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Some Aspects of the Limnology and Heavy Metal Content of Water, Sediment and *Oreochromis niloticus* (Linnaeus, 1758) from Ologe Lagoon, Lagos, Nigeria

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ABSTRACT

This study examined some limnological properties of Ologe Lagoon and the levels of six heavy metals (Cu, Zn, Cd, Pb, Fe and Cr) were also assessed in water, sediment and a commercially important fish, *Oreochromis niloticus* from the lagoon. The study lasted between July, 2010 and April, 2011 spanning both dry and wet season. Some of the physicochemical parameters (temperature, pH, salinity, dissolved oxygen and alkalinity) did not show significant ($p>0.05$) monthly variation. However, others (turbidity, total hardness, conductivity, total dissolved solids, total suspended solids, chemical oxygen demand and biological oxygen demand) showed significant ($p<0.05$) monthly variation. All the water quality variables investigated in this study did not show seasonal variation except turbidity, chemical oxygen demand and biological oxygen demand. The concentrations of five of the heavy metals (Cu, Zn, Cd, Pb and Fe) showed significant monthly variation in water and sediment. The range of concentrations of Cu, Zn, Cd, Pb and Fe in this study is 26.68±2.65-44.79±6.11, 29.41±2.52-94.40±12.08, 4.67±1.45-16.48±1.18, 6.43±1.03-21.60±2.08 and 60±15-290±32 $\mu g\ L^{-1}$, respectively. The concentrations of Zn and Fe in *Oreochromis niloticus* showed significant monthly variation and their range of values are Zn, 0.19±0.15-1.69±0.33 $mg\ kg^{-1}$ and Fe, 5.08±1.50-12.56±3.12 $mg\ kg^{-1}$. This study has shown that these heavy metals are present in Ologe Lagoon, though, their levels are still within the tolerable limits.

Key words: Physicochemical parameters, seasonal variation, bioaccumulation factor, *Oreochromis niloticus*, heavy metals

INTRODUCTION

Africa is blessed with a lot of inland water bodies. These aquatic ecosystems could be lagoons, creeks, rivers, streams etc. They play important roles in the socio-economic lives of the riverine populace. The inhabitants of these areas depend on these water bodies as a source of livelihood, recreation, among other things (Ndimele *et al*., 2011a). Apart from this, some of these aquatic ecosystems are major nursery grounds for marine fish species. So, they are also important in the continuous existence of the marine world (Kumolu-Johnson, 2004).

All these benefits are threatened by industrialization. In the bid to meet the growing demands of the increasing world population, nations are investing massively in industrialization. However, they are not committing enough funds to develop processes that will treat the wastes generated by these industries as well as mitigate their effects on the environment and man (Ndimele *et al.*, 2011b). A lot of industrial effluents are emptied into the aquatic environment untreated. In few cases where they are treated, the products of the treatment plants are still potentially harmful to aquatic flora, fauna and even man. One of the common components of industrial effluent is heavy metal (Kumolu-Johnson *et al.*, 2005).

Heavy metals are pollutants of great ecological concern. This is because they are not biodegradable and thus, persist for a long time in the aquatic environment. Their persistence results in their build up along the food chain, which could lead to bioaccumulation and biomagnification (Ndimele *et al.*, 2011b). Some heavy metals like copper, zinc and chromium have nutritional values while others like mercury, arsenic and cadmium have no known nutritional significance but are very toxic even at low concentrations (Abduljaleel and Shuhaimi-Othman, 2011; Taweel *et al.*, 2012). Copper and chromium are essentials micronutrient for animals and plants. Copper is used as an effective algaecide and molluscicide (Abou-Zaid *et al.*, 1988). Zinc plays a role in the synthesis of nucleic acid and it is also a component of many enzymes. Zinc and its compounds are used in medicine, paint and plumbing works. Drinking water contaminated with zinc can cause illness (Clarke *et al.*, 1981). Cadmium is a toxic metal that is used in electroplating, plastic and battery industries. Cadmium is responsible for several cases of food poisoning and it replaces zinc biochemically to cause high blood pressure, kidney damage etc. (Fishar and Ali, 2005).

Biota have been used to study the heavy metal status of many water bodies (Etesin and Benson, 2007; Kamaruzzaman *et al.*, 2010, 2011). The commonly used biotas are fin-fish and shellfish. This is because they are large and easily identifiable. The Nile tilapia (*Oreochromis niloticus*) is a fast growing species that can adapt to different aquatic ecosystems from freshwater to brackish water (Taweel *et al.*, 2012). It is a major protein source for the inhabitants of the vicinity of the Ologe Lagoon. However, studies on its heavy metal status in Ologe Lagoon have not been previously done. This study is important because the firms in Agbara Industrial Estate discharge their effluents into Ologe Lagoon.

The aim of this study was to measure some limnological properties of Ologe Lagoon and evaluate the heavy metal content of water, sediment and fish (*Oreochromis niloticus*) from the lagoon. This will help to check the indiscriminate dumping of industrial effluents into Ologe Lagoon.

MATERIALS AND METHODS

This study is a continuation of the series of studies that have been investigating the heavy metal content of water, sediment and some fish species in Ologe Lagoon. Some of these studies are Ndimele *et al.* (2009; 2011a), Kumolu-Johnson *et al.* (2010) and Ndimele *et al.* (2011b).

Description of the study area and sampling site: Lagos State lies to the south-western part of Nigeria. It shares boundaries with Ogun State both in the North and East and is bounded on the west by the Republic of Benin. In the South, it stretches for 180 km along the coast of the Atlantic Ocean. Lagos state lies between longitudes 20°42'E to 30°42'E and latitude 60°022'N to 60°42'N (Kumolu-Johnson *et al.*, 2010). The smallest State in Nigeria, it occupies an area of about 3,577 km^2, 22% or 787 km^2 of which consists of lagoons and creeks (Ndimele and Jimoh, 2011). These water bodies acts as sinks for the disposal of industrial and domestic wastes from industries and homes located in the Lagos metropolis (Anetekhai *et al.*, 2007).

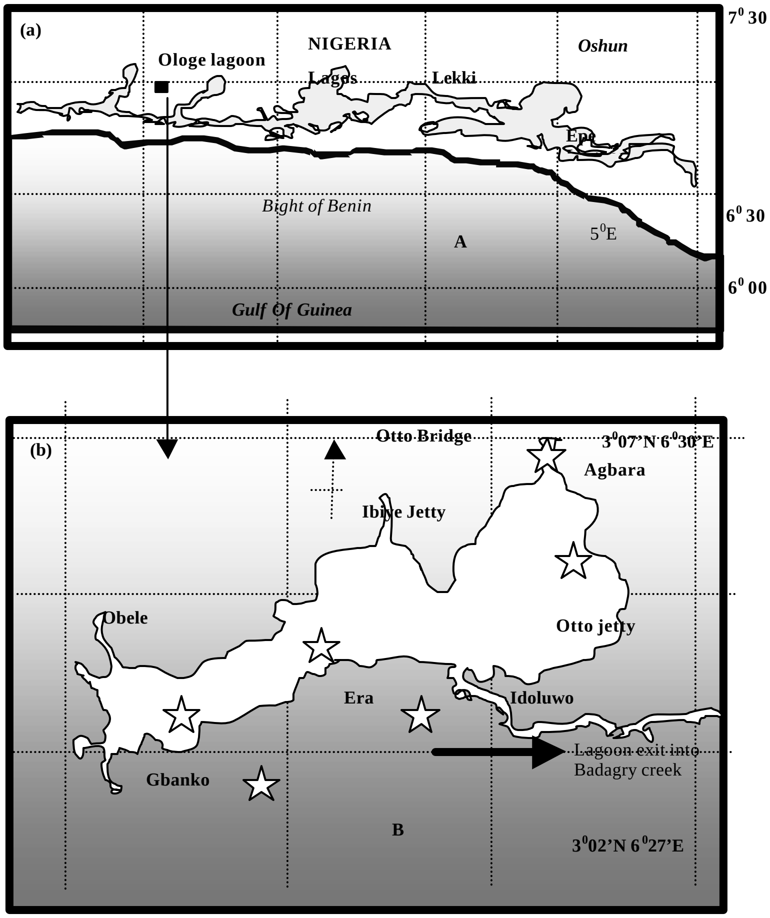

Fig. 1: Location of study site-(A) Map of Lagos lagoon complex-inset: Ologe Lagoon and (b) Map of Ologe Lagoon. Sampling stations are marked with stars (Scale: 1:150,000)

Ologe Lagoon (Fig. 1) is located in the eastern part of Lagos State. It is a seasonal freshwater body with a surface area of about 64.5 km^2 (Kumolu-Johnson *et al.*, 2010). It lies between latitude 6°27'N and 6°30'N and longitudes 3°02'E and 3°07'E. It opens up to the Atlantic ocean via Lagos harbour and Badagry creek (Ndimele *et al.*, 2011b). Ologe Lagoon is deep in the centre but shallow at the edges with an average depth of 2.42 m and an average temperature of 30°C on a sunny day. Ologe Lagoon has a wide navigable mouth, and this allows fishing, transportation and recreation (Anetekhai *et al.*, 2007; Ndimele *et al.*, 2009). It is located in Oto-Awori in Ojo local Government Area, Lagos State, Nigeria and the indigenous inhabitants are the Aworis. Towo-Owo is a nearby town that has a river called River Owo, which is the major source of water to Ologe Lagoon (Ndimele *et al.*, 2011b). Ologe Lagoon is bounded in the north by Igbesa and Agbara in Ogun state and Ijaniki town in Lagos state and in west by Esepe-Mushin and Ale. In the south, it shares boundaries with Gbanko and Badagry creek and in the east by villages such as Ikotun, Idoluwo, Egan, Ojota, Ilemba, Igede and Ojo town. These villages are engaged in fishing and farming activities as their major source of livelihood (Kumolu-Johnson *et al.*, 2010).

Agbara Estate is a model integrated town developed on 4541 ha of land managed by Agbara Estate Limited. It is situated at about 13 km west of Lagos on the Lagos-Badagry expressway and the Estate is named after the neighbouring Agbara village. The estate is on a laterite outcrop in an area of low land behind the swamp forest of the Ologe Lagoon and it contains several industries whose wastes constitute the major metal pollution by direct disposal into the Lagoon (Kusemiju *et al.*, 2001; Kumolu-Johnson *et al.,* 2010). There are 16 industries presently operating in the estate among which includes Wiggins Teape Nigeria Plc, Vitamalt Plc, Guinea Glass Nigeria Plc, Nestle Foods Plc, Evans Nigeria Limited, Pharma Deko, Lever Brothers Plc, Colodense Nigeria Limited. These companies produce goods such as glass, beverages, paint, pharmaceuticals etc. Wastes from these industries and residential quarters are channeled to the treatment zone where it is treated before it is discharged into the swamp leading to Ologe Lagoon.

MATERIALS AND METHODS

Physicochemical parameters: Water samples were collected from the sampling stations (1-6) of Ologe Lagoon from July, 2010 to April, 2011 for analyses of water quality parameters. The water samples were collected in 1 L plastic containers. Temperature and pH were determined *in situ* while dissolved oxygen, salinity, alkalinity, total hardness were determined by titration (Boyd, 1981). Conductivity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) were determined using the methods described by American Public Health Association (APHA, 1985). Temperature was determined using a mercury-in-glass thermometer, pH was measured using a Metrohm Herisau E520 pH meter and turbidity was measured using nephelometer (Analite portable nephelometer Model 156, Mcvan Instrument, Mulgrave).

Heavy metals

Sample collection, storage and preservation: Water, sediment and fish (*Oreochromis niloticus*) samples were collected from the six sampling stations in Ologe Lagoon between July, 2010 and April, 2011 for heavy metal analyses. Water samples were collected at the sample stations at 15 cm depth below water surface in 250 mL plastics bottles with screw caps. Prior to the sampling exercise, the bottles were soaked in 10% nitric acid for 24 h and rinsed with distilled water (Clarke *et al.*, 1981). Immediately after sample collection, the water samples were acidified by adding 5 mL nitric acid (Analar grade) to reduce adsorption of metals onto the walls of the plastic bottles (APHA, 1985; Ademoroti, 1996). Sediment samples were collected using a 2-inch diameter steel pipe pressed through the water column. With this steel pipe, a sediment core of about one foot was obtained (Fishar and Ali, 2005). The sediment samples collected were placed into polythene bags pre-treated with 10% nitric acid. All samples were stored in a deep freezer at -10°C (Ademoroti, 1996). *Oreochromis niloticus* were collected from the catches of the fishers in the sampling stations. The fish were washed and stored in a freezer (-10°C).

Sample treatment: All frozen samples were allowed to thaw at room temperature (i.e., ~27°C). Water samples were not treated any further, but were mixed vigorously before aspiration into the flames of an atomic absorption spectrophotometer (Alpha-4 Cathodeon) for metal determination. Values were expressed in $\mu g\ L^{-1}$.

Sediment samples were dried in an oven to constant weight at 105±20°C, ground to powder and sieved through a 2 mm mesh screen to remove coarse materials. Digestion of all powdered sediment and fish sample were done according to the methods described by American Public Health Association (APHA, 1985) and Food and Agriculture Organisation/Swedish International

Development Cooperation Agency. One gram of the sediment or fish sample was digested in a 1: 5: 1 mixture of 70% perchloric acid, concentrated nitric acid and concentrated sulphuric acid at 80±5°C in a fume chamber. The digestion continued until a colourless liquid was obtained. Alpha 4 cathodeon atomic absorption spectrophotometer (APHA, 1985) were used to analyse for metal concentration in each digested sediment and fish samples. The analytical procedure was checked using reference material (DORM 1, Institute of Environmental Chemistry, NRC Canada). Metals levels were expressed in $\mu g\ L^{-1}$ dry weight.

Bioaccumulation Factors (BAF) for the six heavy metals in *O. niloticus* were determined by the formula given by Otitoloju and Don-Pedro, (2004):

$$BAF = \frac{\text{Concentration of metal in animal tissue}}{\text{Concentration of metal in water}}$$

Statistical analysis: Variations among sampling stations were tested by a one-way Analysis of Variance (ANOVA). Student t-test was used to compare the two seasons (dry and wet). Regression analysis (Pearson's Product-Moment Correlation) was used to examine the relationship among the physicochemical parameters. In all cases, the level of significance was set at $\alpha = 0.05$ except in regression analysis where $\alpha = 0.01$ was also used.

RESULTS AND DISCUSSION

Some of the physicochemical parameters did not show significant ($p>0.05$) temporal (month) variation (Table 1). These parameters are temperature, pH, salinity, dissolved oxygen and alkalinity. However, others (turbidity, total hardness, conductivity, total dissolved solids, total suspended solids, chemical oxygen demand and biological oxygen demand) showed significant ($p<0.05$) variation among the months. All the water quality variables investigated in this study did not show seasonal variation except turbidity, chemical oxygen demand and biological oxygen demand (Table 2). The values of these physicochemical parameters recorded in this study fall within the range reported in previous studies in Ologe Lagoon. The range of values of pH, salinity, turbidity, dissolved oxygen, alkalinity, total hardness, conductivity and total dissolved solids were 6.40±1.56-8.83±1.03, 0.10±0.01-0.30±0.12 ppt, 18.00±4.51-50.00±10.51 NTU, 3.60±1.19-4.60±0.68 mg L^{-1}, 88.40±6.91-146±30 mg L^{-1}, 44.60±4.71-140.03±42.31 mg L^{-1}, 117.00±53.33-605.00±180.58 $\mu S\ cm^{-1}$ and 66.00±14.18-281.00±20.66 mg L^{-1}, respectively (Table 1). These values are similar to what has been reported previously in Ologe Lagoon by Ndimele *et al.* (2011b). Kumolu-Johnson *et al.* (2010) reported the following values; pH, 6.27±0.18-6.63±0.39; dissolved oxygen, 3.03±0.51-4.97±0.65 mg L^{-1}. Ndimele *et al.* (2011b) reported that pH, conductivity, total dissolved solids, dissolved oxygen and salinity range between 7.41±0.14-7.81±0.18, 198±79-289±64 $\mu S\ cm^{-1}$, 101±26-151±30 mg L^{-1}, 3.84±0.51-4.51±0.79 mg L^{-1} and 0.17±0.03-0.20±0.04 ppt, respectively.

The values of physicochemical parameters observed in this study also conforms with the report of studies conducted on Badagry Creek (Badagry Creek and Ologe Lagoon are directly linked and both are part of the Lagos Lagoon complex) by Agboola *et al.* (2008). The physicochemical variables recorded in this study also fall within the limits of the water quality values recommended by Nigeria's Federal Environmental Protection Agency (FEPA, 2003) and Boyd (1981) for fish rearing in tropical waters. Boyd, (1981) suggested a temperature range of 20-30°C and dissolved oxygen range of 3-4 mg L^{-1}. FEPA, (2003) recommended pH (6.5-9.5) and total hardness (0-75 mg L^{-1}). The physicochemical parameters

Table 1: Monthly variation in physicochemical parameters of Ologe Lagoon

Physicochemical parameter	July, 2010	August, 2010	September, 2010	October, 2010	January, 2011	February, 2011	March, 2011	April, 2011
Temperature (°C)	25.00±4.16^{a}	25.00±5.03^{a}	25.00±0.58^{a}	25.00±1.53^{a}	25.00±3.79^{a}	25.00±0.58^{a}	25.00±1.53^{a}	25.00±6.35^{a}
pH	7.60±1.15^{a}	7.10±0.67^{a}	7.80±0.81^{a}	7.78±1.47^{a}	6.40±1.56^{a}	7.11±1.13^{a}	8.83±1.03^{a}	7.99±1.67^{a}
Salinity (ppt)	0.10±0.01^{a}	0.10±0.05^{a}	0.10±0.09^{a}	0.10±0.06^{a}	0.30±0.06^{a}	0.30±0.12^{a}	0.30±0.06^{a}	0.20±0.09^{a}
Turbidity (NTU)	42.00±8.39^{ac}	38.00±15.73^{ac}	32.00±5.29^{ac}	50.00±10.15^{a}	18.00±5.15^{cd}	18.00±4.51^{cd}	38.00±4.58^{ac}	28.00±9.71^{ac}
DO (mg L^{-1})	4.20±1.36^{a}	3.90±1.51^{a}	4.30±1.01^{a}	3.60±1.19^{a}	4.00±0.58^{a}	4.30±0.52^{a}	3.80±0.64^{a}	4.60±0.68^{a}
Alkalinity (mg L^{-1})	90.30±9.28^{a}	95.10±13.15^{a}	88.40±6.91^{a}	146.00±29.92^{a}	90.30±3.95^{a}	108.40±6.59^{a}	139.60±49.61^{a}	128.90±41.10^{a}
Hardness (mg L^{-1})	140.30±42.31^{a}	132.40±28.15^{b}	44.60±4.71^{b}	70.10±8.41^{bc}	80.60±15.90^{abc}	69.30±11.23^{b}	72.10±17.46^{bc}	77.80±12.32^{abc}
EC (µS cm^{-1})	160.00±7.94^{a}	188.00±43.14^{a}	117.00±53.33^{a}	133.00±35.12^{a}	525.00±87.79	605.00±180.58^{b}	220.00±16.37^{a}	209.00±54.60^{a}
TDS (mg L^{-1})	84.00±7.55^{a}	103.00±14.47^{a}	66.00±14.18^{a}	69.00±16.77^{a}	264.00±9.45^{b}	281.00±20.66^{b}	148.00±77.50^{a}	112.00±25.69^{a}
TSS (mg L^{-1})	91.00±19.23^{ae}	143.00±28.35^{bc}	189.00±46.58^{bc}	211.00±11.27^{b}	90.00±12.50^{ae}	41.00±2.08^{de}	100.00±13.58^{a}	110.00±1.73^{a}
COD (mg L^{-1})	180.00±47.16^{ac}	201.00±41.28^{ab}	119.00±20.59^{ab}	266.00±32.02^{c}	52.00±18.01^{b}	63.00±4.93^{b}	208.00±38.12^{ac}	185.00±36.49^{ac}
BOD (mg L^{-1})	40.00±9.62^{a}	39.00±8.08^{a}	31.00±6.11^{a}	40.00±9.54^{a}	8.00±2.65^{b}	4.00±0.58^{b}	44.00±3.21^{a}	38.00±9.29^{a}

Figures in the same row and with the same superscript letters are not significantly ($p>0.05$) different. All values are expressed as Mean±SE

Table 2: Seasonal variation in physicochemical parameters of Ologe Lagoon

Physicochemical parameter	Rainy season	Dry season
pH	7.65±0.079^{a}	7.45±1.058^{a}
Salinity (ppt)	0.12±0.023^{a}	0.30±0.041^{a}
Turbidity (NTU)	38.00±4.041^{a}	19.27±5.055^{b}
Dissolved oxygen (mg L^{-1})	4.12±0.046^{a}	4.03±0.029^{a}
Alkalinity (mg L^{-1})	109.90±11.07^{a}	112.77±16.18^{a}
Total hardness (mg L^{-1})	93.04±13.39^{a}	74.00±7.074^{a}
Temperature (mg L^{-1})	25.00±1.056^{a}	25.00±1.019^{a}
EC (µS cm^{-1})	161.40±18.41^{a}	450.00±82.59^{a}
TDS (mg L^{-1})	86.80±7.099^{a}	231.00±31.31^{a}
TSS (mg L^{-1})	148.80±15.73^{a}	77.00±10.58^{b}
COD (mg L^{-1})	190.20±18.70^{a}	107.67±27.96^{b}
BOD (mg L^{-1})	37.60±3.039^{a}	18.67±06.47^{b}

Figures in the same row and with the same superscript letters are not significantly ($p>0.05$) different. All values are expressed as Mean±SE

of Ologe Lagoon indicate that the water body has favourable conditions for occurrence, survival, growth and multiplication of most tropical fish species.

The correlations of the physicochemical parameters are presented in Table 3. All the water quality variables exhibited significant correlation with at least one other variable except dissolved oxygen, alkalinity and total hardness. Salinity showed significant correlations with conductivity ($r=0.78$, $p<0.05$, $n=8$), total dissolved solids ($r = 0.86$, $p<0.01$, $n = 8$) and total suspended solids ($r = -0.72$, $p<0.05$, $n = 8$) while turbidity exhibited significant correlation with conductivity ($r = -0.83$, $p<0.05$, $n = 8$), total dissolved solids ($r = -0.84$, $p<0.01$, $n = 8$), chemical oxygen demand ($r = 0.90$, $p<0.01$, $n = 8$) and biological oxygen demand ($r = 0.86$, $p<0.01$, $n = 8$). Conductivity was significantly correlated with total dissolved solids ($r = 0.99$, $p<0.01$, $n = 8$), total suspended solids ($r = -0.74$, $p<0.05$, $n = 8$), chemical oxygen demand ($r = -0.80$, $p<0.05$, $n = 8$) and biological oxygen demand ($r = -0.88$, $p<0.01$, $n = 8$).

The concentrations of five of the heavy metals (Cu, Zn, Fe, Cd and Pb) in water column of Ologe Lagoon showed significantly monthly variation (Table 4). However, chromium did not show significant ($p>0.05$) monthly variation in the water column. Seasonal dynamics had no significant ($p>0.05$) effect on the concentrations of investigated heavy metals in the water column of Ologe

Table 3: Pearson correlation matrix for physicochemical parameters of Ologe Lagoon

Physicochemical Parameter	Temp.	pH	Salinity	Turbidity	DO	Alkalinity	Hardness	EC	TDS	TSS	COD	BOD
Temp.	1.00											
pH	0.10	1.00										
Salinity	0.78*	-0.07	1.00									
Turbidity	-0.29	0.64	-0.70	1.00								
DO	-0.32	-0.06	0.08	-0.38	1.00							
Alkalinity	0.35	0.65	0.18	0.43	-0.35	1.00						
Hardness	-0.19	-0.24	-0.35	0.25	-0.09	-0.34	1.00					
EC	0.55	-0.60	0.79*	-0.83*	0.16	-0.21	-0.16	1.00				
TDS	0.64	-0.53	0.86**	-0.84**	0.11	-0.16	-0.18	0.99**	1.00			
TSS	-0.48	0.23	-0.72*	0.58	-0.40	0.21	-0.23	-0.74*	-0.76*	1.00		
COD	-0.17	0.63	-0.55	0.90**	-0.46	0.63	0.25	-0.80*	-0.77*	0.58	1.00	
BOD	-0.29	0.72*	-0.59	0.86**	-0.25	0.40	0.29	-0.93**	-0.88**	0.53	0.99**	1.00

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed)

Table 4: Monthly concentration (μg L^{-1}) of heavy metals in water column of Ologe Lagoon

Heavy metal	July, 2010	August, 2010	September, 2010	October, 2010	January, 2011	February, 2011	March, 2011	April, 2011
Copper	33.13±1.15^{ac}	31.43±2.08^{ae}	30.56±2.65^{a}	40.19±2.52^{cde}	44.79±6.11^{bd}	34.41±2.52^{ac}	41.53±2.68^{cd}	26.68±2.65^{a}
Zinc	42.28±3.61^{a}	51.46±2.52^{ac}	29.41±2.57^{b}	53.48±1.53^{cg}	49.38±2.65^{ag}	39.14±3.06^{d}	72.51±6.03^{e}	94.40±12.08^{f}
Iron	210.00±50.00^{ag}	290.00±32.00^{b}	108.00±20.00^{c}	188.00±25.00^{af}	60.00±15.00^{d}	250.00±32.00^{e}	240.00±41.00^{egh}	210.00±53.00^{ag}
Cadmium	7.30±1.15^{acd}	16.48±1.18^{b}	5.15±1.53^{d}	4.67±1.45^{d}	16.19±2.30^{b}	11.14±1.54^{c}	5.66±1.52^{d}	5.42±1.52^{d}
Lead	11.49±1.58^{a}	21.60±2.08^{b}	10.34±1.77^{a}	8.51±1.44^{a}	13.46±1.81^{ab}	6.43±1.03^{a}	14.04±2.68^{ab}	10.16±1.79^{a}
Chromium	8.61±1.55^{a}	5.15±1.05^{a}	6.43±1.23^{a}	5.56±0.96^{a}	5.44±0.86^{a}	6.16±1.01^{a}	5.96±1.12^{a}	5.28±1.18^{a}

Figures in the same row and with the same superscript letters are not significantly (p>0.05) different. All values are expressed as Mean±SE

Lagoon (Fig 2a). The range of concentrations of Cu, Zn, Fe, Cd, Pb and Cr in this study are 26.68±2.65-44.79±6.11, 29.41±2.52-94.40±12.08, 60±15-290±32, 4.67±1.45-16.48±1.18, 6.43±1.03-21.60±2.08 and 5.15±1.05-8.61±1.55 μg L^{-1}, respectively. All the values of the heavy metals recorded in this study are lower than the World Health Organisation (WHO) limits for drinking water except cadmium. WHO (2008) recommended 2000, 3000, 2000, 3, 10 and 50 μg L^{-1} as limits for Cu, Zn, Fe, Cd, Pb and Cr respectively in drinking water. This implies that the water of Ologe Lagoon is still safe for human consumption but regular monitoring is important.

There was a noticeable increase in concentrations of the heavy metal levels of the water of Ologe Lagoon when compared with previous studies carried out in this water body. Kumolu-Johnson *et al.* (2010) reported a range of 4.35±0.08-4.37±0.12 and 28.5±2.9-58.5±4.8 μg L^{-1} for Cu and Fe, respectively. Ndimele *et al.* (2011b) also reported ranges of 3.83±0.21-4.25±0.12, 50.42±6.35-61.41±5.06 and 4.53±0.04-5.06±0.12 μg L^{-1} for Cu, Fe and Pb, respectively. Agboola *et al.* (2008) did not detect Cd and Cr. However, there has been a decrease in the levels of Zn when compared with previous studies. This increase in heavy metal content in the water of Ologe Lagoon and the detection of two heavy metals (Cd and Cr) previous undetected signifies increased industrial activities around the Ologe Lagoon. Industries in and around Agbara Industrial Estate located in Ogun State, Nigeria empty their effluents into Ologe Lagoon (Kusemiju *et al.*, 2001; Ndimele *et al.*, 2009). In addition, the government of Lagos State, Southwest, Nigeria has embarked on expansion of the road leading to Agbara Industrial Estate. This project has caused increase in vehicular traffic on this road, which might have resulted in the increase in Pb level in water of Ologe Lagoon. Organic Pb compounds (tetraethyl and tetramethyl lead) are used as antiknock in petrol and this becomes available to the environment when such

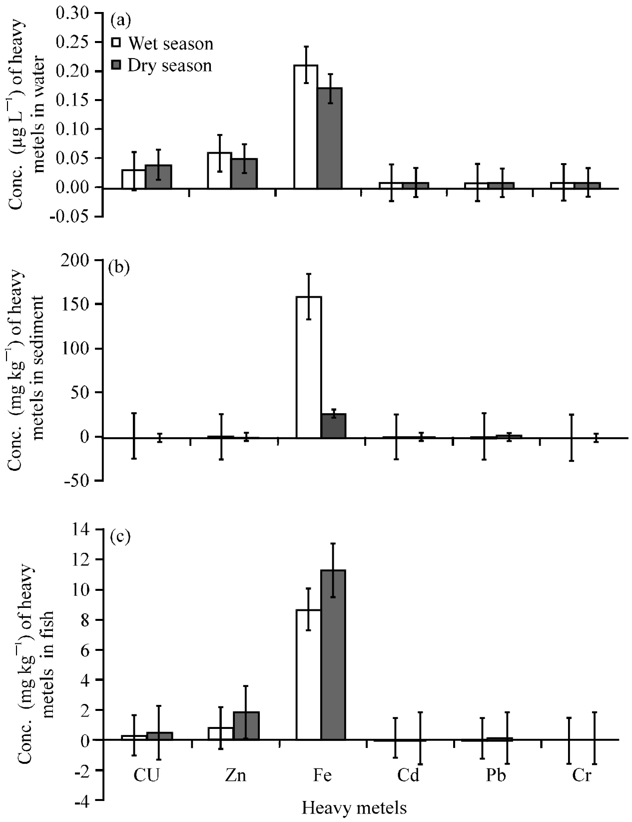

Fig. 2(a-c): Seasonal variation of heavy metals in (a) Water, (b) Sediment and (c) Fish (*Oreochromis niloticus*) from Ologe Lagoon

petrol are used to power automobiles. Pb as most heavy metals is not easily biodegradable and is a neurotoxin to which children are vulnerable (Dietrich *et al.*, 1993).

All the heavy metals in sediment of Ologe Lagoon exhibited significant ($p<0.05$) monthly variation except Cr (Table 5). However, only Cu and Fe were affected by seasonal dynamics (Fig. 2b). The range of concentration of Cu, Zn, Fe, Cd and Pb in the sediment were 0.15±0.02-0.34±0.06, 2.14±0.53-2.14±0.53, 20.60±4.70-212±19, 0.12±0.03-1.56±0.03 and 0.29±0.03-2.39±0.16 mg kg^{-1}, respectively. These values are below the limits set by World Health Organisation (WHO) and United States Environmental Protection Agency (USEPA) except Fe. WHO, 2008 recommended 25, 123 and 6 mg kg^{-1} for Cu, Zn and Cd, respectively while USEPA (2008) recommended 30, 40 and 25 mg kg^{-1} for Fe, Pb and Cr, respectively. The values of heavy metals in the sediments of Ologe Lagoon have been declining since the study conducted by (Anetekhai *et al.*, 2007). They reported that the concentrations of Cu and Zn in the sediment of Ologe Lagoon were 1300±22 mg kg^{-1} and 2920±23 mg kg^{-1}, respectively. Kumolu-Johnson *et al.* (2010) reported a range of 0.45±0.05-1.04±0.06, 47.6±5.3-98.5±10.1 and 81.6±11.7-335±35 mg kg^{-1} for Cu, Zn and Fe, respectively. This reduction in heavy metal content of the sediment of Ologe Lagoon might be attributed to passive phytoremediation by the invasive water hyacinth (*Eichhornia crassipes*) which usually covers a large portion of the water body for most part of the season (Ndimele, 2012). Although, water hyacinth is an aquatic macrophyte whose root stays entirely in the water column but sediment act as reservoir for metals and under favourable conditions, they can be remobilized into the water column, where they are absorbed by water hyacinth (Ndimele *et al.*, 2011b).

Table 5: Monthly concentration (mg kg^{-1}) of heavy metals in sediment of Ologe Lagoon

Metal	July, 2010	August, 2010	September, 2010	October, 2010	January, 2011	February, 2011	March, 2011	April, 2011
Copper	0.15±0.02^{a}	0.17±0.02^{ac}	0.19±0.04^{ac}	0.26±0.06^{bcd}	0.18±0.04^{ac}	0.34±0.06^{b}	0.22±0.01^{ad}	0.20±0.01^{ad}
Zinc	0.89±0.05^{ab}	0.38±0.03^{ae}	0.98±0.04^{bf}	1.14±0.04^{bgh}	0.74±0.09^{afg}	0.19±0.07^{ce}	2.14±0.53^{d}	1.67±0.09^{dh}
Iron	152.00±18.00^{a}	201.00±10.00^{bc}	43.90±10.71^{d}	29.40±5.90^{d}	20.60±4.70^{d}	29.30±4.65^{d}	181.00±15.00^{ac}	212.00±19.00^{b}
Cadmium	0.36±0.02^{a}	0.12±0.03^{b}	1.56±0.03^{c}	1.02±0.04^{d}	1.09±0.04^{d}	0.66±0.07^{e}	1.12±0.05^{d}	0.81±0.09^{e}
Lead	0.64±0.03^{ab}	0.29±0.03^{c}	1.08±0.06^{dhi}	0.85±0.10^{ah}	1.94±0.03^{e}	0.60±0.10^{b}	2.39±0.16^{f}	1.14±0.06^{gi}
Chromium	0.06±0.01^{a}	0.04±0.01^{a}	0.04±0.02^{a}	0.03±0.01^{a}	0.05±0.01^{a}	0.06±0.02^{a}	0.05±0.01^{a}	0.06±0.01^{a}

Figures in the same row and with the same superscript letters are not significantly (p>0.05) different. All values are expressed as Mean±SE

Table 6: Monthly concentration (mg kg^{-1}) of heavy metals in *Oreochromis niloticus* from Ologe Lagoon

Heavy Metals	July, 2010	Aug, 2010	Sept, 2010	Oct, 2010	Jan, 2011	Feb, 2011	March, 2011	April , 2011
Copper	0.23±0.05^{a}	0.31±0.08^{a}	0.41±0.09^{a}	0.45±0.08^{a}	0.34±0.09^{a}	0.07±0.02^{b}	0.07±0.02^{b}	0.38±0.32^{a}
Zinc	0.76±0.12^{a}	1.24±0.22^{b}	0.87±0.10^{a}	0.96±0.13^{ab}	0.66±0.20^{a}	0.19±0.15^{c}	1.22±0.24^{b}	1.69±0.33^{c}
Cadmium	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.00^{a}	0.01±0.01^{a}	0.01±0.01^{a}
Lead	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}
Iron	10.16±2.11^{a}	12.13±3.13^{a}	9.64±2.02^{a}	12.56±3.12^{a}	11.92±0.98^{a}	8.55±4.17^{a}	5.08±1.50^{b}	11.13±0.79^{a}
Chromium	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}	0.01±0.01^{a}

Figures in the same row and with the same superscript letters are not significantly (p>0.05) different. All values are expressed as Mean±SE

The Zn and Fe contents of *Oreochromis niloticus* showed significant (p<0.05) monthly variation while Cu, Cd, Pb and Cr did not (Table 6). Only Zn exhibited significant (p<0.05) seasonal variation while the other heavy metals (Cu, Fe, Cd, Pb and Cr) did not (Fig. 2c). Anetekhai *et al.* (2007) did not detect Cd and Pb in tissues of *Macrobrachium vollenhovenii*. However, Ndimele *et al.* (2009, 2011b) detected Pb in *Cynothrissa mento* and *Chrysichthys nigrodigitatus* from Ologe Lagoon. The concentration (0.07±0.02-0.45±0.08 mg kg^{-1}) of Cu recorded in this study is lower than the values reported in some previous studies in Ologe Lagoon and other water bodies in Nigeria. Kumolu-Johnson *et al.* (2010) reported 1.19±0.23-1.57±0.26 mg kg^{-1} in *Cynothrissa mento*, Ndimele *et al.* (2011b) reported 1.74±0.10-2.74±0.17 mg kg^{-1} in *Chrysichthys nigrodigitatus* from Ologe Lagoon while Obasohan *et al.* (2006) reported 4.17-6.46 mg kg^{-1} in *Malapterurus electricus* and *Chrysichthys nigrodigitatus* from Ogba River in Benin City, south-western, Nigeria.

The values of Zn (0.19±0.15-1.69±0.33 mg kg^{-1}) and Fe (5.08±1.50-12.56±3.12 mg kg^{-1}) recorded in the tissues of *Oreochromis niloticus* in this study is similar to the values (Zn, 0.62-2.33 mg kg^{-1}; Fe, 2.21-10.10 mg kg^{-1}) reported by Adefemi *et al.* (2008) in *Tilapia mossambica* from Ureje Dam, south-western Nigeria. The concentration of Zn is also similar to 0.15±0.05-2.80±0.05 and 0.50±0.01-2.80±0.01 mg kg^{-1} reported for *Parachanna obscura* and *Clarias gariepinus,* respectively in Ikpoba River, Benin, south-western Nigeria by Oguzie (2009). The concentrations of heavy metals in *Oreochromis niloticus* obtained in this study were also below the levels recommended in fish and fishery products by the Food and Agriculture Organisation (FAO) of The United Nations Organisation (Nauen, 1983). The reason for the moderately high concentration of heavy metals in *Oreochromis niloticus* observed in this study can be attributed to the facts that they primarily feed on phytoplankton (blue-green algae and diatoms) but may also consume macrophytes when phytoplankton densities are low. Other organisms that may have higher metal load are the benthic species, which take up additional heavy metals from sediment and accumulates them in their biological systems.

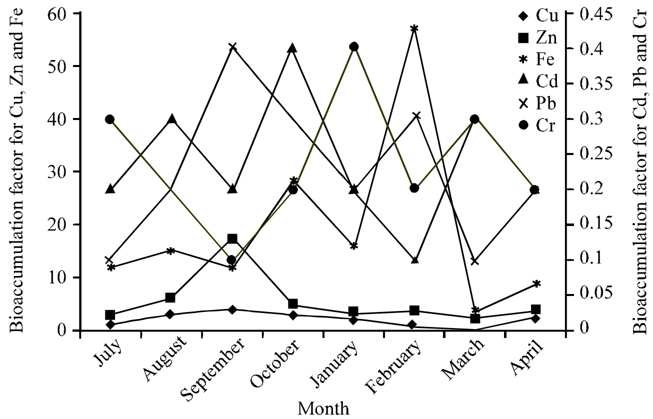

Fig. 3: Bioaccumulation factors of heavy metals in fish (*Oreochromis niloticus*) from Ologe Lagoon

The bioaccumulation factors of the heavy metals are presented in Fig. 3. The values obtained were 0.23-4.10, 2.44-17.40, 0.10-0.40, 0.10-0.40, 3.91-27.91 and 0.10-0.40 for Cu, Zn, Cd, Pb, Fe and Cr, respectively. These bioaccumulation values are lower than those reported in previous studies. Obasohan and Eguavoen (2008) reported 643-3140 and 64-2135 for Cu and Zn, respectively while Kumolu-Johnson *et al.* (2010) reported the following values; Cu: 170-410, Zn: 30-80 and Fe: 370-2320. Though, the bioaccumulation factors were low, it still can be deduced that there was metal accumulation from water to the fish.

CONCLUSION

Heavy metal pollution remains a major challenge to ecologists and other aquatic scientists. The Ologe Lagoon is still safe for fisheries and domestic use. However, there is need for continuous study to detect sudden increase in metal levels.

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