Archives of Current Research International

12(2): 1-9, 2018; Article no.ACRI.39397
ISSN: 2454-7077

Influence of Surrounding Land Use on the Physicochemical Parameters of Agulu Lake, Anambra State, Nigeria

Nelson Mbanefo Okoye[1*] and Louis Chukwuemeka Orakwe[1]

[1]*Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author NMO designed the study, conducted the field sampling, managed the literature searches and wrote the first draft of the manuscript. Author LCO managed the analyses of the study and performed the statistical analysis. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ACRI/2018/39397
Editor(s):
(1) Nguyen Van Toan, School of Biotechnology, Vietnam National University, Ho Chi Minh City, Vietnam.
Reviewers:
(1) Anita Ivanković, University of Mostar, Bosnia and Herzegovina.
(2) Beaven Utete, Chinhoyi University of Technology, Zimbabwe and University of Ibadan, Nigeria.
(3) Osuolale Olayinka, Elizade University, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/23232

Original Research Article

Received 15th November 2017
Accepted 5th February 2018
Published 17th February 2018

ABSTRACT

Effective surface water management requires a detailed understanding of the relationship between land use and water quality. This study investigated the spatial variability of land use impacts on water quality of Agulu Lake in Anambra State, Nigeria. The aim was to look at how the diverse land use types around the lake environment affect pollutant load of the lake. Water samples were collected from six locations within the lake corresponding to the identified land uses in the study area in February and June 2016. Ten physicochemical parameters comprising pH, temperature, EC, turbidity, DO, BOD, TSS, NO_3^--N, PO_4^{3-} and SO_4 were analyzed using standard methods and compared with WHO standards. The results show that except for pH, the prevailing season influenced the other parameters. EC, turbidity, DO, BOD, TSS, NO_3^--N, PO_4^{3-} and SO_4 values were higher in the wet season. There was significant variation in the physicochemical parameters related to different land-use patterns. Water samples from industrial, residential and recreational areas, and the area receiving runoff from transportation were found to have the highest levels of pollutant concentrations.

**Corresponding author: Email: nelsonokoye2003@yahoo.com;*

Keywords: Land use; physicochemical parameters; water quality; Agulu Lake; catchment dynamics; Nigeria.

1. INTRODUCTION

The surface water resources potential of Nigeria is very huge and valued at 267.3 billion cubic meters [1]. However, surface water is vulnerable to pollution from the surrounding environment through point and non-point sources [2]. Catchment runoff is a major contributor to non-point source pollution [3,4]. Land use describes the exploitation and use of land resources by humans within a specific site [5]. Changes in land use patterns occur because of economic development, population growth, technology, removal of vegetation and growing demand for natural resources [6,7,8]. As land use patterns change from unaltered natural landscapes to agricultural and urban uses, forests and wetlands are lost; road density increase; surface runoff also increases; and chemical and wastewater inputs into water bodies increase [9,10]. Because of human activities, the conditions of many aquatic environments have been altered. It is accepted that there is a close relationship between the land use type and water quality [2]. [11] defined water quality in terms of its physical, chemical and biological parameters. Water quality parameters including temperature, dissolved oxygen, pH, total suspended solids, nutrients, and heavy metals are crucial to ecological habitat integrity and critical to water resources ecosystem services. Alterations in water quality cause eutrophication [12,2], stream bank erosion [3] and changes to flora and fauna communities [8]. Therefore, understanding the effects of changes in land use and land cover (LULC) is important for maintaining a desired level of water quality and for restoring water quality in affected areas [7]. Agulu Lake serves multiple designated purposes such as washing, fish and ritual sacrificing, but it is the primarily a source of domestic water supply for the Umuowelle community. Agulu lake catchment has experienced dynamic land use changes from forest to crop lands and residential developments. Subsistence farming is the major land use in the surrounding slopes that drain into the lake. More importantly there is an ongoing effort to develop the Agulu Lake into a tourist attraction. There is a dearth of information on the effects of land uses on the Lake, despite how significant it is. This study investigated the spatial variability of land use impacts on water quality of Agulu Lake. The goal was to look at the effect of the diverse land use types around the lake environment on pollutant load of the lake.

2. MATERIALS AND METHODS

2.1 Study Area

The six-armed natural Agulu Lake in Agulu, Anambra State (Fig. 1) was the study site. Agulu lake is located within latitudes 6°07' and 6°09'N and longitudes 7°01' and 7°03'E, has a mean depth of 5.2 m and greatest water depth of 11.2 m. It has catchment area of 32 km^2 while its surface area has varied over time form 0.6177 km^2 in 1978 to 0.3746 km^2 in 2008 and 0.3583 km^2 in 2013 [13]. Agulu is in the rainforest zone of Nigeria and experiences two distinct seasons brought about by the two main winds i.e: the South Western Monsoon winds from the Atlantic Ocean and the North Eastern dry winds from across the Sahara desert. Seven months of heavy tropical rains (May-October) precedes five months of dryness (November-March) [14].

The harmattan, a particularly dry and dusty period, occurs for about two weeks within the dry season and significantly impacts surface water stream flows and volumes due to the very high evapotranspiration associated with the very dry and windy conditions. The temperature is generally hot and humid in the range of 27-28°C during July through December but rising to 35°C between February and April. The area is underlain by the Eocene (Tertiary) shallow marine to continental Ameki formation, which is dominantly sandy with purple, white, grey, pink, clay-shale-silt bands [11].

2.2 Sampling Locations

Because the land use practices in an area is known to influence the surface water quality due to inputs [2], sampling was carried out on six sites representing different land use patterns in the study area. This involved identifying the land-use types around the Lake which are likely to influence the water quality condition of the Lake. Each sampling site represented one of the land-use categories identified in the study area. Fig. 2 shows some of the land use activities around the lake.

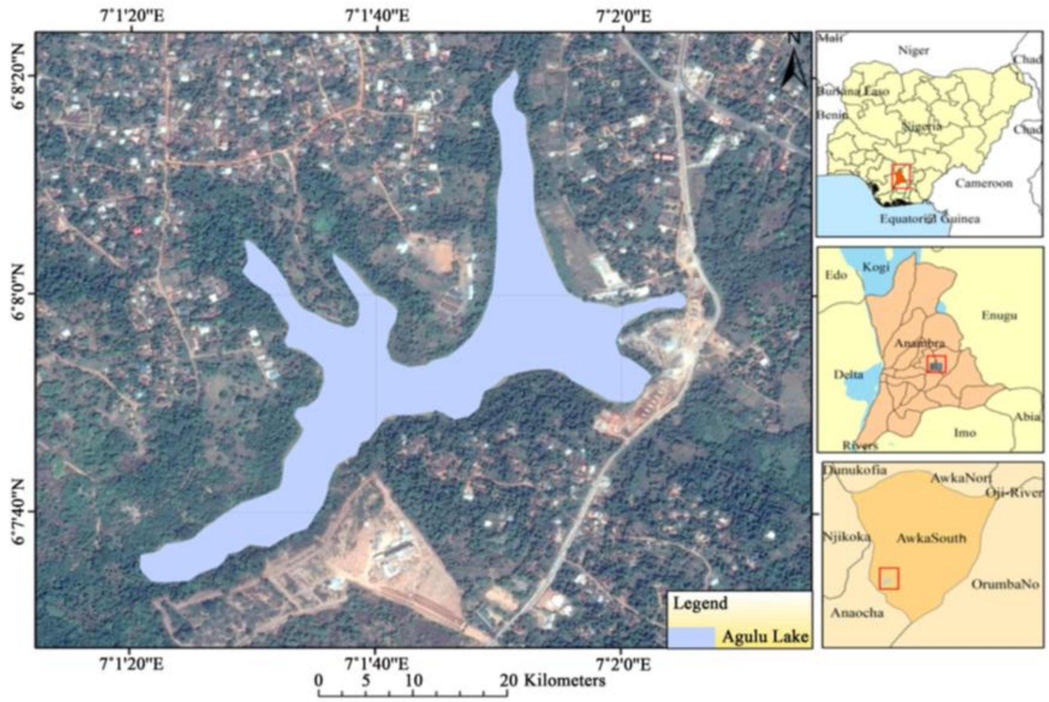

Fig. 1. Map of Agulu Lake, Anambra State, Nigeria (Nzoiwu et al. [13])

Fig. 2. Surrounding land use activities

Fig. 3. Land use pattern and sampling locations

As show in Fig. 3, the first site (S1) received discharge from industrial activities. The second (S2) received discharge from transportation land-use. The third (S3) received discharge from residential areas. The fourth site (S4) receives discharge from agricultural runoff. The fifth (S5) received inflow from the recreational area. The last site (S6) received discharge from the forested area.

2.3 Water Sample Collection

Water samples were collected at the surface with one litre sterilised polyethylene bottles from six different points in the lake twice in February (dry season sample) and June (wet season sample), 2016. The sampling schedule was to make sure that samples were collected at the peaks of the dry and wet seasons to understand the temporal variations in the physicochemical parameters of the lake. The following parameters were measured: pH, temperature, EC, turbidity, dissolved oxygen, BOD, TSS, NO_3^--N, PO_4^{3-} and SO_4. At each site three replication were taken and then aggregated into a composite sample to capture the variations. Temperature, pH, conductivity and turbidity were measured on site. pH was measured using RoHS PH-107 handheld pH meter. Turbidity was measured using a 25 cm (diameter) Secchi disc. Temperature and conductivity were determined using Teika K12 digital handheld TDS-EC meter. The rest of the water samples stored in ice packed cooler box before transportation to the laboratory for the measurement of dissolved oxygen, BOD, TSS, NO_3^--N, PO_4^{3-} and SO_4, according to the methods described in [15].

2.4 Data Analysis

The statistical significance of the mean differences between the water quality parameters at the six sampling locations were determined using one-way multivariate analysis at a confidence level of 95%. Thus, the differences are significant at $p \leq 0.05$. Post hoc test was carried out for multiple comparisons after one-way MANOVA. The Friedman test for statistically significance determined the differences in water quality due to the influence of different seasons (wet and dry seasons).

3. RESULTS

Figs. 4, 5 and 6 shows the mean values of physicochemical parameters at the various locations. The mean wet season pH of the lake ranged from 7.23±0.06 at the residential area to 7.71±0.14 at the recreational area, while the mean dry season pH ranged from 7.23±0.02 at the industrial area to 7.88±0.16 at the forest area. The pH values falls within the WHO standards of 6.5-8.5 [16]. The mean wet season temperature ranged from 22.2±0.28°C at the agricultural area to 24.1±0.07°C at the residential area, while the dry season values ranged from 27.8±0.64 at the forest area to 28.5±0.21°C at the agricultural area. All the water temperature values obtained during the wet season was below the WHO set limit of 25°C, but all the dry season temperature values were above the limits of the WHO standards. The mean wet season conductivity ranged from 164±8.493 μS/cm at the forest area to 271±12.023 μS/cm at the industrial land use, while the dry season values ranged from 209.7±13.013 μS/cm at the recreational area to 435.7±10.393 μS/cm at the industrial area. The dry season values at the industrial and transportation areas were above the WHO set limit of 400 μS/cm. Mean wet season turbidity.

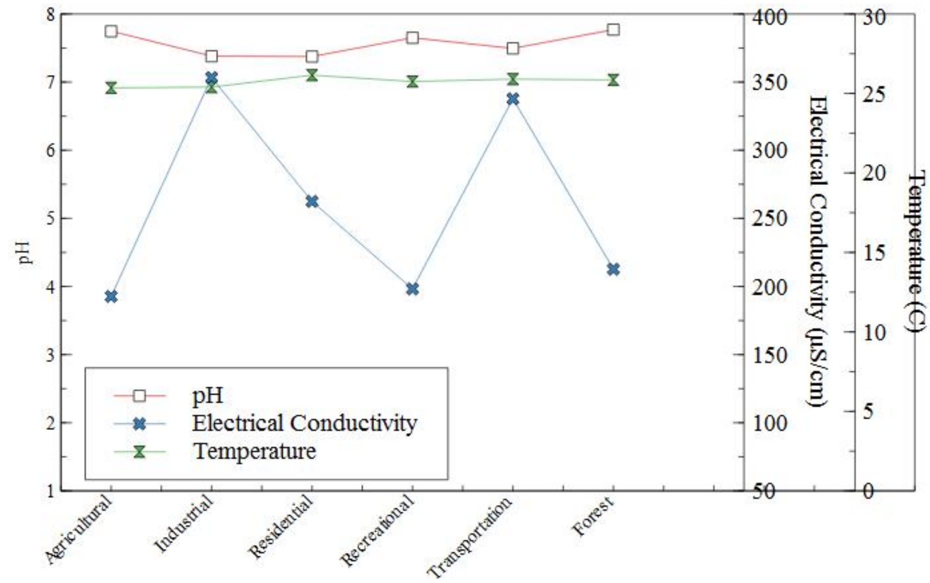

Fig. 4. Mean variations of pH, electrical conductivity and temperature at the sampling locations

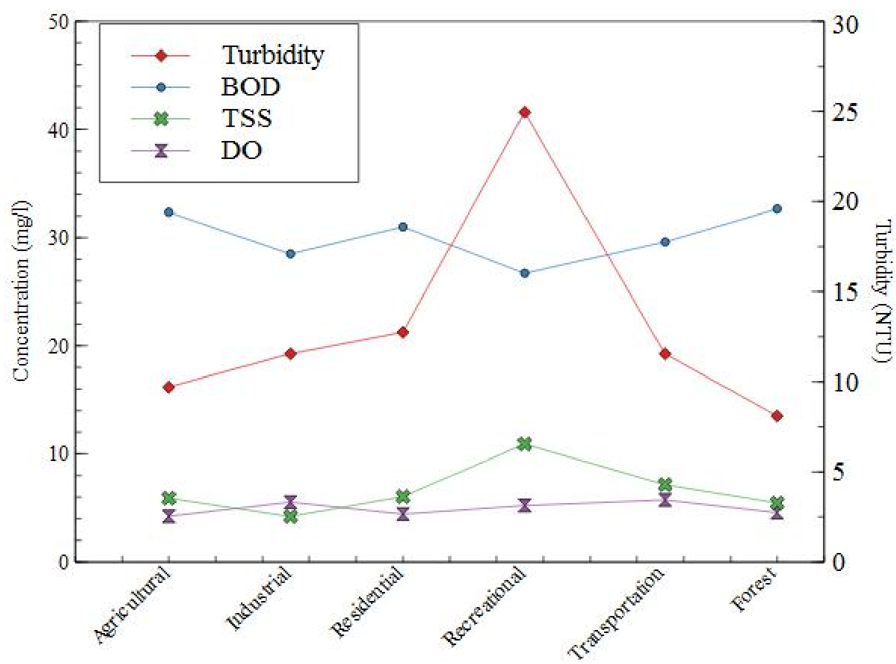

Fig. 5. Mean variations of turbidity, DO, TSS and BOD at the sampling locations

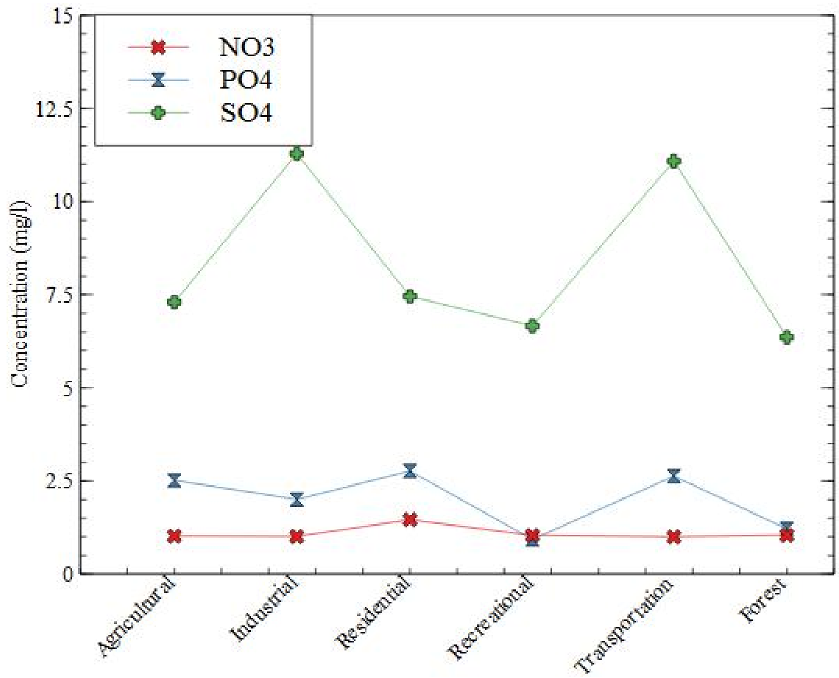

Fig. 6. Mean variations of NO_3-N, PO_4^{3-} and SO_4 at the sampling locations

values ranged from 12.7±0.21 NTU at the forest area to 44.7±0.64 NTU at the recreational area, while the dry season values ranged from 3.1±0.49 NTU at the industrial area to 5.2±0.35 NTU at the recreational area. in the dry season. The turbidity values obtained were well below the set limit of 500 NTU by the WHO. The mean wet season TSS ranged from 5.2±0.07 mg/l at the industrial area to 17.4±0.64 mg/l at the recreational area, while mean dry season values ranged from 3.2±0.28 mg/l at the industrial area to 5.8±1.13 mg/l at the transportation area. All the raining season values were above the WHO limit of 5 mg/l. The mean wet season DO, BOD, NO_3-N, PO_4^{2-} and SO_4 values ranged from 4.83±0.96-7.85±0.40 mg/l, 28.8±0.92-39.5±2.26 mg/l, 1.5±0.05-2.21±0.16 mg/l, 1.56±0.09-3.72±0.11 mg/l and 8.6±0.35-17.5±0.49mg/l respectively, while the dry season values ranged from 3.21±0.07-4.01±0.57 mg/l, 24.6±2.33-30.0±2.83 mg/l, 0.43±0.08-0.71±0.23 mg/l, 0.22±0.06-2.45 mg/l and 4.12±0.11-5.07±0.75 mg/l respectively. All the values obtained for BOD and PO_4^{2-} were above the set limits of 10 and 0.3 mg/l by the WHO, while all the values obtained for SO_4 were below the set limit of 250 mg/l.

One-way Multivariate analysis showed that there was a statistically significant difference in the mean physicochemical parameters of the water samples collected at the different sampling locations, F(50, 44.4) = 9.91, P < 0.005, Wilk's ^ = 0.00, η^2 = 0.898. A Tukey post hoc test revealed that conductivity at the agricultural and industrial areas were significantly different (*P = 0.039*). Also the industrial and recreational areas were significantly different (*P = 0.042*). The difference in PO_4^{2-} values were statistically significant at the agricultural and recreational areas (*P = 0.035*), agricultural and forest areas (*P = 0.051*), residential and recreational areas (*P = 0.03*), residential and forest areas (*P = 0.044*), recreational and transport areas (*P = 0.025*) and transportation and forest areas (*P = 0.036*). A Friedman test of statistical significance revealed that apart from pH which was not significantly different (*P = 1.00*) during the wet and dry seasons, the dry season temperature was significantly higher (*P = 0.014*) than the wet season temperature, while the wet season values were significantly higher for EC (*P = 0.032*), turbidity (*P = 0.016*), dissolved oxygen (*P = 0.014*), BOD (*P = 0.04*), TSS (*P = 0.026*), NO_3^--N (*P = 0.014*), PO_4^{3-} (*P = 0.024*) and SO_4 (*P = 0.042*).

4. DISCUSSION

The results of the study suggests that recreational, residential, industrial and transportation land uses had negative impacts on the water quality of the lake, particularly in the wet season. Forest and agricultural land use had a less negative impact on the water quality. Residential land use was the strongest contributor of nitrogen and phosphorus in the lake as a result of domestic wastewater and sewage discharge from some of the homes, which is known to be high in nutrients. Discharge of domestic waste and sewage result in variety of changes in the hydrology and water quality [12]. This may have also been highly influenced by other point source as well as non-point source pollution. Due to the fact that urban developments have a lot of impervious areas and do not allow for much infiltration of water, runoffs carry pollutants to water bodies which increases the concentration of pollutants in such water bodies [17]. The very high conductivity values recorded in the dry season is due to the effect of a lowered stream flow and volume due to evapotranspiration, which invariably increased the concentration of ions in the lake. Recreational land use was the strongest contributor to turbidity. This is due to the high sediment load from the site of the Agulu Lake Resort. Two of the important land use practices that result in increased soil erosion and subsequent load of sediments and nutrients into aquatic systems are urbanization and deforestation [18]. The satellite image below (Fig. 7) shows the level of distortion of the environment between 2011 and 2016 due to deforestation and urbanization. The high sediments load into the lake due to the resort development is visible in the red mark.

Transportation as a land use also contributed to high pollutant load in the lake. This is due to the large inflows from road drainage channels. There has also been visible reduction in the vegetative cover around the lake due to bridge construction as seen in Fig. 8.

Fig. 7. Deforestation between 2011 and 2016 due to Agulu Lake Resort development

Fig. 8. Deforestation between 2011 and 2016 due to bridge construction

The lowest pollutant loading was observed at the forested and agricultural land uses. The low values obtained for forested land use is due to the low anthropogenic activities and retention of nutrients. This is in line with [19] who stated that forests generally yield higher water quality than other land uses. According to [10], "Forests have a strong influence on catchment hydrology and water quality. Interception and evapotranspiration processes in forests cut the amount of precipitation reaching the forest floor". The physical, biological and chemical characteristics of forest soils facilitate water filtration, contaminant removal and nutrient recycling [10]. Agriculture is known to have negative impacts on water quality especially when inputs such as herbicides, insecticides, and fertilizers are used, because they can run off into water bodies or percolate to the groundwater [20]. However, the results of the study showed that agricultural land use did not significantly affect the lake water quality, which is contrary to general observations. This is likely due to the fact that cassava cultivation is the primary agricultural land use in the area and majority of the farmers depend on the soils natural fertility to nourish the crops and as such no significant quantity of fertilizer is used. Nevertheless, the impacts of agricultural chemicals and agricultural runoffs should not be overlooked since the positive result can change in just one planting season. The marked seasonality in the pollutant concentration might be due to increased leaching due to rains and results to a higher value during rainy season.

5. CONCLUSION

The study analyzed the physicochemical parameters of Agulu Lake with respect to land use and concludes that observed that the water quality is negatively affected by surrounding land-use activities. The observed high pollutant loads results probably from runoffs. The study highlighted the adverse effects of the various activities around the lake. Most of the parameters analyzed exceeded the limits set by World Health Organization and thus utilization of the lake water for domestic purposes poses great health risks. Based on the findings of this study, there is an urgent need for a more comprehensive study at a catchment scale, to find all major contributors to the declining quality of the lake water and the general lake environment. Improved land-use optimization, awareness campaigns and water pollution control strategies are the key recommendations to improve the water quality of Agulu Lake.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/23232