Full Length Research Paper

Spatial and Temporal Variation of Selected Water Quality Parameters in the Tanzanian Side of Lake Victoria

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ABSTRACT

Lake Victoria's water quality is increasingly becoming under heavy pressure mainly due to land based activities and aerial inputs which are taking place within the basin. This study was carried out to assess the spatial, including vertical and temporal, variation of the water quality of Lake Victoria on the Tanzanian side. Historical water quality data for the period from 2000 to 2016 was collected. Temperature, pH, Dissolved Oxygen (DO) and Turbidity were selected for study since they are the mostly measured and monitored water quality parameters. Land use-land cover changes were analysed using ArcGIS. ILWIS 3.7 software was used to classify the land use and land cover for the years 2000, 2010 and 2014. MERIS was used to analyse the spatial variation. One-way ANOVA was employed to test the significant variation between different parameters. The results showed that, for the pelagic zone, the range of temperature, pH, DO, and turbidity were 22.8°C-28.68°C, 6.3-10.52, 3.42-10.21 mg/l, 1.0 NTU-15.8 NTU respectively. The corresponding values for the littoral zones were 22.3°C-26.8°C, 6.47-10.16, 3.99-8.6 mg/l, 1.3-347 NTU respectively. The ANOVA analysis results show that there was a significant variation of $NO_3(p<0.01)$. Temperature, pH and DO decreased with the lake depth to the bottom for both zones. For the littoral zone, a strong correlation was observed between temperature and depth, temperature and DO, and between temperature and pH with $R^2=0.6$, $p<0.03$, $R^2=-0.78$, $p<0.01$ and $R^2=0.96$, $p<0.01$, respectively. The bare soil, urban settlements and farm land increased by 38.9%, 8.4% and 10.7% respectively from the year 2000 to 2014 on the Tanzanian side. This could have led to water quality changes. Water quality parameters varied significantly between pelagic and littoral zones. Littoral zones are mostly polluted and thus should be the priority pollution control intervention areas.

Key words: *Spatial-temporal variation, water quality, strong correlation, land use change.*

INTRODUCTION

The United Nations' (UN's) Sustainable Development Goals (SDGs) provides framework for sustainable management of our environment (UN, 2015). SDG target 6.3 seeks to improve water quality, wastewater treatment and safe reuse while SDG target 6.6 aims to protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. Indicator 6.6.1 is the *"change in the extent of*

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water-related ecosystems over time" (UN, 2015). Lakes are important and sensitive ecosystems which must be sustainably managed to achieve the two SDG 6 targets (UN, 2015). Lake Victoria (LV) is recognized for its high levels of freshwater species diversity and endemism, which are of critical importance to local livelihoods and national economies within the basin (Semayo, 2021). This crucial ecosystem for the region is being plagued with frequent fish kills, oxygen depletion of deep waters and poor water quality, which is characterized by blooms of harmful algae and aquatic weeds (Semayo, 2021).

Most of the LV riparian populations depend on LV for various economic activities (Kayombo and Jorgensen, 2006). For example, along the shoreline of LV on the Tanzania side, there is a number of towns which depend on LV for their domestic, industrial and institutional water needs (Cheruiyot et al., 2014). These towns include, Mwanza City, Musoma and Bukoba Municipalities, Misungwi, Lamadi, Magu, Sengerema, Chato, Muleba and other District Councils (COWI, 2017). The total population of lake dependants is estimated to be more than 1,000,000 (Tanzania NBS, 2012). Also, though not good practice, LV is used as a disposal site for the untreated, partially treated and treated wastewater (COWI, 2002; Kayombo and Jorgensen, 2006; Cheruiyot et al., 2014).

Over the last three decades, the increase in population, urbanisation and economic growth have resulted in escalated anthropogenic pollution of the Lake Victoria (COWI, 2002; Kayombo and Jorgensen, 2006; Oyoo, 2009; Kimwaga et al., 2011). The rapid growth of the riparian community, industrialization and an increase in commercial activities, coupled with inadequate provision of sanitation services to the residents and towns around the lake has resulted into the increased effluent which then finds its way to the lake, thereby, causing pollution (Oyoo, 2009). Some of the rivers which feed the lake are polluted by municipal and industrial wastes (COWI, 2002).

The various LV water quality studies have been conducted focusing mainly on the water hyacinth and fishing activities (Scheren et al., 2000; Okungu et al., 2004; Kateregga and Sterner 2007; Kateregga and Sterner, 2009). The lake's water quality deterioration has not long been adequately addressed. Studies have also shown that the nutrients which enter the lake are mostly bound up within the bottom part of the lake, with little recirculation (Lehman and Branstrator, 1994; COWI, 2002; Boehrer and Schultze, 2008), causing water deterioration and eutrophication. Aquatic plant mapping within the lake has revealed that the aquatic plants in the lake have decreased, compared to the 1990's (Cheruiyot et al., 2014). Further, the lake has been polluted by non-point source of pollution (Kimwaga et al., 2011).

Despite the various efforts in addressing the water quality management challenges, there is still insufficient information on the spatial and temporal variation of water quality on the Tanzanian side of Lake Victoria waters. An understanding of the spatial and temporal variation of water quality will help in identifying the pollution hotspots areas needing immediate water quality intervention measures. Besides, the land use land cover factors which can be attributed to the changes of the water quality of the lake have not been well understood.

METHODS AND MATERIALS

Description of Study Area

This study was conducted in the Tanzanian side of the Lake Victoria (Figure 1).
The catchment area in the Tanzania side is 115,400 km^2, the lake's surface area is 35,720 km^2 and the length of shoreline is 1,150km. The rainfall in the eastern part of the Lake Victoria Basin, especially in highlands of Tarime, is distinctively bimodal. In the south portion, in Mwanza Region, the pattern is unimodal with a wet

and dry season. The western part receives rainfall almost throughout the year with minimum rainfalls in July. There are considerable variations in the average yearly rainfall over the lake surface and the surrounding land area. Over the extreme eastern area of the lake, rainfall varies between 500 to 2000 mm per year. The main rivers draining into the lake include Kagera, Simiyu, Mbarageti, Grumeti, Mara and Mori Rivers. There are three trans-boundary rivers within the basin which are Mara, Kagera and Grumeti rivers and small rivers which are Mwisa, Ngono, Duma, Nyashishi, Suguti, Magogo, Moame and Mato rivers.

The Tanzania part of the lake basin contributes significantly to the welfare of many communities who rely on it as a source of food in terms of fish, employment, and trade (Kayombo and Jorgensen, 2006). Besides food, the lake provides transport, communication, tourism, water supply for domestic, agricultural and industrial use, wastewater disposal, recreation, sports and biodiversity conservation (Kayombo and Jorgensen, 2006). The dominant socio-economic activities in the lake and its catchment include agriculture, fisheries, water transportation, recreation, and water supplies for domestic and industrial use in the urban centres on its shoreline (BICO, 2020). There are also Gold and Nickel mining activities being conducted in the basin including the presence of major mining sites like Geita Gold Mine and North Mara gold mine and local small-scale mining sites, which also have an impact on the environment (BICO, 2020).

Figure 1: The map of the Tanzania side of Lake Victoria Basin (BICO, 2020)

The percentage contribution of rivers to Lake Victoria on the Tanzanian side basin and the whole basin of Lake Victoria is shown in **Error! Reference source not found.**.

Table 1: River contribution to the Lake Victoria waters and catchment (Kayombo and Jorgensen, 2006)

| River name	Discharge (m³/s)	% contribution for Tanzanian side basin	% contribution for whole basin
Mara	37.5	7.87	4.8
Grumeti	11.5	2.41	1.5
Mbalageti	4.3	0.90	0.5
E. Shore Stream	18.6	3.90	2.4
Simuyu	39.0	8.19	5.0
Magogo Moame*	8.3	1.74	1.1
Nyashishi*	1.6	0.34	0.2
Issanga	30.6	6.42	3.9
S. Shore Stream*	25.6	5.37	3.3
Biharamulo	17.8	3.74	2.3
W. Shore Stream	20.7	4.35	2.7
Kagera	260.9	54.76	33.5
Sub-total	**476.4**	**100**	**61.2**

Population around Lake Victoria

According to NASA (2006), Lake Victoria basin is the most densely populated rural area in the world with a population of about 30 million. According to NBS (2012) statistics, about 1.5 million people are found on the Tanzanian side along the lake shore. The average density on the Tanzanian side is 97 persons/km^2 (UNEP, 2006). The population growth rate is about 6% per annum (Kayombo and Jorgensen, 2006).

Data collection

Historical water quality data from LVEMP data base from year 2000-2016
The water quality data which were used in this study were historical data which were collected from Lake Victoria Environmental Management Programme (LVEMP) database. The data are from the existing water quality monitoring points used by Lake the Victoria Basin Water Organization (LVBWO). LVBWO is an institution responsible for monitoring the water quality of Lake Victoria on Tanzanian side and advising the government on issues pertaining to water quality of Lake Victoria and other related activities in the lake's catchment. The data were for the two main zones, namely the open Tanzania Pelagic zone (TP), and the near shore areas herein referred to as the Tanzania Littoral zone (TL) (Figure 2).
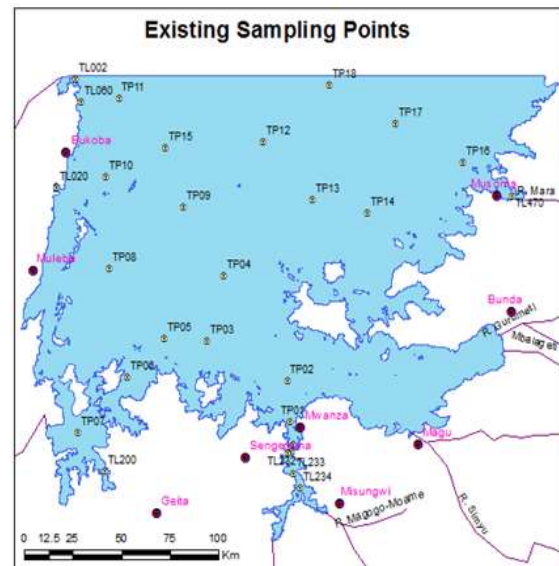
Figure 1: The water quality monitoring points for the Tanzanian side of the Lake Victoria (COWI, 2002)

This classification is based on depths, with the pelagic area having depths greater than 15 metres and the littoral area having depth less than 15 metres. A total of 29 monitoring stations, out of which 18 are pelagic and 11 are littoral stations, as depicted in Figure 2, were considered in this work.

The water quality data collected were physicochemical lake water quality parameters which included Temperature, pH, Turbidity, DO, EC, Nitrates and Chlorophyll-*a*. The Standard Methods for Examination of Water and Wastewater (APHA, 2000) were used for the analysis of these parameters. The biological water parameters were not available. The data obtained were for the period from 2000 to 2003, 2011 to 2014, and 2016. A preliminary quality check of water quality data indicated that the sampling campaigns were either not covering all points within a single sampling campaign or in any one of the sampling years. Hence, there was a lack of continuity for some sampling points and water quality parameters. The selection of water quality parameters used in this study was based on the mostly measured and monitored parameters. The analysis of historical data for this work was based on the sampling depth of 0.5 m throughout because for each sampling point, at least a depth of 0.5 m below the water surface was sampled and analysed for all parameters used. This was in contrary to other depths below 0.5 m which was not consistency for all sampling points.

Data analysis

The temporal variation of water quality was done to assess the effect of time on pollution. This aimed to enable us to understand the trend of water quality pollution; if it is increasing, decreasing or remains unchanged with time. The statistical analysis tools were used to analyze the collected historical water quality data. Statistical software SPSS version 23.0 was employed to analyze physical and chemical water quality data

for different statistics including Pearson correlation (looking for relationships), coefficient of determination and one-way Analysis of Variance (ANOVA). ANOVA was used to find out if there were statistically significant variation of water quality parameters between lake zones. The statistical significance level used for all tests was 0.05 for two-tailed tests. The Microsoft Excel tool was used for producing graphs like histograms and tables. The spatial variation of water quality for different parameters was undertaken using ArcGIS and QGIS software. Since the physical sampled water quality data did not cover the whole lake for the same sampling in a year, remote sensing techniques were used. Medium Resolution Imaging Spectrometer (MERIS), a sensor on board the polar-orbiting ENVISAT-1, with inbuilt algorithm and high spatial resolution suitable for a large water body like Lake Victoria, was used to analyze the spatial variation of Chrollophyl-*a* and Total Suspended Matter (TSM). Tanzania Standards for the receiving water bodies (2008) and World Health Organization guidelines (2008) for drinking water were used for checking the compliance.

**The land use and land cover classification for 2000, 2010 and 2014**

To classify the land use and land cover, Landsat Thematic Mapper (TM) satellite images with 30m resolution were acquired from United States Geological Survey (USGS) website (http://glovis.usgs.gov) for August 2000, August 2010 and August 2014. Images with a cloud cover of less than 10% were used. The choice of Landsat images for this analysis was based on its relatively high spatial resolution of 30m, which is good for land classification. Its temporal resolution of 15 days makes it suitable for land change detection overtime. Nine tiles covering the Lake Victoria Catchment Basin (LVCB) were glued together and the LVCB area was clipped out of it.

The land classification used the maximum likelihood digital image classification using the supervised classification method. This type of classification normally uses the training data by means of estimating the means and variance of the classes, which are used to estimate probabilities, variance of the classes and also consider the variability of brightness values in each class. The classification is based on Bayesian probability theory. It is the most powerful classification method when accurate training data is provided and is the most widely used algorithm. In order to validate the classification output, ground control points were collected from different classes of land use and land cover at the study area using the Global Positioning System (GPS) and were used for validation of the 2015 classified map. ILWIS 3.7 software was used to analyse the image classification.
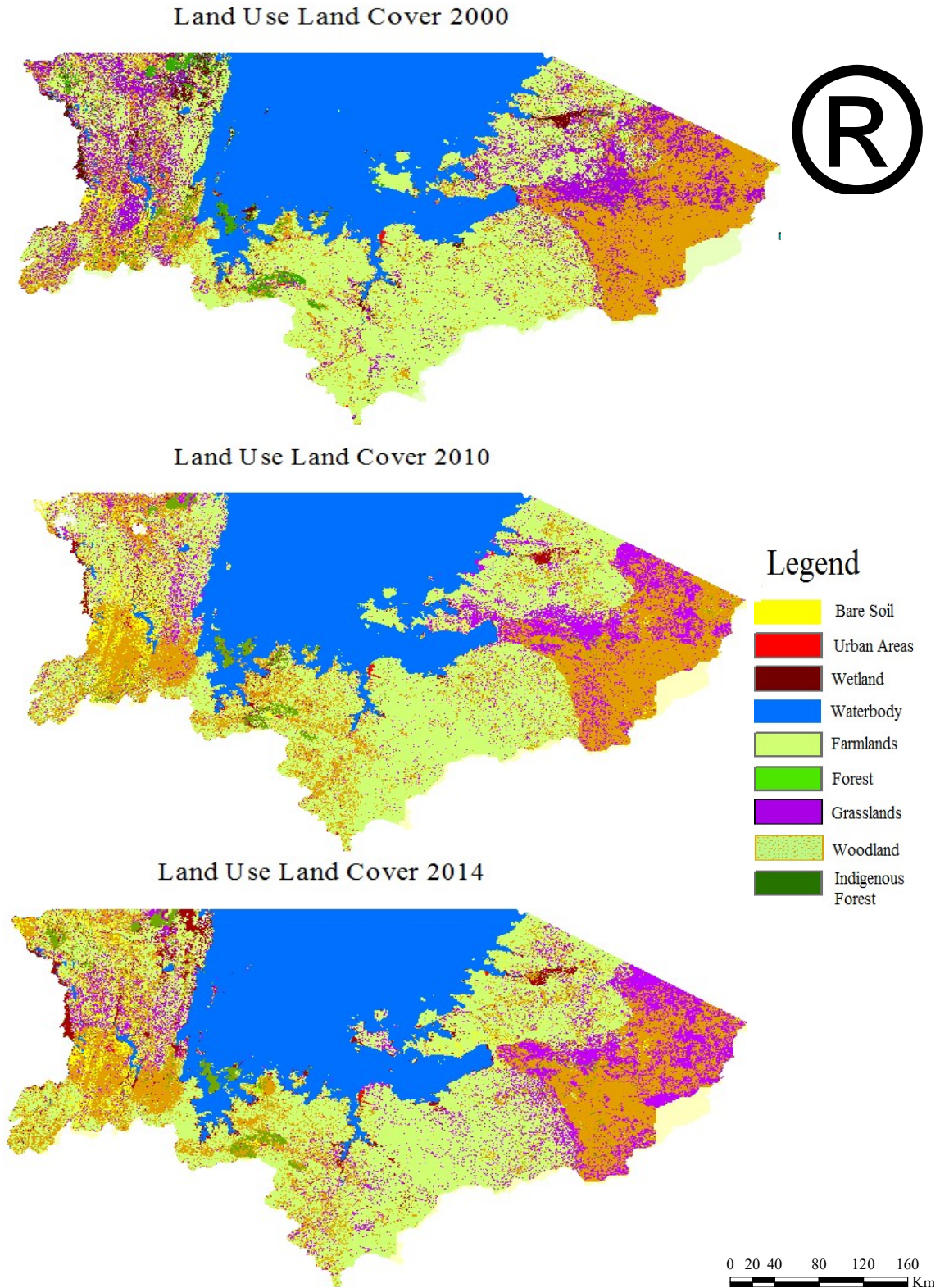
RESULTS AND DISCUSSION

The land use land cover changes within Tanzanian side of Lake Victoria basin

Land use land cover changes in a water basin play an important role in the environmental dynamics of the area (Schilling *et al.,* 2008). Various human activities like agricultural activities, increase in population (which is attributed to increase in urbanisation and wastewater production), settlement construction and deforestation have significant effect to the water quality within that catchment (Tahiru *et al*., 2020). Figure and **Error! Reference source not found.** show the changes in land use and land cover for Lake Victoria on the Tanzanian side for the year 2000 to 2014. The figures show the land use land cover changes that took place with regard to the bare soil, urban areas, wetlands, water bodies, farm land, forest, grassland, woodland and indigenous forest from 2000 to 2014.
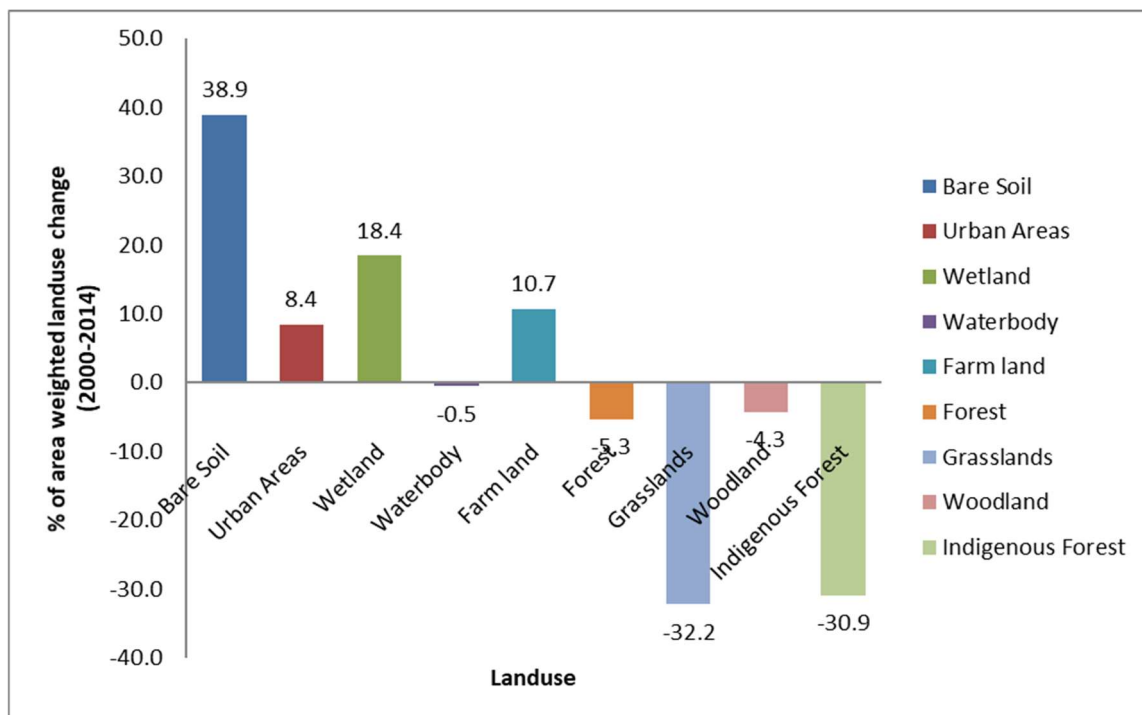
Figure 3: The area weighted land use change from year 2000 to 2014 in the LV in the Tanzanian side

Land Use Land Cover 2000

Land Use Land Cover 2010

Legend

Bare Soil
Urban Areas
Wetland
Waterbody
Farmlands
Forest
Grasslands
Woodland
Indigenous Forest

Land Use Land Cover 2014

0 20 40   80   120   160
                              Km

Figure 4: The land use land cover changes from 2000 to 2014 for the Tanzanian side of the Lake Victoria

The bare soil was observed to increase by 38.9%, urban areas were observed to increase by 8.4%, farm land increased by 10.7%, wetlands increased by 18.4% and water bodies increased by 0.5%.On the other hand, forest area decreased by 5.3%, grassland decreased by 32.2%, woodland decreased by 4.3% and indigenous forest decreased by 30.9%.

The land use land cover changes could be probably due to the increase in urban space, bare soil and farmland resulting in the decrease in grassland, woodland and indigenous forest, as these were cleared either to get an area for cultivation or land for different developments, while the forest, where cut down for firewood or for various activities (Schilling *et al*., 2008; Anhwange *et al*., 2012; Hua, 2017).The use of veld fires to clear land for cultivation could also be one of the causes of the decrease in grassland and woodland areas. These

activities expose bare soil to erosion during the rainy season. The findings from this study correspond to the findings which were reported elsewhere (Schilling et al., 2008; Hua, 2017; Tahiru et al., 2020, Rather and Dar, 2020; Kibena et al., 2014) whereby it was observed that the changes in land use and land covers, especially the increase in settlements, bare soil and farming activities within the catchment, led to decreases in the water quality of the respective study areas.

Variation of Water Quality Concentrations for Pelagic Zone

Error! Reference source not found. below shows the results summary for water quality measurements of Lake Victoria from year 2000 to 2016. The measurements were done in the years 2000-2004, and then it was resumed again in the years 2011-2014 and 2016 by LVBWO. The one-way ANOVA was used for analysis.

Table 2: Summary of water quality for Lake Victoria from 2000 to 2016 for pelagic zone

Water quality parameter	No. of measurements	Min	Max	Mean
Temperature (ºC)	86.00	22.80	28.68	24.90
pH	94.00	6.30	10.52	8.07
DO (mg/l)	81.00	3.42	10.21	6.92
Nitrates (mg/l)	105.00	1.00	447.00	32.20
Turbidity (NTU)	110.00	1.00	15.80	2.00
EC (µS/cm)	90.00	59.20	155.44	96.05
Chlorophyll-a (µg/l)	105.00	1.0	72.17	6.14

The temporal variation of pH values for pelagic stations

Eighty-six sampling campaigns conducted from year 2000 to 2016 were used for the analysis. The minimum value of pH observed for the identified period was 6.3, the maximum value of pH was 10.52 and the mean value for the same period was 8.07. Figure 0 below shows the variation of pH for pelagic stations in Lake Victoria.

From Figure 0, the analysis of variation of pH within time and points revealed that there was a variation of pH with time and points within the lake. The lowest levels of pH 6.3 and 6.8 were observed in year 2001 and 2002 respectively while the highest value of pH 10.52 was observed in 2014.The analysis showed that the variation
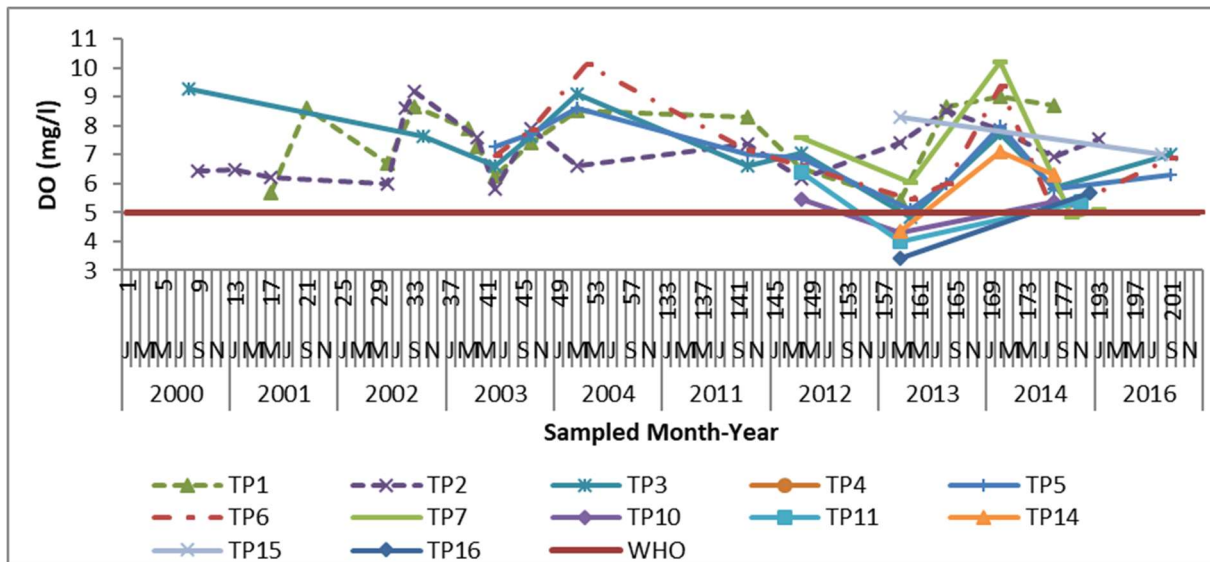
of pH between the points was not significant with p>0.05 (p=0.08). The weak positive correlation (R^2=0.26) of pH and DO pelagic zone of Lake Victoria corresponds to the positive correlation between pH and DO for lake Ilorion in Nigeria which was reported by (Araoye, 2009).

Figure 0: The temporal variation of pH values for pelagic zone

The temporal variation of DO concentration values for pelagic stations

The variation of DO concentration values for each point sampled was analyzed to identify the variation of the DO concentration of each point with time. The DO concentration values obtained were compared to the WHO guidelines and Tanzania Standards. The minimum value of DO concentration observed at the time of analysis was 3.42 mg/l and the maximum value was 10.21 mg/l, with the average DO concentration value of 6.92 mg/l. **Error! Reference source not found.** shows that there has been a variation of DO concentration values within the points with time.

It has been observed that for the period of 2000-2012, none of the points had a DO concentration values of less than 5 mg/l, a minimum standard recommended by (WHO, 2010) as the allowable minimum standard for DO concentration values in a lake. For the period of March 2013, some points experienced DO oxygen of less than 5 mg/l. The low experienced DO concentration values at this time can be attributed to the presence of high rainfall whereby storm water carrying waste from the catchment and urban areas were discharged to the lake (Scheren *et al.,* 2000). The discharge of the waste resulted to decomposition of waste and hence more oxygen was used to decompose the waste (Scheren *et al.,* 2000).

Figure 6: The temporal variation of DO concentration values for pelagic zone for the period of 2000 to 2016

The temporal variation of Nitrates for concentration values pelagic stations

The variation of nitrates for concentration valuesfor pelagic zone was conducted. The analysis was from the years 2000-2016. The NO_3 concentration values obtained after each sampling campaign for every month and year when the sampling was done was used for the analysis. It was observed that for the specified period of time the minimum value of nitrates was found to be 1 mg/l and the maximum value was observed to be 447 mg/l, with a mean value of 32.2 mg/l.

It was observed that the values of nitrates concentration varied within the points for the pelagic stations. Njuru, (2012) observed that the values of nitrates concentration values were high when the monitoring campaign for the lake started in year 2000-2003. The values of nitrates concentration were observed to be low in year 2011-2012. This can be attributed to the monitoring campaign which was conducted by LVEMP together with other stakeholders around the lake aiming to reduce the water hyacinth which are mostly as a result of presence of nitrates and phosphates. Repeated Analysis of variance showed that there was no significant variation of nitrates concentration between the sampling points as p>0.05. The sharp increase in nitrates observed in Figure 2can be attributed to the time of sampling campaign. Similar findings were observed by (Boström, 1981). The water quality sampling campaigning for year 2013-2016 was carried out during the rainy season. The period of March to May is marked by high rainfall in the area. As a result, the values of Nitrates were observed to be higher than the values of sampling which was conducted in the dry season or less rainfall. This shows that most of the runoff which goes to the lake was likely to have high values of nitrates (Scheren *et al.,* 2000).
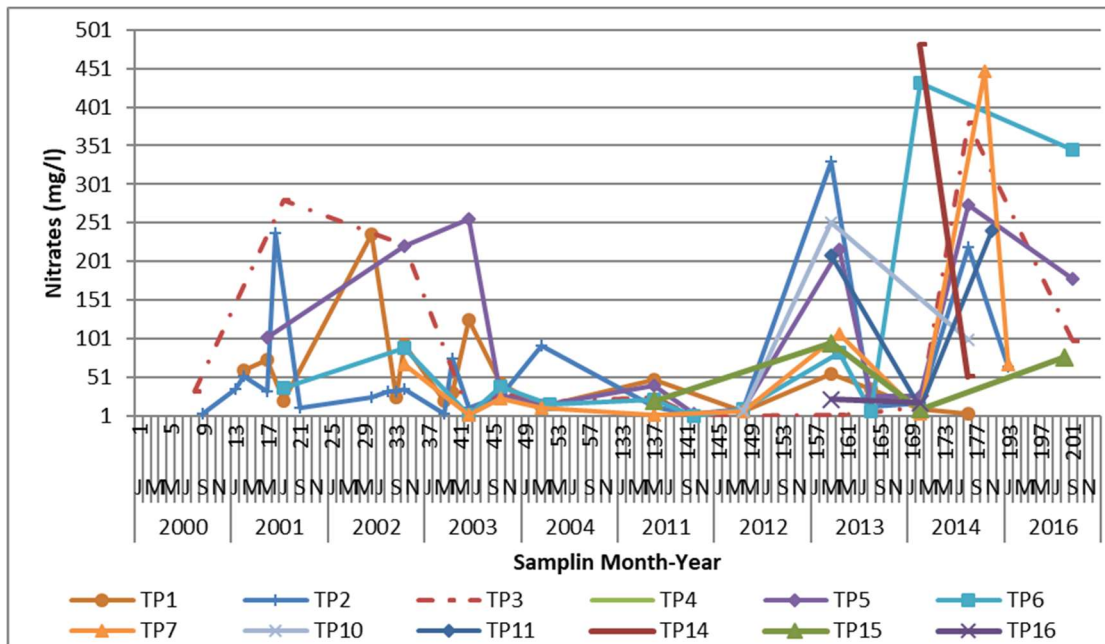
Figure 2: The temporal variation of Nitrates concentration values for pelagic stations
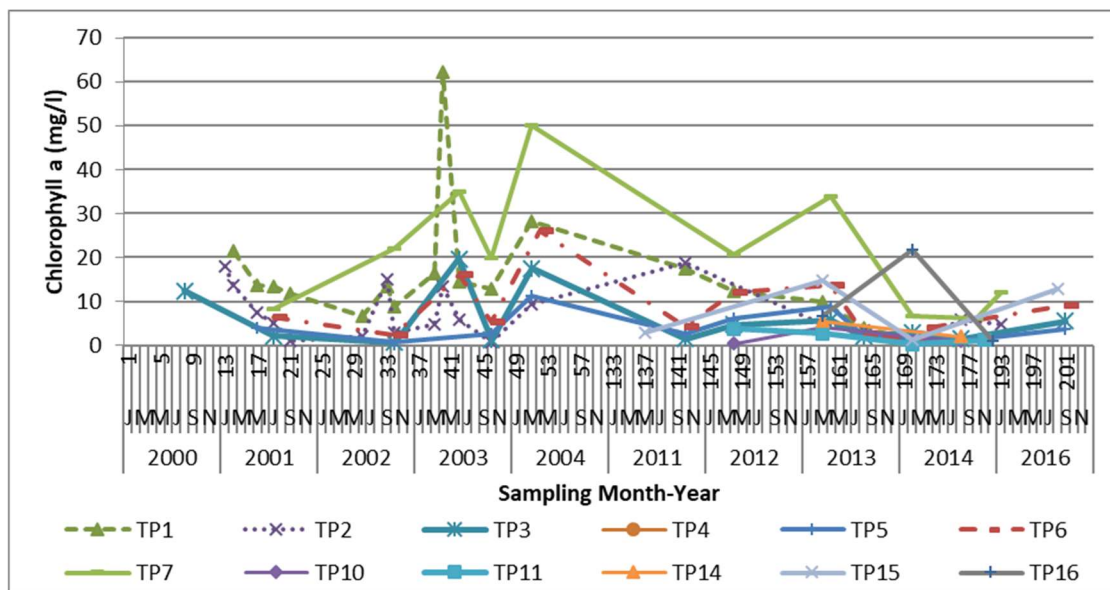
Figure 3: Temporal variation of Chlorophyll-*a* values for pelagic stations

Temporal variation of Chlorophyll-*a* values for pelagic stations

Chlorophyll-*a* was observed to vary with time and seasons as shown in Figure 3. The Chlorophyll-*a* concentration values were observed to decrease from 20.8µg/l in 2004 to 11.3 µg/l in 2016. It was observed that the Chlorophyll-*a* concentration was higher during the rainy seasons than the dry seasons. This complies with the study by Wondie *et al.*, (2007), who observed that the Chlorophyll-*a* concentration varies seasonally in lake Tana of Ethiopia. The increase in Chlorophyll-*a* concentration during rainy season can be attributed to the increase in nitrates and phosphates which are carried by runoff and discharged to the lake. It was also observed that there was a negligible relationship between Chlorophyll-*a* concentration and pH values, the polynomial relationship gave the

coefficient of $R^2=0.16$ and $p>0.05$ for pelagic zone. This was contrary to what was reported by Zang *et al.*, (2011), who observed a positive correlation between Chlorophyll-*a* and pH. This could probably be due to the fact that the existence of pH could be contributed by factors other than Chlorophyll-*a* (Wondie *et al.*, 2007).

The temporal variation of Turbidity values for pelagic stations

Analysis of variation of turbidity values for pelagic points in Lake Victoria was done as shown in **Error! Reference source not found.**. The minimum value of turbidity for the study period was observed to be 1 NTU and maximum value was 15.8 NTU, with a mean value of 2 NTU. Turbidity values were observed to vary for the pelagic stations. The variation of turbidity values

within the lake were observed to be low. Only one sampling point, TP2, was observed to have a value of turbidity higher than 5 NTU, which is recommended by WHO. The same point was also observed to have a higher value than the allowable standard in year 2011. Most of the sampling points were observed to have the values of turbidity within the allowable limit by WHO, except in the years 2012 and 2014, where the turbidity values were recorded to be higher than the recommended limit of 5 NTU. This can be attributed to a runoff which was introduced to the lake during the sampling campaign as the month of March to May is the season of high rainfall in the area (Scheren *et al.,* 2000). Hence all runoff from the catchment is discharged to the lake (Scheren *et al.,* 2000).
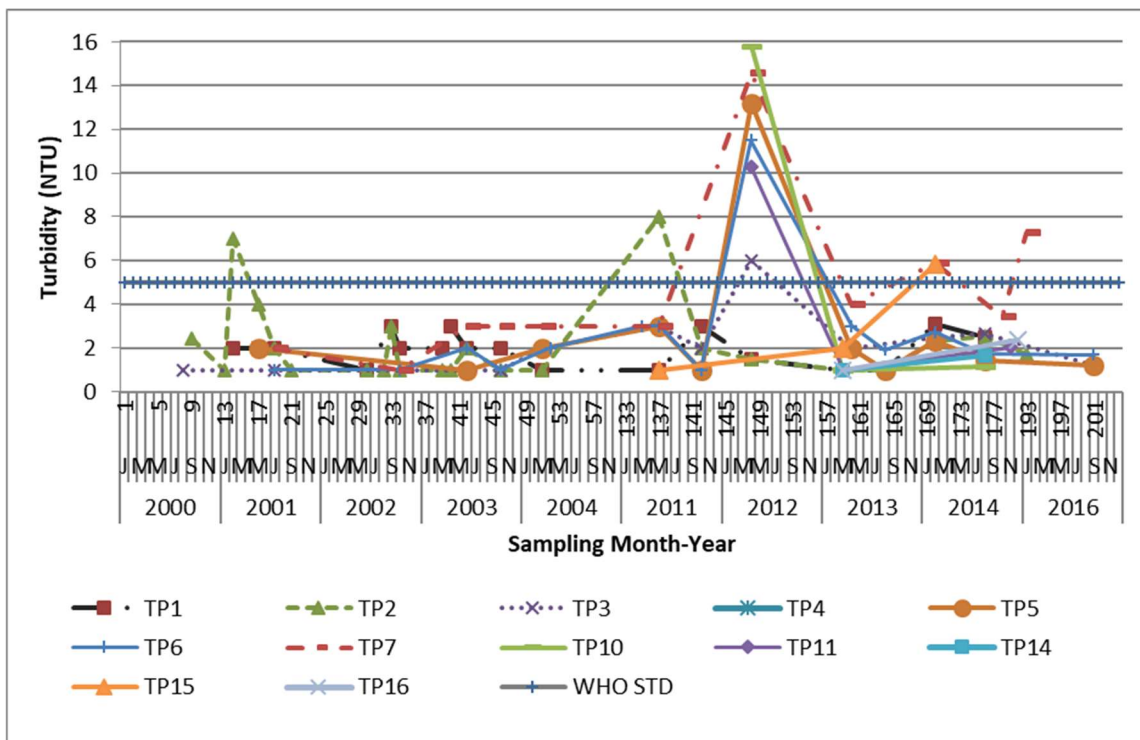
Figure 4: Temporal variation of turbidity values for pelagic stations

Variation of physicochemical parameters with depth for pelagic stations

Analysis of the variation of physical parameters with depth was also undertaken. The analysis was undertaken for stations TP1, TP2 TP3, TP4, TP5, TP6 and TP7

since they are the most sampled points. Figure 5 presents the analysis results of physicochemical parameters which were conducted for pelagic stations. The measurement was undertaken from the water surface to the bottom of the lake (80 m deep).

The physicochemical parameters of the lake (DO, Temperature, pH and EC) for pelagic zones were observed to vary with depth as shown in Figure 5. It was observed that DO, Temperature and pH were decreasing towards the bottom of the lake. Electrical conductivity was observed to increase with an increase in depth. The same trend of decrease in physical parameter with increase in depth of the lake was observed by Pukate and Rim-Rukeh, (2008). DO was observed to decrease from 8.59 mg/l at the surface of the lake to 1.8 mg/l at a depth of 80 m. The decrease in DO at the bottom of the lake is supported by observed increase in EC which implies that more saltiness is found at the bottom of lake which reduces the solubility of the dissolved gases (Sharma and Tiwari, 2018). Temperature decreased from 25 ºC from the surface of the lake to 24 ºC at a depth of 80 m. The pH of the lake was observed to decrease with depth from 8 to 7.4m. The value of electrical conductivity was observed to be slightly constant ranging from 87.4-88.9 µS/cm up to a depth of 30 m. Beyond 30 m, the value of EC was observed to increase to 106.3 µS/cm at a depth of 80 m.
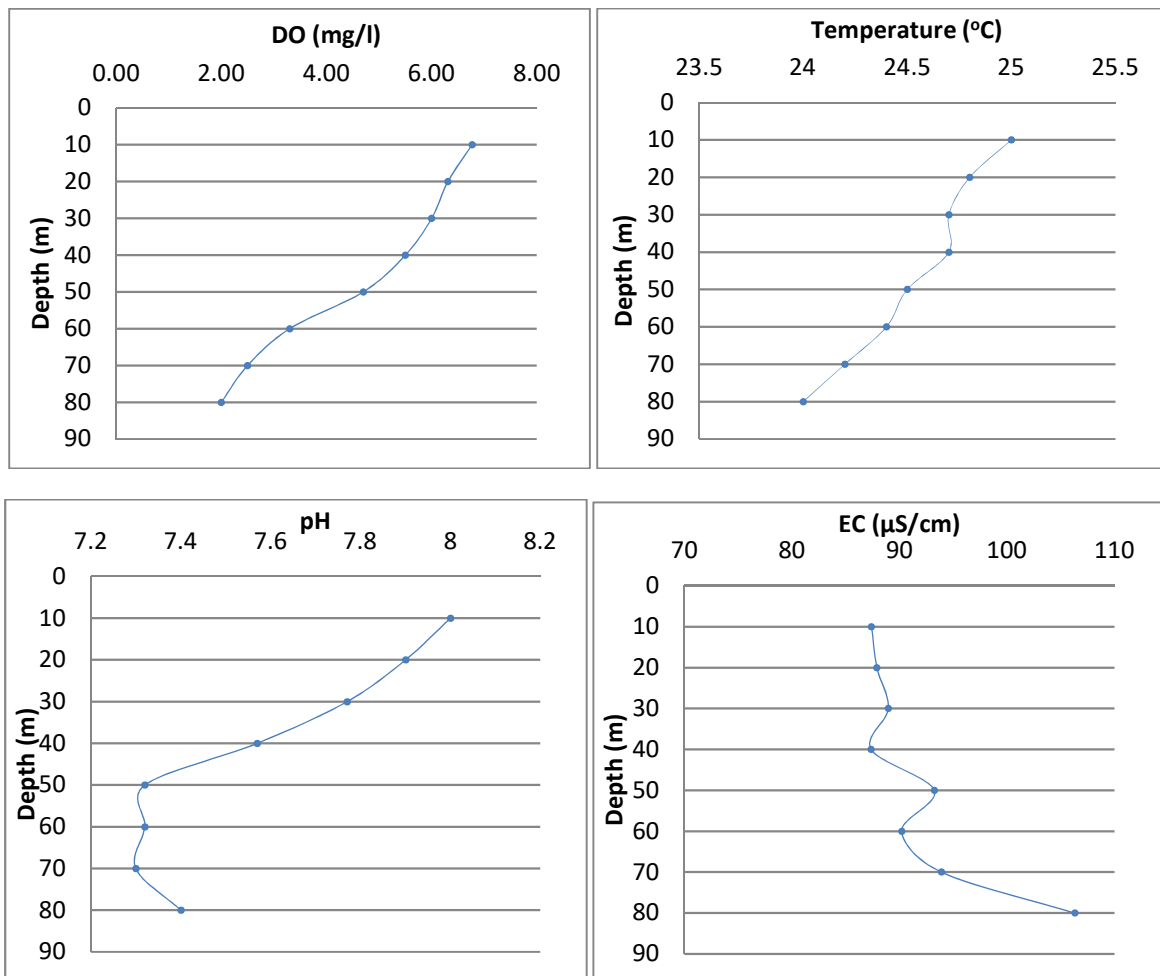
Figure 5: Variation of physicochemical parameters with depth for pelagic stations

This could be due to the fact that the lake acts as a repository for most wastes which are introduced to it, therefore the settled waste may have more impact on the bottom of the lake where it settles (Sharma and Tiwari, 2018). Hence more solute can be found at the bottom of the lake than at the top (Sharma and Tiwari 2018).

The Variation of Water Quality Concentrations for Littoral Zone

Error! Reference source not found. below shows the statistics results summary for water quality measurements of Lake Victoria from the year 2000 to 2016 for littoral zone. The measurements were done in the year 2000 and then it was resumed again in the years 2011-2014 and 2016. Six sampling points were used, sampling and analysis was undertaken by LVEMP. The monthly values obtained for each year of the sampling campaign were used for analysis of each parameter.

Table 3: Summary of water quality for Lake Victoria from 2000 to 2016 for littoral zone

Water quality parameter	No. measurements	Min	Max	Mean
Temperature (^{o}C)	35.00	22.30	26.80	24.90
pH	37.00	6.47	10.16	9.06
DO (mg/l)	38.00	3.99	8.60	6.67
Nitrates (µg /l)	41.00	4.00	590.16	28.00
Turbidity (NTU)	38.00	1.30	75.00	6.00
EC (µS/cm)	32.00	8.35	189.00	113.20
Chlorophyll-*a* (µg/l)	37.00	1.79	64.99	12.37

Temporal variation of pH values for littoral stations

The monthly values of pH obtained for each sampling campaign for each year were used to analyze the variation of pH values with time. **Error! Reference source not found.** below shows the variation of pH in Lake Victoria for littoral stations.

Six sampling points, TL002, TL230, TL231, TL232, TL233 and TL 234 were used. These sampling points were the only sampling points which were sampled for at least more than three years in all sampling campaign.
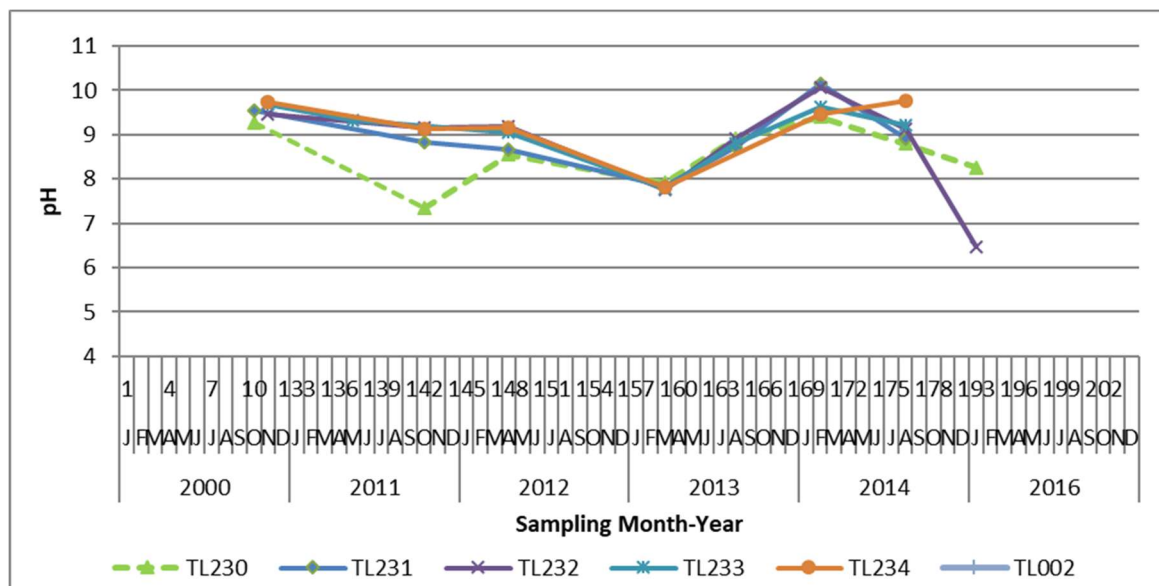
Figure 6: Variation of pH values for littoral zone

From **Error! Reference source not found.**, it is observed that the pH values were varying within the sampling points. But the variation of pH of Lake Victoria waters was still within the acceptable range of pH 6.5-8.5 recommended by WHO for surface water. According to Zang *et al.*, (2011), there is a relationship between the pH and DO in water body whereby increase in pH results in increase in DO and decrease in pH results in decrease in DO. The relationship was tested and it was observed that any increase in pH resulted to an increase in DO and the vice versa. This is due to the reduction-oxidation reaction which exists in the water body which relates to its acidity. Tadesse *et al.,* (2004) reported similar observations in their work studying the seasonal and diurnal variations of temperature, pH and dissolved oxygen in advanced integrated wastewater pond system treating tannery effluent.

Temporal variation of DO concentration values for littoral stations

The variation of DO concentration values for littoral zone was analysed. DO concentration values for littoral zone ranged from 3.99-8.6 mg/l for the period of the study. Variations of DO were observed as shown in Figure 7. It was observed that most of the sampling points from the study period had the value of DO greater than the WHO minimum recommended value of DO for surface water body. Nevertheless, it was observed that one sampling point had the value of DO concentration less than 5 mg/l as recommended by WHO in year 2013 and 2014. The variation within the sampling points was statistically not significant with $p > 0.71$.
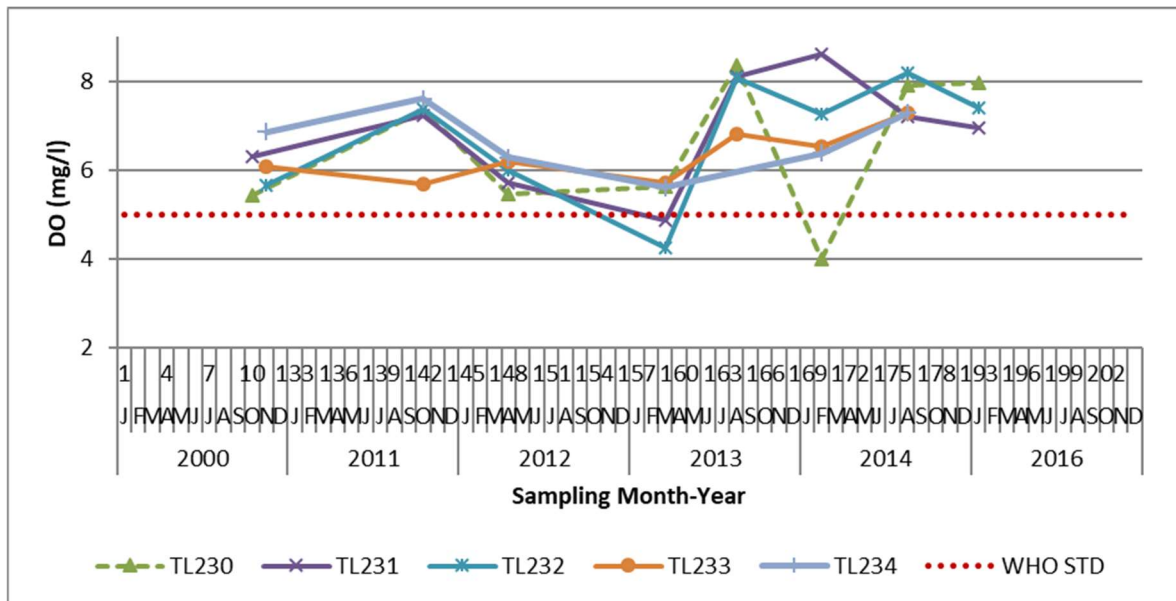
Figure 7: Spatial Temporal variation of DO concentration values for littoral zone

Temporal variation of Nitrates concentration values for littoral stations

The analysis of variation of nitrate concentration values for littoral zone was undertaken and analyzed. The sampling

was done in year 2000 and resumed again in year 2011 to 2014 and 2016. The analysis results are presented in Figure 13. It was observed that for the specified period of time, the minimum value of nitrates concentration was observed to be 4 mg/l

and the maximum value was observed to be
590.16 mg/l, with a mean value of 28 mg/l.
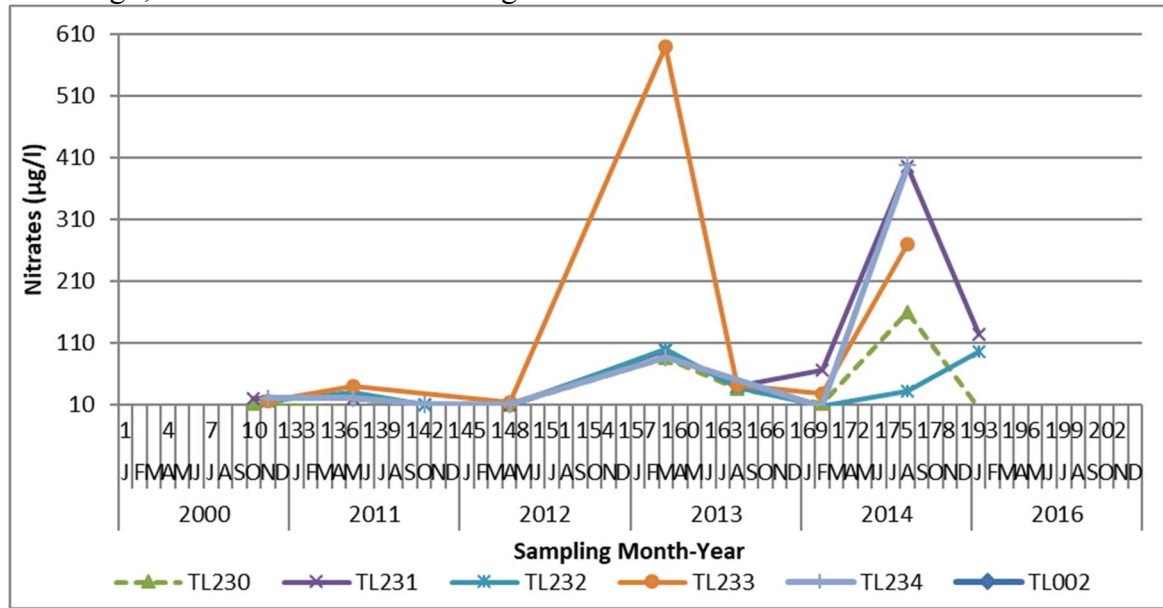
Figure 8: Variation of nitrates concentration values for littoral stations

Further, it was observed that the value of
nitrates concentration were almost constant
with the range of 10-110 mg/l throughout
except for year 2013 and 2014 were the
value of nitrates were observed to be high
510.16 mg/l and 398 mg/l respectively. The
sharp increase in nitrates observed in **Error!
Reference source not found.** can be attributed
to the time of sampling campaign, the
sampling for year 2013 and 2014 done
during the rainy season, the period of
March to May is the season of high rainfall
in the area.

**Temporal variation of Chlorophyll-*a*
values for littoral stations**

Although for littoral zones Chlorophyll-*a*
measurement was done from year 2011 to
2016, it was also observed that
Chlorophyll-*a* was varying with time and
seasons as shown in **Error! Reference source
not found.**. The Chlorophyll-*a* concentration
was observed

to be higher in littoral zones compared to
pelagic zones for the measurements which
were done in same month for the same year.
Chlorophyll-*a* concentration was observed
to be high in concentration for the
measurements which were taken in rainy
seasons (March-May) than those which
were taken in dry season (June-September).
The high concentration of Chlorophyll-*a*
observed in the year 2013 was due to high
rainfall which occurred in March 2013. This
could have attributed to the increase in
concentration as more nutrients from the
environment were discharged to the lake.
There was a negligible relationship between
Chlorophyll-*a* and pH, the polynomial
relationship gave the coefficient of R^2=
0.23 and p>0.05 for the littoral zone. This
was in contrary to what was reported by
Zang et al., (2011) who observed a positive
correlation between Chlorophyll-*a* and pH.
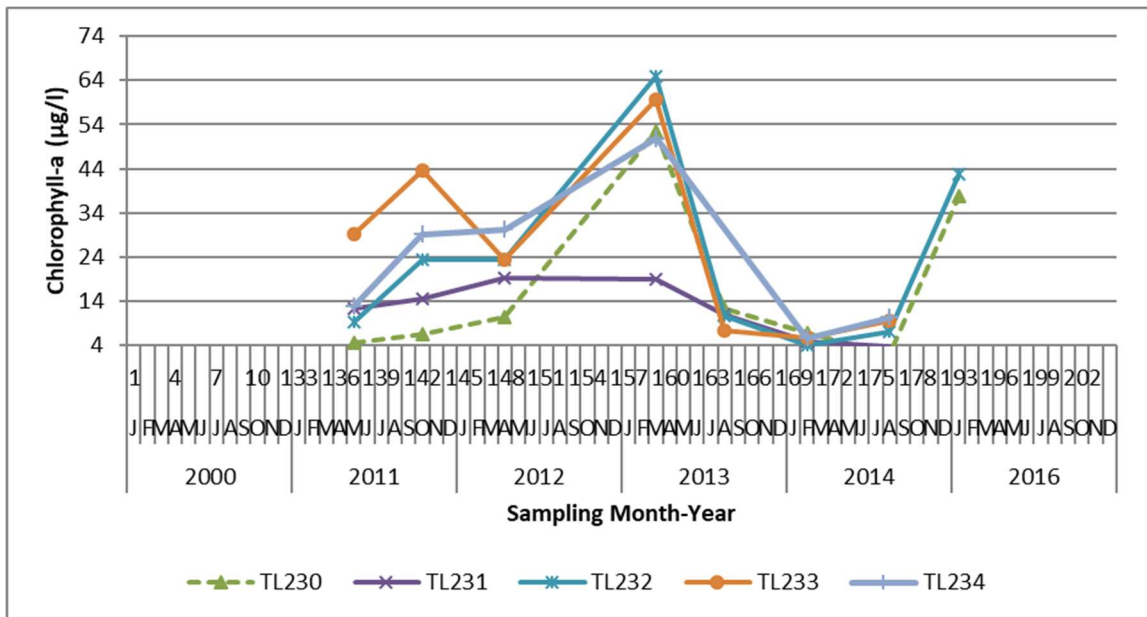
Figure 9: Variation of Chlorophyll-*a* values for littoral stations

Variation of physiochemical parameters with depth for littoral stations

Analysis of the variation of physical parameters with depth for littoral stations was also carried out. The analysis was done for averages of stations TL230, TL231, TL232, TL233 and TL235 as they are the most sampled points in littoral zone. **Error! Reference source not found.** presents the analysis of physical parameters which were observed for littoral stations. The analyzed parameters were dissolved oxygen, temperature, pH and electrical conductivity.

The observed variation of physical conditions for littoral stations was similar to that of pelagic stations; they were found to be decreasing towards the bottom of the lake as shown in **Error! Reference source not found.**. There was a significant correlation between the value of physical parameters and the depth of sampling except for electrical conductivity. The physicochemical parameters were observed to decrease with an increase with depth, but EC was observed not to obey the same trend. This could be due to suspension of dissolved particles in water.

It was observed that the relationship between temperature and depth in the lake for the littoral zone was positively correlated with coefficient of $R^2=0.6$ at $p<0.03$. A strong positive correlation was observed between DO and temperature with coefficient of $R^2=0.78$ and $p<0.01$. DO for the littoral zone. It was observed to be higher on the surface compared to what was observed on the pelagic zone. This could be due to the presence of more phytoplankton, which releases oxygen during the photosynthesis process than those found in pelagic zone. A similar observation was reported by Pukate and Rim-Rukeh (2008) pH and temperature were observed to have a strong correlation with coefficient of $R^2= 0.95$ and $p<0.01$.

The correlation between electrical conductivity and depth for the littoral zone was observed to be weak with coefficient $R^2 = 0.37$ and $p>0.05$. Therefore, it can also be concluded that the observed trend of EC variation might be due to the suspension of dissolved and suspended solids in water due to mixing up of the water at the littoral zone. Dissolved solids and suspended solids are reported to increase the value of EC (Butler and Ford, 2018).
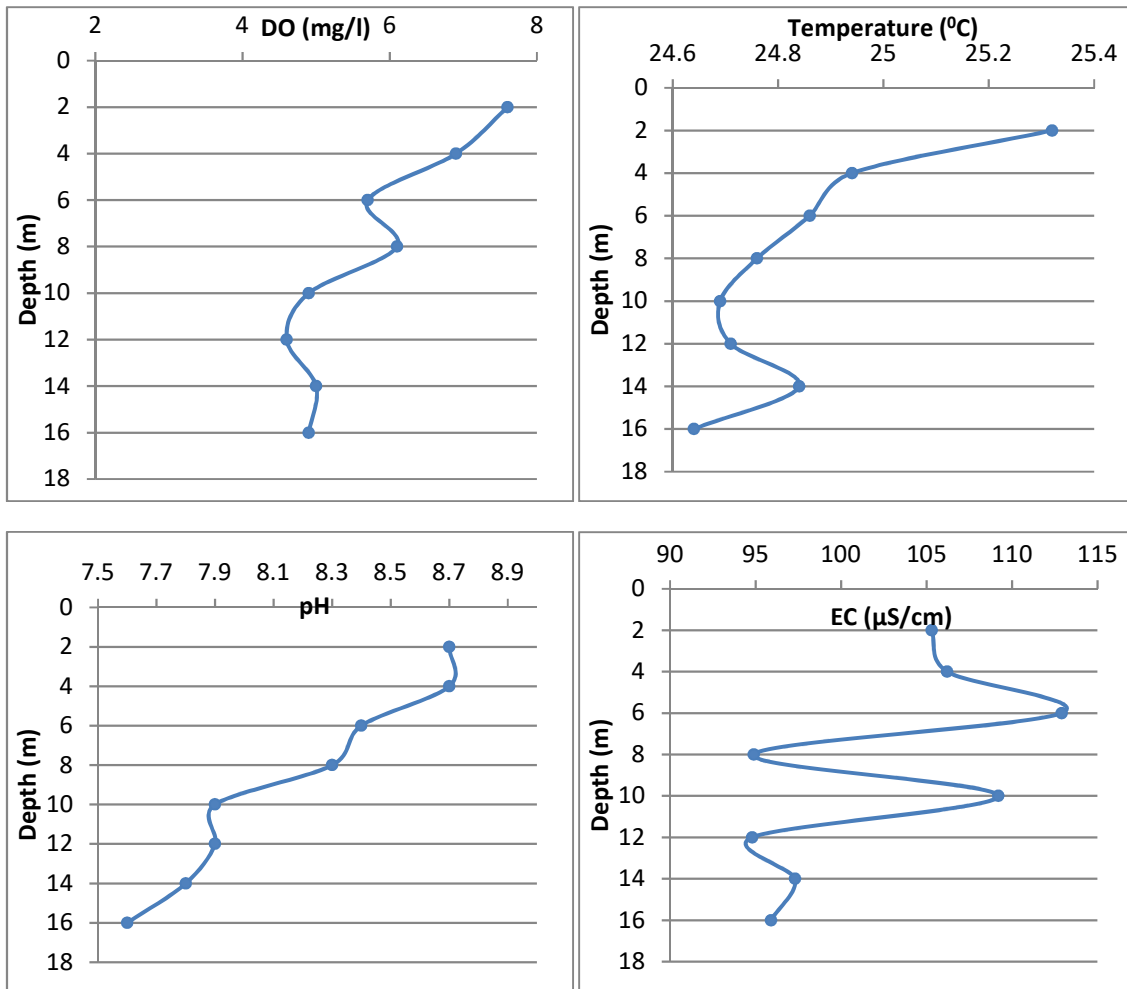
Figure 10: Variation of physiochemical parameters with depth for littoral stations

The correlation between electrical conductivity and depth for the littoral zone was observed to be weak with coefficient $R^2 = 0.37$ and p>0.05. Therefore, it can also be concluded that the observed trend of EC variation might be due to the suspension of dissolved and suspended solids in water due to mixing up of the water at the littoral zone. Dissolved solids and suspended solids are reported to increase the value of EC (Butler and Ford, 2018).

Variation of Chlorophyll a and Total Suspended Matter

Spatial analysis of water quality was done for the whole lake. The analysis results is

shown in **Error! Reference source not found.** and Figure 12. From **Error! Reference source not found.** and Figure 12, it can be observed that the concentration of Chlorophyll-*a* and

Total Suspended Matter (TSM) of the lake has been increasing with time especially on the southern part, south east and south west of the lake. In 2003, the minimum concentration of Chlorophyll-*a* in the lake was observed to be 0.045 g/m^3 while the maximum concentration was 41.26 g/m^3. In 2011, the minimum concentration of Chlorophyll-*a* in the lake was observed to be 0.053 g/m^3 while the maximum concentration was 41.62 g/m^3.
The same areas were observed to have more concentration of TSM compared to other

areas. In 2003, the minimum concentration of TSM in the lake was observed to be 0.026g/m^3 while the maximum value was 39.98 g/m^3. In year 2011, the minimum value of TSM in the lake was observed to be 0.04 g/m^3 while the maximum value was 52.18 g/m^3. The increase in concentration of Chlorophyll-*a* and total suspended matter can be attributed to the increase in anthropogenic activities around the lake. The identified areas are subjected to pollution due to the presence of the rivers from the catchment which discharge water to the lakes through the identified areas.

Chlorophylla (August 2003)
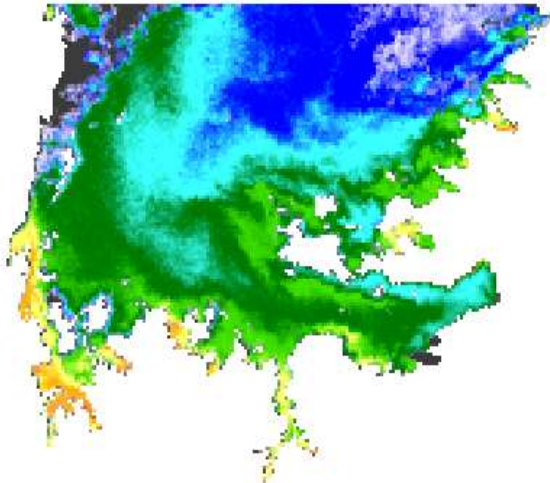
Chlorophylla (August 2006)
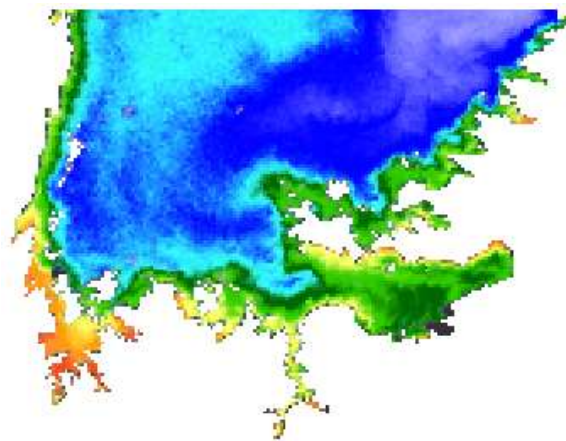
Chlorophylla (August 2009)

Chlorophylla (August 2011)

Name: chl_conc
Unit: mg m^-3
Min: 0.053
Max: 41.692
Rough statistics!
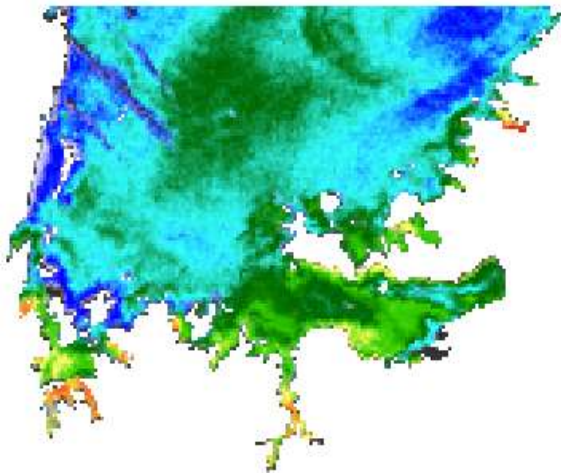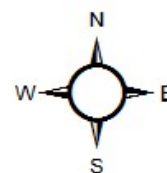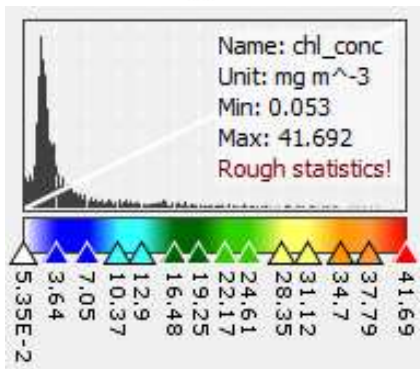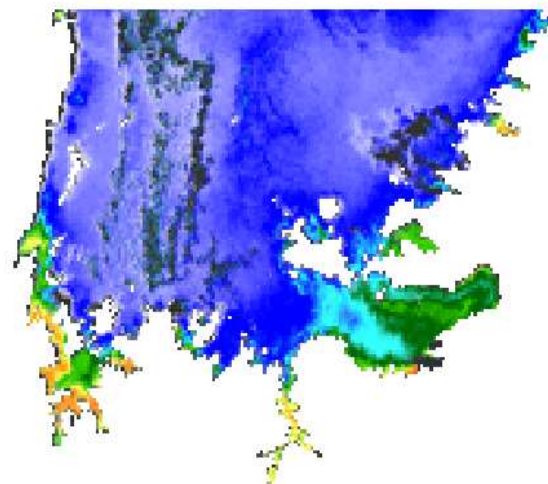
Figure 11: Spatial temporal variation of Chlorophyll-*a* in a lake
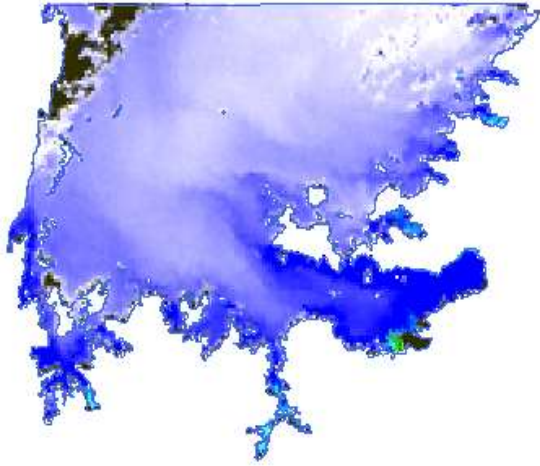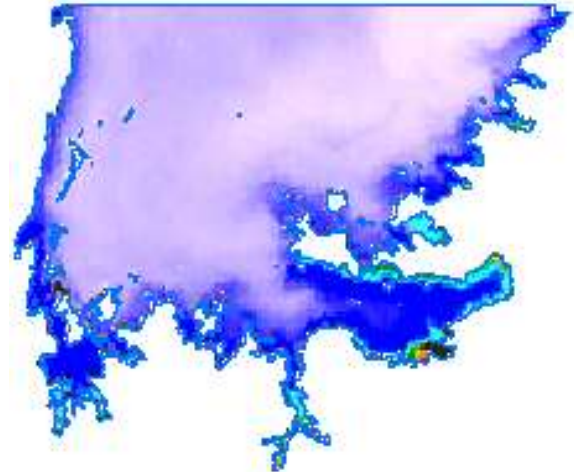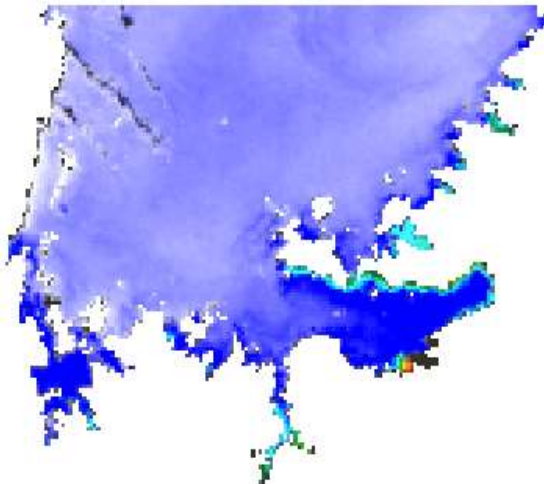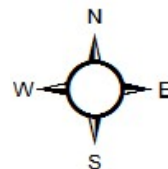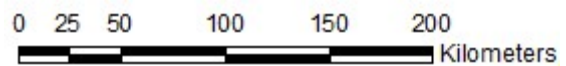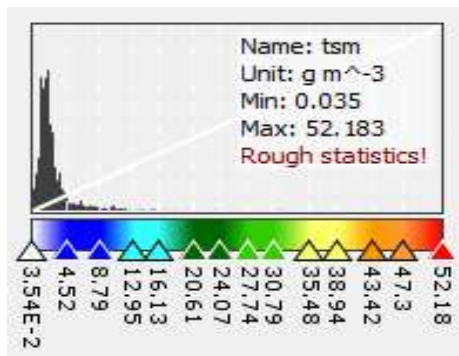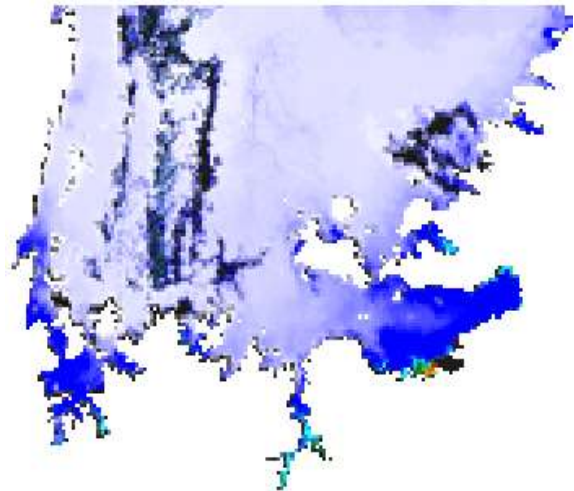
Figure 12: Spatial temporal variation of Total Suspended Matter in a lake

CONLUSIONS AND RECOMMENDATIONS

Introduction

The study was conducted to assess the spatial temporal variation of selected water quality parameters in the Tanzanian side of Lake Victoria. Water quality parameters vary across different lake locations and with times. The water quality for the littoral zone was found to be more polluted than the pelagic zone. Although the water quality is still within the allowable receiving water standards, the water quality of the lake is deteriorating with time. This could be due to the activities taking place in the catchment area, especially agriculture, wastewater discharged from urban areas, invasion of wetlands for agriculture and deforestation. Therefore, if no action is put in place to rescue the situation, in long run, the water quality of the lake will be polluted above the allowable standard. However, the results are not conclusive as other parameters of water quality for the lake, including biological water quality parameters and heavy metals were not analyzed.

Conclusions

The assessed water quality parameters in the pelagic and littoral zones of the lake were found to vary with time and space. During the study period, the water quality of Lake Victoria was still within WHO limits. It generally complies with the Tanzania Bureau of standards for the receiving water bodies standards. The water on the littoral zone of the lake was found to be more polluted than in the pelagic zone for most of the parameters measured.

Recommendation

Although a lot of the efforts were made by LVEMP (and now LVBWO) to monitor the water quality of Lake Victoria, a robust, effective and efficient water quality monitoring programme (WQMP) should be set. The WQMP should take into consideration the seasonality effects (dry and wet) of sampling and the prescribed fixed depths of sampling should be emphasized. Currently, the sampling campaigns depend on the availability of funds. The existing WQMP should be reviewed to reflect its reality and appropriateness. This will give a good interpretation when someone plans to carry out an analysis of the data. Since the littoral zones are mostly polluted, thus they should be the priority pollution control intervention areas.

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