6-35.35 mg/l) and magnesium (0.05-14.70 mg/l). Statistical analysis shows that there is no significant correlation between the concentration of the water quality parameters, stream order and distance downstream. This however suggests that pollutants infiltrate and sink at different random points along the stream channels to contaminate the subsurface layers and subsequently the groundwater system. Based on the result of this study, the level of pollution for the selected parameters has not attained a critical level, however, there is a need to put in place an effective water quality monitoring scheme to control further pollution.

Keywords: Downstream; surface water quality; urbanizing; sub-catchment; Ibadan.

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1. Introduction

The variation in surface water quality from place to place is caused by various factors (Sharma et al., 2016). Natural factors include processes such as changes in precipitation input, denudation of surficial and crustal materials, forest fire, and volcanic ash and lava. On the other hand, anthropogenic influences relate to agricultural, industrial, transport and urban activities (Hamid et al., 2020). About 60% of the world's largest rivers have their natural systems altered by damming and other developmental activities leading to considerable modification of sediment mobility to downstream reaches, deterioration of water characteristics and devastation of ecosystem health (WWAP, 2003).

On a global basis, about two million tons of agricultural, industrial, and sewage wastes are discharged into water bodies daily, equivalent to the weight of 6.8 billion persons (WWAP, 2003). Due to poor waste management systems, especially in developing countries, surface water bodies have been made depositories for refuse, human sewage, and wastewater from kitchens, abattoirs, and industries making rivers the most impaired of all the water bodies (Fashae et al. 2017; Fashae & Obateru, 2021). These influences can singularly or collectively impair the viability of river use for domestic, agricultural, industrial, recreation purposes and other flow services (Ramírez et al. 2014; Kim & An, 2015; Hamid et al., 2020). About 80% of all diseases in third-world countries are directly associated with the consumption of poor-quality water and unhygienic conditions (WHO, 2003).

Variations in land use patterns along the riparian corridor will significantly inform the surface water physiochemical characteristics (Fashae et al., 2019; Obateru et al., 2022). Ecologists have established that water bodies are impacted by the land use/land cover through which they flow (Hynes 1975; Vannote et al. 1980; Schuetz et al., 2016). As reported by Hamid et al. (2020), land use characteristics in a catchment affect the transportation of sediments, nutrients and pollutants into receiving water bodies via overland flow, through flow, base flow, atmospheric deposition and organic inputs (Huang et al., 2014). Spatial variation is a functional feature of diverse ecological drivers encircling the incoming tributaries, catchment land use dynamics, and geological and pedological characteristics (Townsend et al., 1983; Schultz et al., 1993; Huang et al., 2014). Liu et al. (2021) argued that variation in stream channel geometry can influence the response of contaminants to biochemical processes and nutrient flux in a fluvial system. This tends credence to the concept of River Continuum (Vannote et al., 1980) which identified a cyclical interaction pattern between the river channel, fluxes of water and material, and biota. Thus, it becomes relevant to appraise the downstream variation in ecological conditions across diverse riverscapes with varying levels of development (Obateru et al., 2022). Given the aforementioned, this study aimed to assess the downstream variation in selected water quality parameters in urbanizing sub-catchment in Ibadan, southwestern Nigeria. This study is focused on the following specific objectives (a) to evaluate the spatial pattern of selected water quality parameters along the river longitudinal profile, and (b) to assess the degree of association between the selected water quality parameters, stream orders and distance downstream.

2. Materials and Methods

2.1 Study area

River Olosun is a third-order stream that drains a small urbanizing sub-catchment in the eastern part of Ibadan, Nigeria (Figure 1). The climate of subcatchment, just like that of Ibadan, is characterized by two marked seasons: the wet season, which spans between March and October under the influence of wet tropical maritime air mass, and the dry tropical continental air mass, with the latter bringing about the dry season that extends from November to February (Fashae & Olusola 2017). This study area has gently undulating topography with elevations ranging between 190 m and 210 m above sea level. The soil is formed from fine-grained biotite gneisses and schist that weather readily with texture ranging between clayey and sandy clay. The sub-catchment is characterized by conflicting land uses with no adequate planning. Residential quarters are intertwined among industrial, commercial and agricultural areas. Brewing, agro-allied and automobile industries are found in the area.

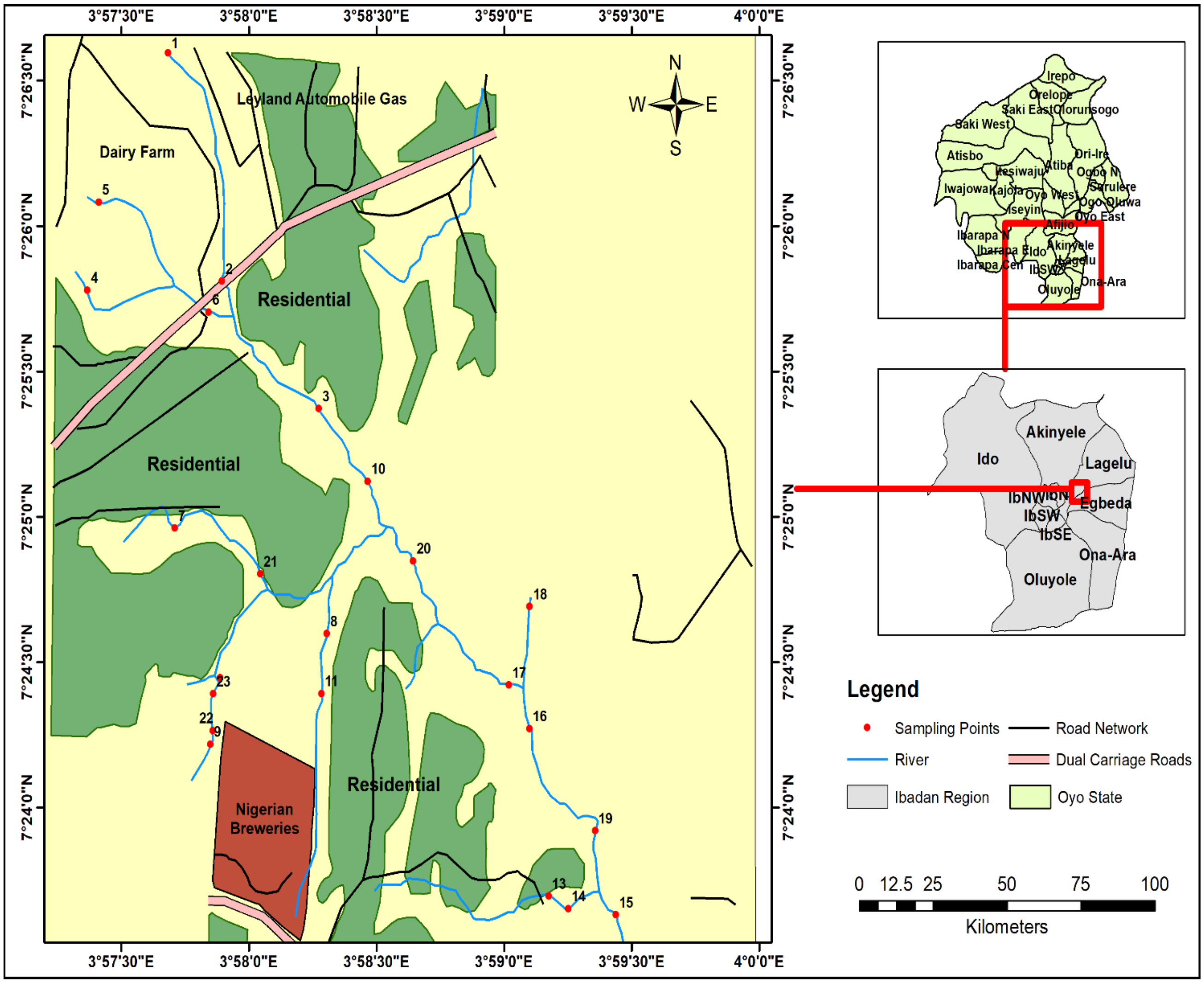

Figure 1. Map of the study area and sampling points

2.2 Data collection and analysis

The sub-catchment is characterized by 14 first-order streams, 4 second-order streams and 5 third-order streams according to Strahler (1954). A total of 23 sampling points which are evenly distributed along the river channel and its tributaries were identified for surface water collection and analysis (Figure 1) in the middle of a dry season (January). The sampling took place at regular intervals along the river course from the source of the river at Alakia to its mouth at Ajadi, in other to show upstream, midstream and downstream variations in the river's physiochemical properties. The stream straddles a mix of different land use types with no clearly defined spatial pattern.

Notable land use types include farmland and agro-processing industry, brewing industry, petrochemical firm, commercial land use and residential areas.

Twenty-three water samples were collected in 75 cl transparent plastic bottles across the sampling points using the composite sampling method. The collected water samples were instantly transported in an ice chest to the laboratory. To avoid the water composition from degrading, the samples were preserved in the refrigerator on arrival at the laboratory. pH, total dissolved solids (TDS), alkalinity and total hardness were measured *in situ* using a WET-PRO field kit. The concentration of magnesium and calcium ions was determined using the flame Atomic Absorption Spectrophotometer.

The concentration of the water quality parameters at the different sampling points was imported into ArcGIS 10.5 environment. Interpolation along the stream network was carried out using the spherical semi variograms kriging technique to generate thematic maps for the parameters (Fashae and Obateru, 2021). Pearson product-moment correlation was used to assess the degree of association between the water quality parameters and distance and stream order; a scattergram of this association was plotted using the "ggplot2" package in the R programming environment.

3. Results

The summary of the selected water quality parameters is presented in Table 1 while the spatial pattern of these parameters across the stream networks is presented in Figures 2 and 3. The values of pH largely ranged between 3.89 and 7.50; the highest value (7.5) was obtained at point 1 which is 1.35 km downstream of the river source. The dominant land use at the location is farming, with the stream water used for crop irrigating and animal consumption. The stream was observed to be most acidic at points 22 (0.15 km downstream) and 23 (0.65 downstream) with values of 4.5 and 3.8 respectively. At these locations, effluent from industries is discharged into the stream without prior treatment.

The total dissolved solids (TDS) values ranged between 70 ppm and 1095 ppm. The least value was obtained at point 5, a distance of 0.15 km downstream; this is a residential zone that is relatively free from industrial effluent and agricultural pollutants.

Table 1. Summary statistics of the selected water quality parameters

Parameter	Mean	Min	Max
pH	6.43 ± 0.87	3.89	7.50
TDS (ppm)	289.57 ± 277.50	70.00	1095.00
Alkalinity (mg/l)	2.05 ± 1.37	0.65	4.95
Total hardness (mg/l)	9.38 ± 8.33	2.35	36.95
Calcium (mg/l)	7.39 ± 7.80	1.60	35.35
Magnesium (mg/l)	1.99 ± 3.23	0.05	14.70

Alkalinity values ranged between 0.65 ml and 4.95 ml across the catchment. At point 5, the highest concentration was observed at a distance of 1.45 km in a residential area downstream of the river source. In areas like points 11, 14 and 15 points where residential and commercial activities are intertwined, alkalinity concentration is relatively high (4.90 ml, 4.80 ml and 3.85 ml respectively), irrespective of the distance from the river source. The least value for total hardness was observed in an area of agricultural activities, that is, points 2–6, with distances 1.45 km from the river source. Total hardness was found to be of relatively high concentrations 10.85 ml, 14.40 ml and 36.95 ml) at points 8, 22 and 23 respectively, bearing the impact of the effluent from the pharmaceutical and brewing industries in the area. Relatively high values, ranging between 10 and 26 ml, were recorded in some residential areas like points 6 and 20.

Calcium concentration was observed to be greatest in point 23 with a value of 35.35 mg/l (0.65 km downstream). Other locations with relatively high values are point 6 (1.25 km downstream) and point 11 (2.10 km downstream). This however suggests that the concentration of calcium increases with increasing distance from the river source. A similar pattern was also observed for magnesium wherein high concentrations ranging between 3.85–6.20 mg/l were observed between points 16 and 20.

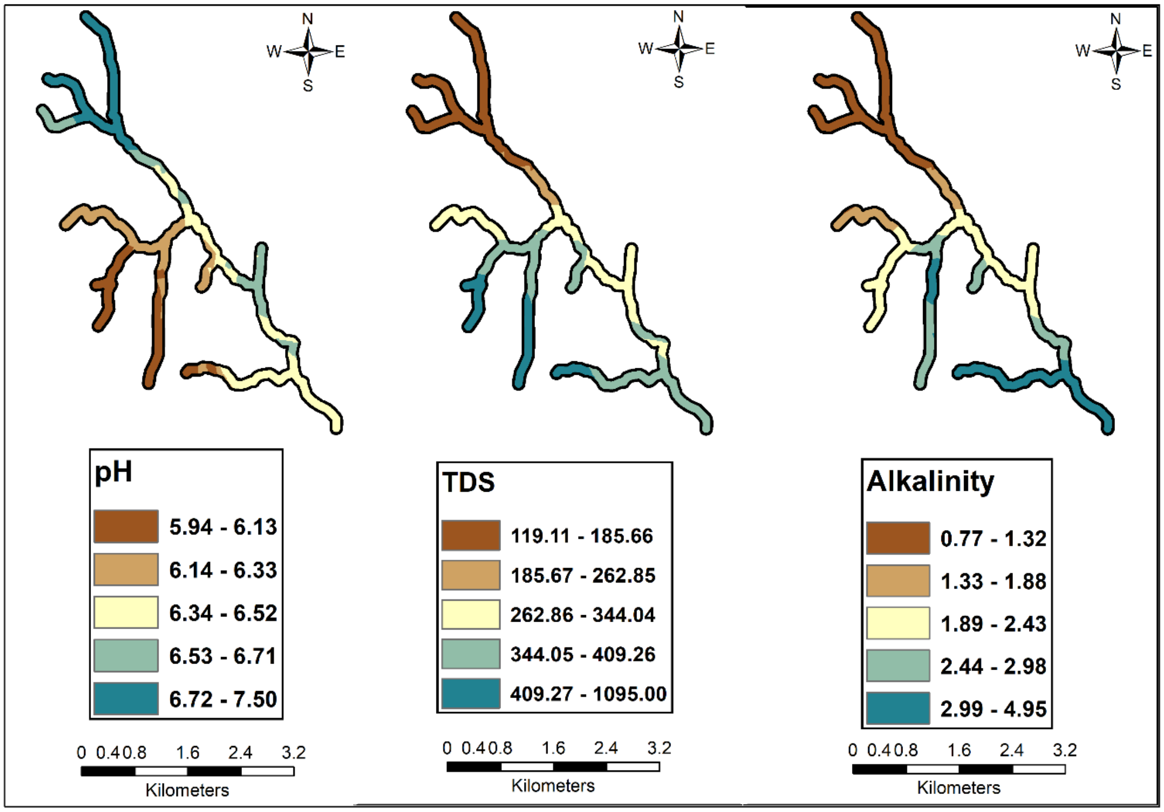

Figure 2. Spatial pattern of pH. Total dissolved solids (TDS), and alkalinity.

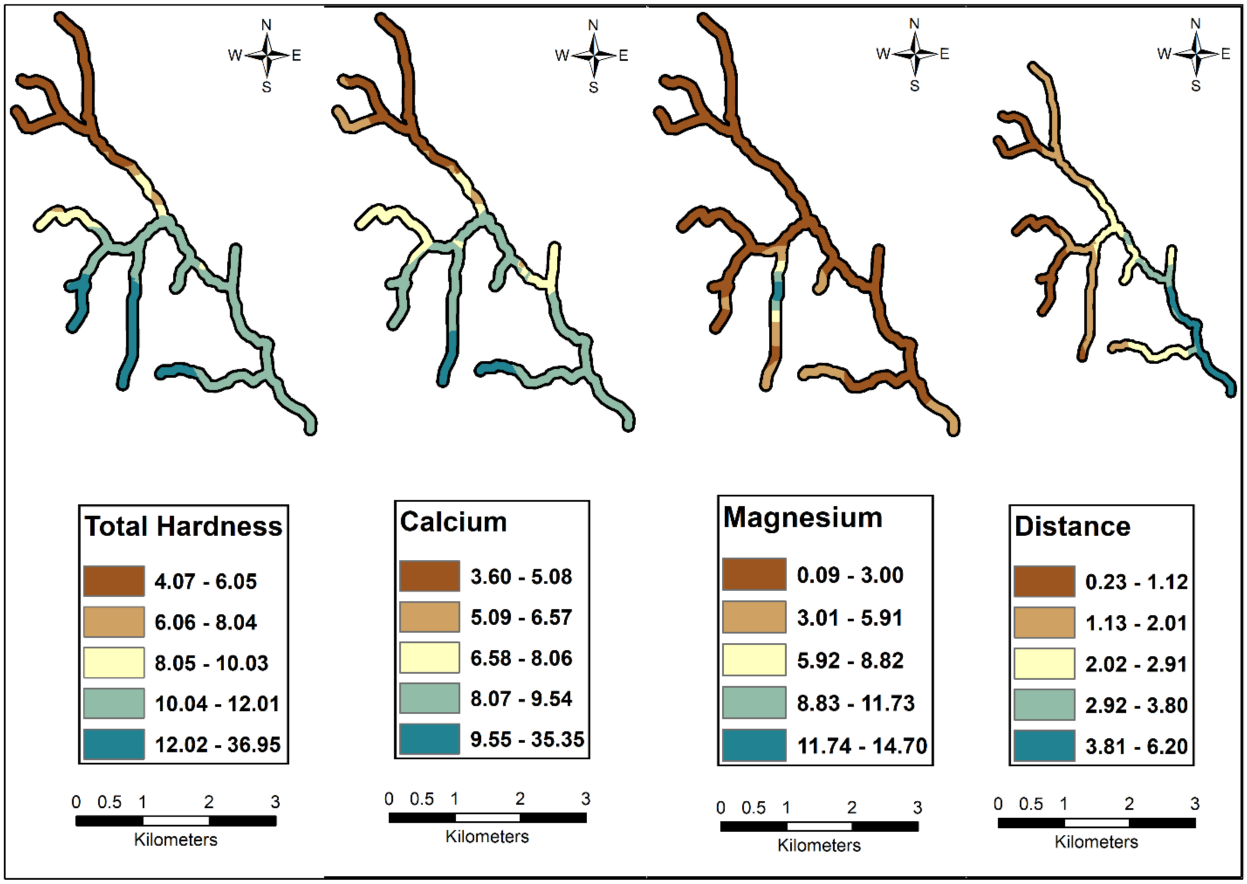

Figure 3. Spatial pattern of total hardness, calcium, and magnesium relative to distance

In an attempt to further assess how water characteristics, change with increasing distance from the source of the river, the Pearson product-moment correlation was used (Table 2). The analysis revealed that there is no statistically significant correlation between the concentration of all the physicochemical parameters and distance from the river source. Also, there is no statistically significant correlation between stream order and concentration of the parameters (Table 2, Figure 4). This suggests that even though various human activities in sub-catchment contribute in varying degrees to the situation of surface water contamination, some areas serve as pollutant sinks. Instead of pollutant concentration increasing downstream, they infiltrate at different points to contaminate the soil and groundwater systems.

Table 2. Correlation between order, stream and physiochemical parameters

		pH	TDS	Alkalinity	Total hardness	Ca	Mg
Order	Pearson Cor.	0.311	-0.089	0.048	-0.054	-0.072	0.034
	Sig. (2-tailed)	0.685	0.828	0.807	0.745	0.877	0.000
	N	23	23	23	23	23	23
Distance	Pearson Cor.	0.323	-0.072	0.157	-0.02	-0.024	0.006
	Sig. (2-tailed)	0.133	0.746	0.475	0.926	0.912	0.979
	N	23	23	23	23	23	23

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

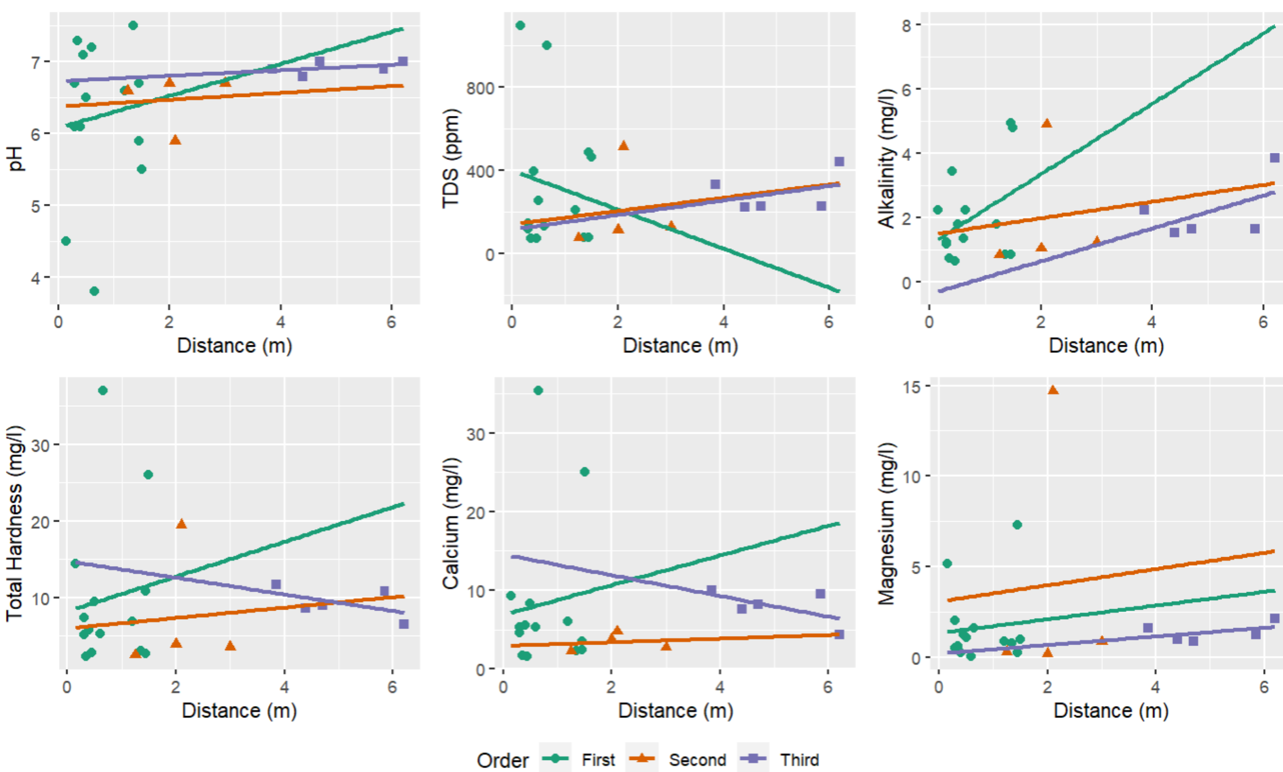

Figure 4. Variation in water quality parameters across stream orders

4. Discussion

Given the observed pH range (3.89–7.50), the effluents are largely acidic and hence the stream water is however at variance with the WHO (2003) ingest desirable and maximum permissible levels of 7.0–8.5 and 6.5–9.2, respectively, for drinking water. This situation will facilitate the dissolution of metallic ions (Davie, 2008). Just like pH, industrial activities bear an imprint on the concentration of TDS, as the highest value of 1095 ppm was observed at point 22. This exceeds the WHO (2003) ingest desirable and maximum permissible levels of 500 ppm and 1000 ppm, respectively. The concentration of TDS to a significant extent physically connotes the quality of drinking water, and its excess concentration devalues water's aesthetic characteristics through increased turbidity (Mendie 2005; Ayeni et al. 2006; Fashae et al., 2019). For instance, TDS concentration can be influenced by industrial activities wherein particulate matter from industrial processes amalgamates into thick floats on stream surfaces and hence reducing the level of water transparency (Singh & Gupta, 2017). In addition, surface water bodies may have high TDS concentrations because of the improper discharge of municipal wastewater into drains and the excessively used of fertilizers from agricultural activities (Mendie, 2005; Fashae et al., 2019). Alkalinity influences the buffering capability of water bodies to resist a pH after absorbing hydrogen ions (Viessman & Hammer, 1998). It particularly denotes the concentration of bicarbonate (HCO^{3-}) ions and the possibility of water hardness (Davie, 2008). Total hardness (2.35–36.35 mg/l) lies below the WHO (2003) limits - ingest desirable level (100 mg/l) and maximum permissible level (500 mg/l) The concentration of calcium (1.60–35.35 mg/l) ranged below the WHO (2003) ingest desirable level (75 mg/l) and maximum permissible level (200 mg/l). The same trend goes for magnesium (0.05–14.70 mg/l) which ranged below the WHO (2003) ingest desirable level (30 mg/l) and maximum permissible level (150 mg/l).

Even though the concentrations of pollutants do not increase downstream (Table 1), pollutants which are supposed to increase in concentration downstream are infiltrated into the soil rapidly in pockets of locations and may eventually be fed into the groundwater system or translocated by vegetation. However, the presence of pollutants from the intermix of land use types has strong environmental implications for community health and ecosystem functioning. The intake of contaminants by plants can encourage bioaccumulation in plants and then navigate the food chain sequence to animals and humans (Inyinbor et al. 2018; Fashae & Obateru, 2021). It is also likely that the concentrations of contaminants will increase across the food chain levels in a situation known as biomagnification.

5. Conclusion

In developing countries like Nigeria, urban centres are usually beset with environmental problems largely in the forms of surface and groundwater pollution, atmosphere pollution and ecosystem health impairment. This study examined the variation in selected water quality parameters in a rapidly urbanizing sub-catchment with intertwining land uses in Ibadan, Nigeria. The concentration of pH, total dissolved solids, alkalinity, total hardness, calcium and magnesium were examined relative to stream order and increase distance downstream. It was observed that the concentration of these parameters varies randomly along the stream channels; hence correlation analysis shows that there is no statistically significant correlation between the concentration of the parameters, distance downstream and stream order. The pollutants readily infiltrate into the subsurface layers and most like percolate into the groundwater system. This situation is characterized by significant ecological risk, especially to the inhabitants who utilize water from both surface and groundwater sources for various functions. Based on the result of this study, the pollution level at the sub-catchment is still at a minimal level, however, there is a dire need to for effective water quality monitoring spatially and temporally. Since the conflicting nature of the land use has come to stay, there is a need to enlighten the inhabitants on ecological friendliness and its relevance which are paramount to maintaining water quality standards.

References

Ayeni, A. O., Balogun, I. I., & Adeaga, O. A. (2005). Impact of selected landuse types on surface water quality downstream of ASA Dam in Kwara State, Nigeria. *Journal of Environmental Systems*, *32*(3).

Davie, T. (2008). *Fundamentals of hydrology*. Routledge.

Fashae, O. A., & Obateru, R. O. (2021). Geospatial Assessment of Surface Water Pollution and Industrial Activities in Ibadan, Nigeria. In *Spatial Modeling and Assessment of Environmental Contaminants* (pp. 189-211). Springer, Cham.

Fashae, O. A., & Olusola, A. O. (2017). Land use Types within Channel Corridor and River Channel Morphology of River Ona, Ibadan, Nigeria. *The Indonesian Journal of Geography*, *49*(2), 111-117.

Fashae, O. A., Ayomanor, R., & Orimoogunje, O. O. (2017). Land use dynamics and surface water quality in a typical urban centre of south-western, Nigeria. *Analele Universităţii din Oradea, Seria Geografie*, *27*(1), 98-107.

Fashae, O. A., Ayorinde, H. A., Olusola, A. O., & Obateru, R. O. (2019). Landuse and surface water quality in an emerging urban city. *Applied Water Science*, *9*(2), 25.

Hamid, A., Bhat, S. U., & Jehangir, A. (2020). Local determinants influencing stream water quality. *Applied Water Science*, *10* (1), 1-16.

Huang, J., Huang, Y., & Zhang, Z. (2014). Coupled effects of natural and anthropogenic controls on seasonal and spatial variations of river water quality during baseflow in a coastal watershed of Southeast China. *PloS one*, *9*(3), e91528.

Hynes, H. B. N. (1975). The stream and its valley: With 4 figures and 2 tables in the text. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*, *19*(1), 1-15.

Inyinbor Adejumoke, A., Adebesin Babatunde, O., Oluyori Abimbola, P., Adelani Akande Tabitha, A., Dada Adewumi, O., & Oreofe Toyin, A. (2018). Water pollution: effects, prevention, and climatic impact. *Water Challenges of an Urbanizing World*, *33*.

Kim, J. Y., & An, K. G. (2015). Integrated ecological river health assessments, based on water chemistry, physical habitat quality and biological integrity. *Water*, *7*(11), 6378-6403.

Liu, Y., Zhang, H., Zeng, P., Wang, Y., Li, G., Sun, F., & Che, Y. (2021). Linking hydraulic geometry, land use, and stream water quality in the Taihu Basin, China. Environmental Monitoring and Assessment, 193, 1-17.

Mendie, U. E., (2005). *The theory and practice of clean water production for domestic and industrial use: Purified and package water*. Lacto-Medal Ltd, Lagos.

Obateru, R. O., Fashae, O. A., Osakunih, O. I., & Olusola, A. O. (2022). Hydraulic geometry influences some water quality parameters in a tropical headwater basin in southwestern Nigeria. *Acta Geophysica*, 1-10.

Ramírez, A., Rosas, K. G., Lugo, A. E., & Ramos-González, O. M. (2014). Spatio-temporal variation in stream water chemistry in a tropical urban watershed. *Ecology and Society*, *19*(2).

Sharma, R. C., Singh, N., & Chauhan, A. (2016). The influence of physico-chemical parameters on phytoplankton distribution in a headwater stream of Garhwal Himalayas: a case study. *The Egyptian Journal of Aquatic Research*, *42*(1), 11-21.

Strahler, A. N. (1954). Statistical analysis in geomorphic research. *The journal of Geology*, *62*(1), 1-25.

Shultz, A. M., Begemann, M. H., Schmidt, D. A., & Weathers, K. C. (1993). Longitudinal trends in pH and aluminum chemistry of the Coxing Kill, Ulster County, New York. *Water, Air, and Soil Pollution*, *69*(1), 113-125.

Singh, M. R., & Gupta, A. (2016). Water pollution-sources, effects and control. *Centre for Biodiversity, Department of Botany, Nagaland University*.

Townsend, C. R., Hildrew, A. G., & Francis, J. (1983). Community structure in some southern English streams: the influence of physicochemical factors. *Freshwater biology*, *13*(6), 521-544.

Vannote, R. L., & Sweeney, B. W. (1980). Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. *The American Naturalist*, *115*(5), 667-695.

Viessman, W. Jr., Hammer, M.J., 1998. Water Supply and Pollution Control, 6th Ed. Addison-Wesley Longman Inc, Menlo Park, CA

WHO (2003). Guidelines for drinking-water quality, Volume 1, Recommendations (1st Addendum to 3rd ed.). Geneva: World Health Organization.

WWAP (2003). United Nations World Water Assessment Programme. *The World Water Development Report 1: Water for People, Water for Life.* UNESCO: Paris, France.

Vannote, R., Minshall, G. W., Cummins, K., Scdcll, J. R., & Cushing, C. E. (1980). The river continuum concept. CanJ Fish Aquat Sci 37: 130–137.

Liu, Y., Zhang, H., Zeng, P., Wang, Y., Li, G., Sun, F., & Che, Y. (2021). Linking hydraulic geometry, land use, and stream water quality in the Taihu Basin, China. Environmental Monitoring and Assessment, 193, 1-17.