Temporal changes in limno-morphometric characteristics in a floodplain lake within Cross River ecosystem during low water period

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Abstract

Iyieke Lake is one of the floodplain lakes within the middle reaches of the Cross River, it is a major foraging and breeding site of several fish species. It is not directly connected to any river, so the water level depends on seasonal inundation by the Cross River. With gradual changes in precipitation and consequent alteration in flooding pattern, and increased agricultural activities around the lake, there are indications of steady annual decline in water level and quality, and lake area. In order to understand the effect of these changes on the aquatic biota, the morphology and some limnological parameters of the lake were studied during low water period (March-May) in 2005, 2011 and 2019 at interval of 6.5 years. Water samples were collected from the lake and the limno-morphological parameters measured at the littoral and limnetic zones of the lake following standard procedures. The results showed that monthly rainfall was significantly ($p<0.05$) lower in 2019 compared to 2005 and 2011, while minimum and maximum temperature trended conversely ($p<0.05$). The mean total dissolved solids (TDS) increased from 13.00mg/l in 2005 to 39.33mg/l in 2019 and conductivity trended the same. Mean nitrate (0.92mg/l) and phosphate (1.78mg/l) were higher in 2019 compared to 2005 and 2011. Contrarily, transparency decreased from 0.45m in 2005 to 0.19m in 2019. Similarly, mean dissolved oxygen (3.80mg/l), maximum length (443.20m) and width (314.50m) declined significantly toward 2019 ($p<0.05$). Lake length, transparency, conductivity and TDS that were seemingly good predictors of water deterioration could be useful in modelling, which is vital in conserving the biodiversity of the Cross River floodplain ecosystem.

Keywords: Conservation, anthropogenic activities, water quality, biodiversity, climate change.

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Introduction

Many large tropical rivers are often adorned with numerous floodplain lakes that mark the abandoned path of the river (Bovo-Scomparin and Train 2008; Okogwu and Ugwumba 2012). The lakes, the main river channel and the riparian environment connect to form a continuum during seasonal flooding (Junk *et al* 1989). The continuum allows for exchange of species, distribution of nutrients and unfortunately pollutants amongst the connecting systems (Watzel 2001; Quirino *et al* 2017). However, during low water periods after floods, the lakes disconnect from the main river channel and other lakes, forming autonomous entities (Junk *et al* 1989; Okogwu and Ugwumba 2012). Flooding partition floodplain lakes into periods of high and low water level (Junk *et al* 1989; Okogwu and Ugwumba 2012; Nwonumara and Okogwu 2013; Quirino *et al* 2017), this creates heterogeneous environments with numerous niches that are utilized by diverse life forms (Röpke *et al* 2015; Bicoff *et al* 2016). Flooding therefore promote species diversity in river-floodplain lake ecosystem (Bozelli *et al* 2015; Röpke *et al* 2015), which explains why river-floodplains are the most biologically diverse ecosystems in the world (Bicoff *et al* 2016). Floods are regarded as the dominant factor shaping the ecology of floodplain lakes (Junk *et al* 1989).

Seasonal connectivity benefits spawning and, foraging shell and fin fish species that opportunistically move to the food rich lakes during periods of connection to breed and feed (Okogwu *et al* 2009; Silva *et al* 2013; Röpke *et al* 2015; Quirino *et al* 2015; Okogwu *et al* 2021). When the lakes disconnect after flood episodes, the shallow water level, abundance of food and absence of predators in the lake provide a suitable habitat for the spawned fish to thrive (Röpke *et al* 2015). These are recruited into the adult stock in one or two years when the lake reconnects with the main river channel (King 1996). Therefore, this connection and disconnection process creates hydromorphological heterogeneity that drives the

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high biological diversity often associated with river-floodplain ecosystems (Junk *et al* 1989; Okogwu and Ugwumba 2012; Röpke *et al* 2015).

Floodplain lakes serve several socioeconomic purposes by supporting intensive and extensive agricultural activities within their catchments and tourism (Nwonumara and Okogwu 2021). Although floodplain lakes are ecologically and socioeconomically important, they are highly vulnerable to climate change and the human activities they support (Bicoff *et al* 2016). Dam construction on the main river channel, intensive riparian agricultural activities and water abstraction have been reported to reduce flooding events (Barneth *et al* 2005; Nwonumara 2012; Röpke *et al* 2015; Bicoff *et al* 2016). Similarly, natural events such as frequent droughts due to climate change, decreased rainfall and high atmospheric temperature reduce the frequency, duration, intensity and timing of floods (Woodwand *et al* 2010; Castello *et al* 2013; Röpke *et al* 2015). Unfortunately, these activities are reportedly on the increase (Barneth *et al* 2005; Woodwand *et al* 2010), meaning that most floodplain lakes may persistently suffer water level decline, especially during low water periods.

Steady annual reduction in water level, especially during low water period without commensurate compensation from flooding and pluvials will increase periods of isolation, which may impact negatively on the biodiversity of the entire river-floodplain ecosystem (Röpke *et al* 2015; Bicoff *et al* 2016; Quirino *et al* 2017). During periods of isolation, the biota are predominantly influenced by local factors (Röpke *et al* 2015) and, abiotic stress and competition increase significantly (Quirino *et al* 2017). The impact of increased periods of isolation on the ecology of floodplain lakes are poorly understood, though necessary for proper conversation of biodiversity. It is important to identify key environmental variables that could be used to model scenarios of prolonged isolation in order to predict overall implication for the biodiversity of the floodplain-river ecosystem.

Subtle changes within floodplain lakes could be identified by simple evaluation of temporal changes in lake morphometry (depth, surface area, volume, shoreline length, shoreline development and index of basin permanence). Lake morphometry is an important variable that provides essential information on annual changes in the lake (Moses *et al* 2011; Okogwu and Ugwumba 2012). Iyieke, one of the several lakes within the Cross River floodplain is a notable foraging and breeding site for several fish species (Okogwu *et al* 2009), which sustains the huge biodiversity of the Cross River floodplain (King 1996; Okogwu *et al* 2010). It is very close to the ever busy Ndibe beach that supports thousands of tourists and commercial businesses annually (Nwonumara and Okogwu 2021). Human residence development is fast approaching the lake and there are also increasing evidence of waste deposition, extensive agricultural activities and shrinking of the lake area (Nwonumara and Okogwu 2021). These anthropogenic (if unchecked) and natural activities are likely to affect the lake adversely and could imperil the rich biodiversity of the Cross-River floodplain ecosystem. Therefore, this study was undertaken to evaluate temporal changes in limno-morphometric variables in Iyieke Lake between 2015 and 2019 in order to identify the major drivers and proffer sustainable solution to protect the biodiversity of the lake and the entire Cross River-floodplain ecosystem.

Material and methods

Study area

The study site, Iyieke Lake (05° 50.2' 33.4" N, 007° 56.2' 40.88" E) is located on the floodplain of the Cross River within Afikpo North Local Government Area, Ebonyi State, Nigeria (Figure 1). The lake is 50m away from the main Cross River channel (Okogwu and Ugwumba 2012) near Ndibe Beach. At the south-eastern part of the lake is a patch of forest vegetation dominated by *Afzelia africana,* which is facing serious deforestation, while the north to south-western part are used for extensive agricultural activities. Some artisanal fishermen purloin fish from the lake despite been reserved. These activities may affect the water level of the lake as pictures of the lake show that the lake area has reduced in 2019, when compared to the same period of low water level in 2005 (Plate 1).

Sample collection and measurement of limno-morphometric variables

Water samples for physico-chemical parameters analysis were collected from the littoral and limnetic zones of the lake in triplicates during low water period (March-May) in 2005, 2011 and 2019 when the lake was isolated from the main river channel. The length and width of the lake were measured using a line following standard procedures (Hakanson 1981) while the depth was measured using a calibrated pole. Temperature, total dissolved solids (TDS) and electrical conductivity were measured using Hanna hand held TDS and conductivity meter (Model HI 98303). The pH and dissolved oxygen (DO) were measured using Hanna pH (Model HI77700P) DO (Model HI 9142) meters, respectively. Transparency was measured using a Secchi disc while nitrate and phosphate were determined spectrophotometrically (APHA 2012). Meteorological data (rainfall and, minimum and maximum temperature for the previous years (i.e. 2004, 2010 and 2018) for the region were obtained from Nigerian Meteorological Services (NIMET) and evaluated for trends.

Statistical analysis

The mean values of measured variables including rainfall and, minimum and maximum temperature were compared between 2005, 2011 and 2019 using Analysis of Variance (ANOVA). Person's correlation was used to determine the relationship between variables. The lake morphometric parameters that correlated the most with other limnological variables were considered good determinants of changes in the lake and were used in Principal Component Analysis (PCA). All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 23 and PC-ORD version 5.

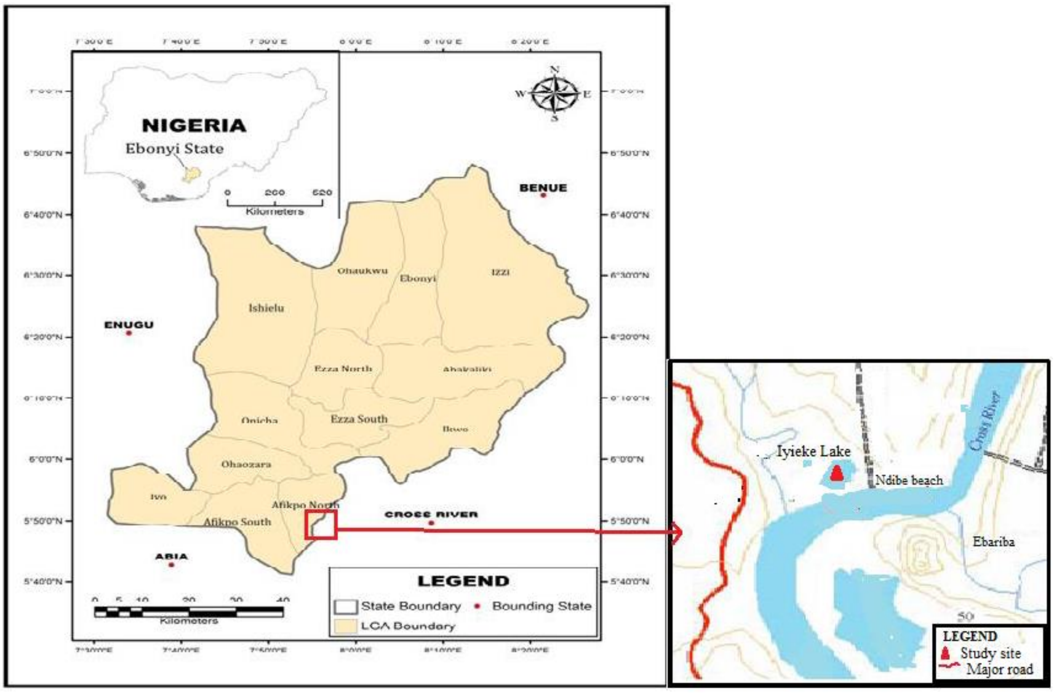

Figure 1. Map of Cross River floodplain showing the lake with an insert of map of Ebonyi State and Nigeria (Modified from Nwonumara *et al* 2021)

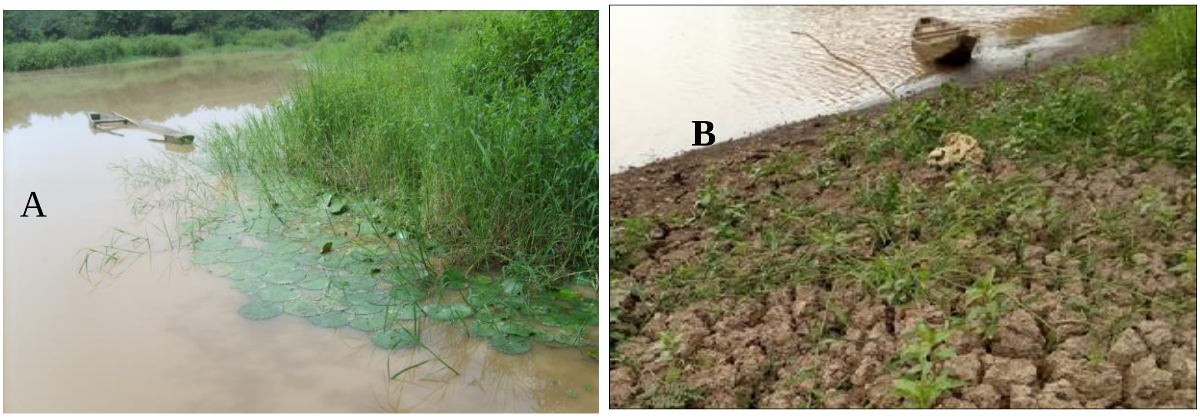

Plate 1. The shoreline of Lake during March (A) 2005 and (B) 2019

Results

Monthly rainfall was significantly ($p<0.05$) lower in 2018 (65.99±71.25cm) compared to 2004 (196.34±139.42cm) and 2010 (255.99±185.26cm) (Figure 2 and Table 1). Conversely, minimum (25.59±1.54ºC) and maximum (35.54±3.17ºC) temperature were significantly ($p<0.05$) higher in 2018 compared to the other years (Figures 3 and 4; Table 1). The mean total dissolved solids (TDS) increased from 13.00mg/l in 2005 to 39.33mg/l in 2019 while conductivity trended the same (Table 2). Mean nitrate (0.92mg/l), phosphate (1.78mg/l) were significantly higher in 2019 compared to 2005 and 2011($p<0.05$). Contrarily, transparency decreased significantly from 0.45m in 2005 to 0.19m in 2019 ($p<0.05$), while dissolved oxygen, depth, maximum length and width declined by 81.18%, 30.67%, 14.81% and 9.81%, respectively in 2019 compared to 2005. Maximum length correlated with most variables; TDS (-0.83), conductivity (-0.82), transparency (-0.99), depth (0.91), NO_3 (-0.80) and PO_4 (0.87) compared to other morphological variables (Table 2). Principal component analysis (PCA) showed that axis 1 and 2 accounted for 90.89% of total variation and maximum length (-0.99), transparency (0.99), conductivity and TDS (0.84), PO_4 (-0.83) and NO_3 (0.81) were the dominant variables on axis 1. Graphing of Axis 1 and 2 of PCA clearly separated the three periods and showed that conductivity, TDS, PO_4, and lake length were the dominant factors in 2019 (Figure 5).

Discussion

Meteorological data clearly showed remarkable decrease in precipitation and increase in atmospheric temperature in 2019 compared to 2004. Such conditions have been reported to reduce the frequency, intensity and duration of flooding (Woodwand *et al* 2010; Castello *et al* 2013; Röpke *et al* 2015), which will increase periods of low water and isolation of Iyieke Lake from the main river channel and other lakes within the Cross River floodplain. Increased periods of isolation would reduce species exchange, increase environmental stress and species competition (Röpke *et al* 2015; Quirino *et al* 2017). Prolonged isolation of the lake will impact negatively on several fish species that rely on annual connections to reach breeding and foraging sites and those bred previously would be marooned and unable to recruit into adult stock. The biodiversity of most floodplains is largely dependent on connectivity between the lakes and river channel (King 1996; Okogwu *et al* 2009; Okogwu *et al* 2010; Silva *et al* 2013; Röpke *et al* 2015; Quirino *et al* 2015; Okogwu *et al* 2021). Besides, connectivity affords the lake the opportunity to relieve stress and renew its water (Quirino *et al* 2017).

Compared to previous studies (Akpan 1994; Okogwu and Ugwumba 2009; Nwonumara 2012; Nwonumara and Idumah 2019; Nwonumara and Okogwu 2021), our study shows that nutrients concentration in the Cross River floodplain increased steadily. Elevated nutrients, especially phosphorous, persistently low water level and high water temperature could alter phytoplankton community structure in the lake. Several studies have shown that these conditions confer cyanobacteria competitive advantage over other phytoplankton (Blomqvist *et al* 1994; Okogwu and Ugwumba 2009; Mancuso *et al* 2021; Kim *et al* 2021).

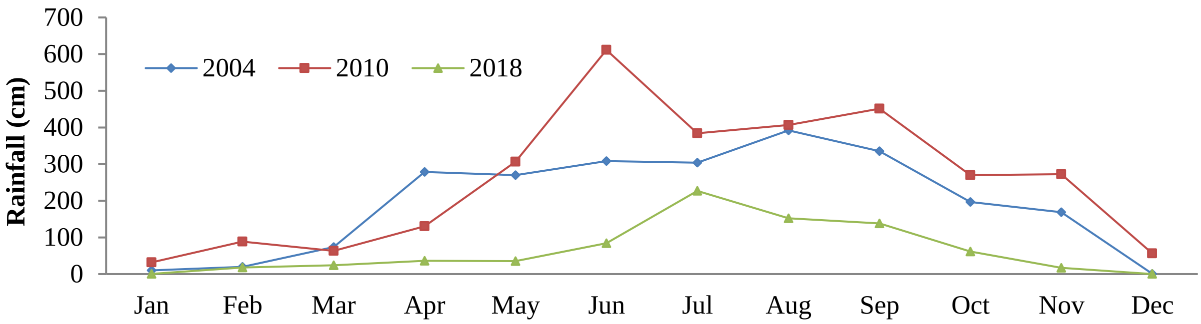

Figure 2. Monthly variation in rainfall within the Iyieke catchment for 2004, 2010 and 2018

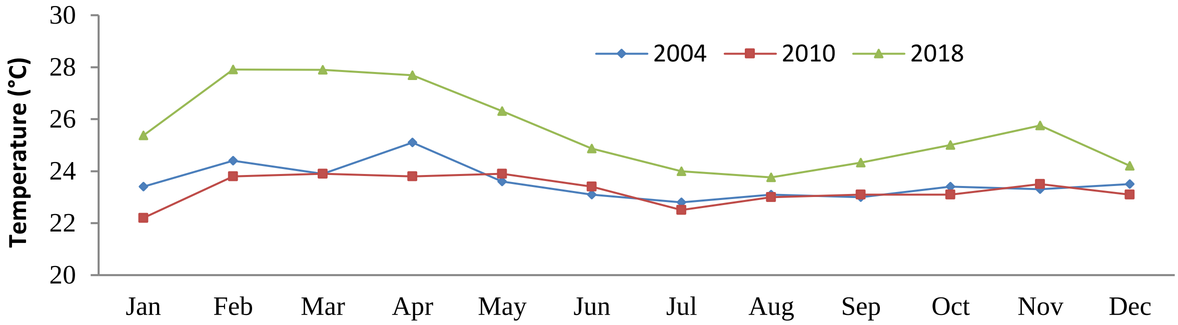

Figure 3. Mean monthly minimum air temperature for 2004, 2010 and 2018 within the Iyieke Lake region

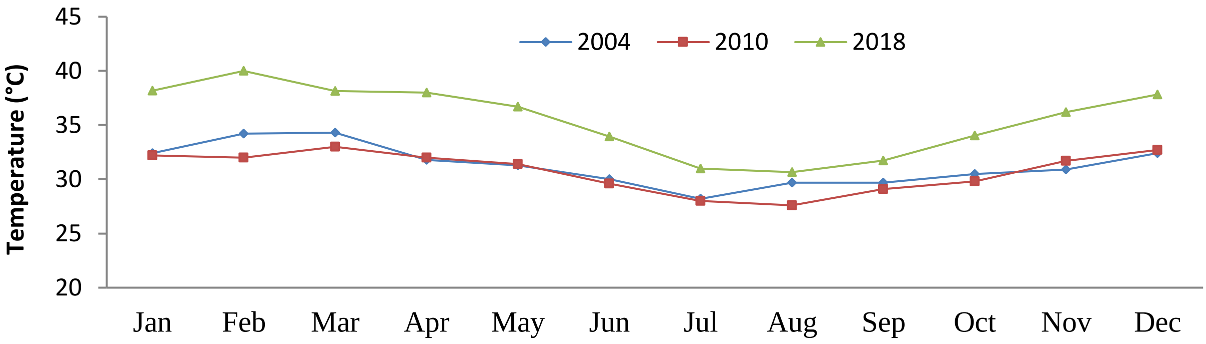

Figure 4. Mean monthly maximum air temperature for 2004, 2010 and 2018 within the Iyieke Lake region

Table 1: Mean, standard deviation and range of rainfall, minimum and maximum temperature within the catchment of Iyieke Lake

Parameter	2004	2011	2018
Rainfall (cm)	196.34±139.42^{a} (0.60-391.90)	255.99±185.26^{a} (31.80-611.30)	65.99.93±71.25^{b} (0-226.80)
Minimum Temperature (°C)	23.55±0.65^{a} (22.80-25.10)	23.28±0.55^{a} (22.20-23.90)	25.59±1.54^{b} (23.76-27.91)
Maximum Temperature (°C)	31.28±1.84^{a} (28.20-34.30)	30.76±1.85^{a} (27.60-33.00)	35.54±3.17^{b} (30.66-40.00)

Table 1: Mean and standard deviation of limno-morphological variables March-May in 2005, 2011 and 2019 compared

Parameters	Study Period		
	2005	2011	2019
Water temperature (ºC)	32.80±0.24^{a}	33.25±1.76^{a}	32.00±1.08^{a}
TDS (mg/L)	8.00±3.56^{a}	20.13±8.11^{b}	39.33±0.82^{c}
Conductivity (µS/cm)	26.60±8.60^{a}	40.50±13.18^{b}	61.33±0.82^{c}
pH	6.30±0.40^{a}	6.50±0.00^{a}	6.40±0.10^{a}
Transparency (m)	0.45±0.20^{b}	0.20±0.03^{a}	0.19±0.04^{a}
DO (mg/L)	5.70±1.80^{c}	1.28±0.07^{b}	1.04±0.09^{a}
Depth (m)	1.50±0.70^{c}	1.28±0.07^{b}	1.04±0.09^{a}
Maximum length (m)	520.25^{b}	449.10^{a}	443.20^{a}
Maximum width (m)	324.30^{b}	320.20^{b}	314.50^{a}
Nitrate (mg/L)	0.80±0.70^{a}	0.81±0.04^{a}	0.92±0.23^{b}
Phosphate (mg/L)	1.00±0.50^{a}	1.40±0.02^{b}	1.78±1.19^{c}

Horizontal means with the same subscript letters are not significantly different ($p<0.05$)

Table 2: Pearson correlation of the limno-morphological parameters of Iyieke Lake for 2005, 2011 and 2019

Parameters	Rain	Min Temp	Max Temp	TDS	Cond	pH	Trans	DO	Depth	Length	Width	NO_3
Rain												
Min Temp	-0.62											
Max Temp	-0.77*	0.90**										
TDS	-0.52	0.61	0.75*									
Cond	-0.50	0.60	0.75*	0.99**								
pH	-0.11	-0.09	0.05	0.57	0.57							
Trans	0.28	-0.40	-0.42	-0.87**	-0.86**	-0.79*						
DO	-0.07	-0.25	0.05	-0.01	0.05	-0.25	0.27					
Depth	-0.22	0.06	0.24	0.74*	0.77*	0.71*	-0.81**	0.29				
Length	-0.25	0.35	0.36	0.83**	0.82**	0.82**	-0.99**	-0.33	0.79*			
Width	-0.09	0.08	0.08	0.58	0.57	0.93**	-0.88**	-0.48	0.65	0.91**		
NO_3	-0.18	0.25	0.22	-0.45	-0.44	-0.83**	0.77*	0.16	-0.79*	-0.80**	-0.86**	
PO_4	-0.44	0.63	0.60	0.79*	0.77*	0.69*	-0.86**	-0.55	0.46	0.87**	0.80**	-0.44

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).
Rain =rainfall, Min Temp= minimum temperature, Max Temp =maximum temperature, Cond = conductivity, TDS= total dissolved solids, Trans=transparency, Length = maximum lake length, Width=lake width

Harmful cyanobacteria may become dominant, form dense surface blooms, release harmful toxins, deplete dissolved oxygen, deteriorate water quality, imperil other aquatic organisms and threaten public health (Dignum *et al* 2005; Kim *et al* 2021; Liu *et al* 2021). High population density of cyanobacteria in Iyieke Lake have been reported (Okogwu and Ugwumba 2009). The consequences of harmful cyanobacteria dominance in a lake as ecologically and socioeconomically important as Iyieke Lake is enormous but avoidable, if precautionary measures are applied. For example, most of the cyanobacteria that are dominant under the aforementioned condition include *Aphanizomenon*, *Anabaena*, *Dolichospermum*, *Microcystis*, and *Planktothrix* (Okogwu and Ugwumba 2009; Kim *et al* 2021). These species are either colonial or filamentous, unpalatable and are known to clog the filtering apparatus of zooplankton (Wetzel 2001; Okogwu and Ugwumba

2009). Their dominance and elimination of nutritious green algae and diatom may lead to collapse of the zooplankton population that have been reported to support juvenile fish in the lake (Okogwu *et al* 2010). This will affect the productivity of *Chrysichthys nigroditatus, Clarias gariepinus Oreochromis niloticus and Tilapia zilli* that are reportedly dependent on the lake for annual recruitment (Okogwu and Ugwumba 2009); a situation that could lead to decline in biodiversity and huge economic loss.

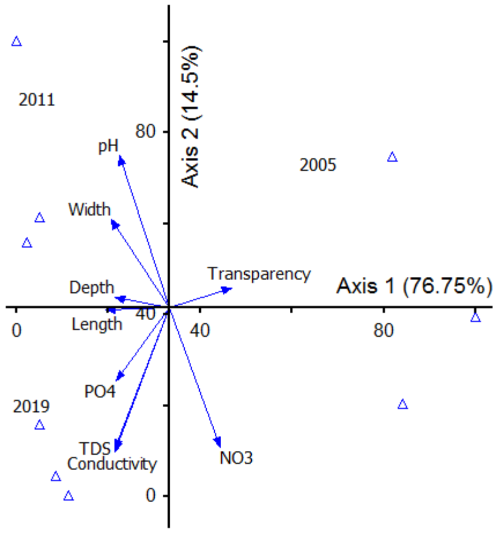

Figure 5. Principal component analysis of the dominant variables in Iyieke Lake in 2005, 2011 and 2019

Our study has shown that the major predictors of deteriorating water quality in the lake are length, depth, width, transparency, PO_4, conductivity and total dissolved solids. Among the measured morphological variables, maximum length appears to be a better predictor of changes in water quality than depth and width although Okogwu and Ugwumba (2012) credited that to lake width and water volume in a previous study on Iyieke and Ehoma lakes. It thus appears that at different levels of low water, different morphological variables could be used to predict water quality decline in floodplain lakes. Identification of reliable and easy to measure environmental variables (predicators) that could correctly predict water quality deterioration is key to successful modelling of aquatic ecosystems (Gotthold *et al* 2016; Segura *et al* 2017). Measuring the maximum length of a floodplain may pose some challenges but the PCA analysis shows that conductivity and TDS could serve as surrogates. Therefore, simple models developed to predict changes in Iyieke Lake and other ecosystems within the Cross River floodplain ecosystem should consider maximum length, transparency, TDS and conductivity.

Conclusion

Our study has shown that there are temporal changes in limno-morphometric parameters of Iyieke Lake, which are attributable to naturogenic and anthropogenic processes. The lake is becoming eutrophic due to agricultural activities, pollution and irregular water renewal. This condition may affect biodiversity and commercial fisheries. However, the study also showed that easy-to-measure environmental variables such as conductivity, TDS and lake morphology could easily be used to predict water quality deterioration. Such models are essential for restoration, conservation and protection of biodiversity.

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