Heavy metals concentrations in water, sediment, water hyacinth (*Eichhornia crassipes*) and Frillfin Goby (*Bathygobius soporator*, Cuvier and Valenciennes, 1837) from Ologe Lagoon, Southwest, Nigeria

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Abstract

The level of heavy metals in water, sediment, water hyacinth (*Eichhornia crassipes*) and frillfin goby (*Bathygobius soporator*) from Ologe Lagoon and its tributaries were monitored because of the importance of the water bodies to the socio-economic well-being of the rural population. Physico-chemical parameters and selected heavy metals (Fe, Zn, Cu, Pb and Cd) contents of water, sediment, *E. crassipes* and *B. soporator* from six sampling stations in Ologe Lagoon were measured monthly from February to November, 2015. The range of concentration of heavy metals in sediment are: Fe (454±112-2756±1213mg/kg), Zn (3.89±3.08-18.7±6.83mg/kg), Cu (7.68±5.65-36.8±16.9mg/kg), Pb (6.24±2.56-11.2±4.45mg/kg) and Cd (0.42±0.17-0.92±0.42mg/kg). Heavy metal concentration in *E. crassipes* were 68.5±16.5-987±86.8mg/kg, 13.2±6.40-162±46.2mg/kg, 0.56±0.25-6.54±1.45mg/kg, 5.06±2.41-12.2±4.71mg/kg and 0.28±0.22-1.21±0.49mg/kg for Fe, Zn, Cu, Pb and Cd respectively. The concentrations of heavy metals in the muscle of *B. soporator* in wet season were: Fe, 8.30±2.29 mg/kg; Zn, 0.78±0.28 mg/kg; Cu, 16.20±6.20 mg/kg; Pb, 2.21±0.33mg/kg; Cd, 0.16±0.05mg/kg while in dry season, they were: Fe, 27.19±7.28 mg/kg; Zn, 24.47±6.27 mg/kg; Cu, 0.18±0.16 mg/kg; Pb, 1.72±0.07mg/kg; Cd, 0.19±0.03mg/kg. Hardness and turbidity showed significant ($p<0.05$) spatial variation. Concentrations of Fe, Zn and Cu in sediment varied significantly ($p<0.05$) among the sampling sites but Pb and Cd did not. The heavy metal content of water hyacinth from the six sampling stations exhibited significant ($p<0.05$) spatial variation except Cd. The concentrations of Fe, Zn and Cu in *B. soporator* were significantly ($p<0.05$) affected by season but Pb and Cd were not. Although only Pb exceeded the FAO/WHO maximum permissible limits in the tissue of *B. soporator*, regular monitoring of Ologe Lagoon is advocated in order stern further deterioration of the ecosystem and to protect the rural population that depend on it for sustenance.

Keywords: Heavy metals; *Eichhornia crassipes; Bathygobius soporator;* Ologe Lagoon.

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Introduction

Heavy metals accumulation in aquatics around the globe has become an issue of great concern because of the threat they pose to the environment and man. Heavy metals can be essential or non-essential (Kumolu-Johnson *et al* 2010). The former are metals required in small quantity for the growth and development of organisms and only become toxic when the tolerable limits or thresholds are exceeded. Examples of such metals are Fe, Cu and Zn. The non-essential metals play no known physiological role in organisms. They are toxic even at very low concentrations and examples are Hg, Pb and Cd. Two factors contribute to the deleterious effects of heavy metals as environmental pollutants. Firstly, they cannot be destroyed by biological processes as in the case of most organic pollutants and so, they remain in the system of the organism in a potentially harmful form. Secondly, they are easily assimilated and can bio-accumulate in the protoplasm of aquatic organisms (Egborge 1994). Organisms in wetlands might be exposed to high levels of metals due to frequent discharge of effluents into aquatic ecosystems. Consequently, the metals are ingested and accumulated in biological systems or transported to higher levels through food web (Green *et al* 2010). Various forms of ill health (cancer, low intelligent quotient and congenital malformation) are associated with metal consumption by aquatic organisms and their terrestrial predators, including man. Death could also result in severe cases

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(Dummee *et al* 2012). Monitoring of aquatic pollution requires sampling of organisms in the environment of interest for the analysis of different biological responses to chemical exposures (Li *et al* 2010). Good bio-indicators are important for successful biomonitoring exercise. An ideal bio-indicator is expected to have the following qualities: accumulate high levels of pollutants without dying; sedentary in nature or limited in mobility, thus representing the local pollution; abundant and wide in distribution for repetitious sampling and comparison; longevity to allow for comparison between various ages; easy to sample in the wild and raise in the laboratory; readily survives in water; occupies important niche in the food chain; and dose-effect relationship can be observed in the organism (Zhou *et al* 2008). It is almost impossible to find a bio-indicator with the above attributes to prosecute a biomonitoring programme. Therefore, the bio-indicator with the most practicable qualities according to the objectives of the study is chosen.

The metal pollution status of an aquatic environment can be determined by analyzing the abiotic (water, sediment) and biotic (plant, animal) components of the ecosystem (Hamed and Emara 2006). Studying the metal concentration in water is important because some of the aquatic organisms especially fin fishes, which are consumed by man live in the water. It also important to study the sediment metal concentration because sediment act as source or reservoir of chemicals in water and their metal concentration are often higher than the values in water column. Aquatic animals such as goby (*Bathygobius soporator*) living in polluted waters often bioconcentrate metals in their tissues (Li *et al* 2009). Due to their geographical, tolerance to wide range of salinity, high abundance in mangrove swamps (Lawson and Thomas 2010), *B. soporator* can be used as a biomonitor to show the bioavailability of pollutants and the intensity of pollution (Schuhmacher 1996). In the same vein, water hyacinth is an aquatic weed of enormous ecological interest because of its high rate of proliferation, which has impacted negatively on fisheries, water transportation and hydro-electricity. It is an aquatic macrophyte which can absorb pollutants like heavy metals from water bodies even when the concentration of the metals is low (Ndimele and Ndimele 2013). This attribute makes it a good candidate for biomonitoring.

This study investigated heavy metal concentrations in water, sediments, water hyacinth (*E. crassipes*) and frillfin goby (*B. soporator*) in Ologe Lagoon and its tributaries to ascertain the health status of the ecosystem and the potential danger heavy metals may pose to indigenous communities that depend on the aquatics for their livelihood.

Materials and methods

Description of Ologe Lagoon (sampling site)

Ologe Lagoon (Figure 1) is a freshwater ecosystem located in the eastern part of Lagos State, Nigeria with a surface area of about 64.5km^2 (Kumolu-Johnson *et al* 2010). It lies between latitudes 6°27′N and 6°30′N and longitudes 3°02′E and 3°07′E. The lagoon opens into the Atlantic Ocean via Lagos Harbour and Badagry Creeks (Ndimele *et al* 2011). Ologe Lagoon is deep at the centre but shallow at the edges with an average depth of 2.42m and a mean temperature of 30°C on a sunny day. The lagoon has a wide navigable mouth, which allows fishing, recreation and transportation (Anetekhai *et al* 2007; Ndimele *et al* 2009). The water body is located in Oto-Awori in Ojo Local Government Area (LGA) of Lagos State, Nigeria. The area is predominantly occupied by the Aworis. The major source of water into Ologe Lagoon is River Owo located in Towo-Owo (Ndimele *et al* 2011). The lagoon shares boundary in the north with Igbesa and Agbara in Ogun State and Ijaniki town in Lagos State, in the west with Esepe-Mushin and Ale, in the south with Gbanko and Badagry Creek and in the east with Idoluwo, Ikotun, Egan, Igede, Ilemba, Ojota and Ojo towns. Fishing and farming are the major economic activities of the people in these towns (Kumolu-Johnson *et al* 2010).

Collection of samples

This study was conducted for a period of ten months (February-November, 2015). Samples were collected monthly from six sampling stations; Ologe Jetty, Agbara, Imude, Era, Morogbo and Underbridge. Water samples were collected monthly for physicochemical parameters and heavy metals analyses from the six sampling stations using amber sampling bottle (250ml) and 20ml plastic bottle, respectively. The bottle was dipped about 15cm below the water level at designated sampling stations and water was allowed to flow gently into the bottle. After sample collection, the sampling bottles were acidified to preserve the integrity of the samples by adding 0.5ml of nitric acid to every 100ml of water. Thereafter, the samples were labelled with dates and collection locations, and later stored at 4°C. Sediment samples were collected at a depth of 1-2m on a monthly basis too from the sampling stations 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.

Physico-chemical parameters of water samples

Water quality variables, temperature, pH, alkalinity, salinity, dissolved oxygen, total hardness and turbidity were determined. The temperature of the water and pH were measured *in situ* with probe meter (Hanna portable pH/EC/TDS/temperature meter, HI 98129 model, USA) while turbidity was determined using nephelometer (Analite portable nephelometer Model 156, Mcvan Instrument, Mulgrave, Australia).

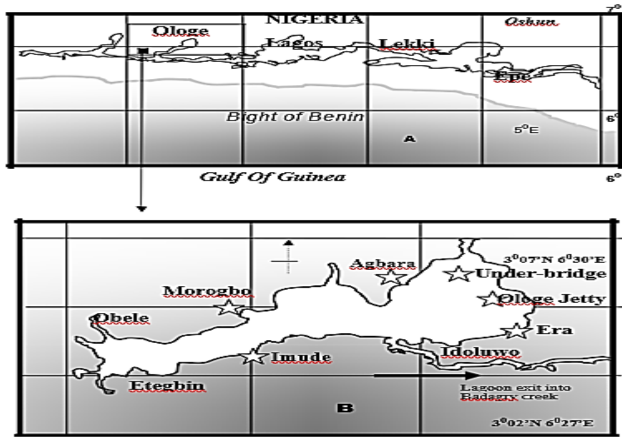

Figure 1. Map showing Ologe Lagoon and sampling stations are marked with stars (Scale: 1:150,000).

Dissolved oxygen was measured with a portable dissolved oxygen meter (Hanna portable dissolved oxygen meter, HI 9146 model, USA) while salinity, alkalinity and total hardness were determined using titrimetric method (Boyd 1981).

Salinity

Salinity was determined by measuring 10ml of the water sample into conical flask. Fifteen millilitre (15ml) of the indicator (potassium chromate, K_2CrO_3) was carefully added into the water sample. The water sample turned yellow. Then this was titrated with silver nitrate solution until the colour changed to brick red.

Salinity (ppt) = ml of titrant x 1.80655

Total Alkalinity

In order to test total alkalinity of the water sample, 4 drops of methyl orange indicator were added to 100ml of water sample and it turned yellow. This was then titrated with standard sulphuric acid (0.02N H_2SO_4) until the colour change to light orange.

$$\text{Total alkalinity (mg/l)} = \frac{ml\ of\ standard\ \mathrm{H_2SO_4}\ \text{x}\ 0.02\text{N x } 50 \text{ x } 100}{vol.\ of\ water\ sampled\ (ml)}$$

Total Hardness

Total hardness was determined by adding 2ml of buffer solution to 100ml of water sample in a conical flask. The sample was thoroughly mixed after which 8 drops of Eriochrome B-T (EBT) (indicator) was added to the water sample using dropping pipette and it turned wine red. The sample was then titrated with 0.010M standard disodium ethylenediamine tetra acetic acid (EDTA) solution until the sample turned to blue.

$$\text{Total hardness} = \frac{ml\ of\ EDTA \times 0.01M \times 100.1 \times 1000}{vol. of\ water\ sampled}$$

Sample pre-treatment and analyses

Water

Water samples were given no further treatment but were shaken thoroughly and then the heavy metals (Zn, Fe, Cu, Cd and Pb) concentrations in the samples were determined using Buck Scientific Atomic Absorption Spectrophotometer (VGP 210 model, USA).

Sediment, water hyacinth and fish

Sediment, water hyacinth and fish samples were digested before their heavy metals contents were determined with atomic absorption spectrophotometer (AAS). The sediment was first dried on a hotplate for 10 minutes, allowed to cool and sieved with 0.5mm sieve (Varol 2011). Exactly 2g of the sample was weighed out into a beaker using Mettler balance (DM-11-K). Exactly 10ml of nitric acid and 5ml of hydrogen peroxide were added to the sample, then the sample was heated on a hot plate in a fume cupboard for about 45 minutes until the solid dissolved and the volume of the content was reduced to about 5ml (APHA 2005). The content was then filtered by gravity through a 0.45µm membrane filter paper into a 50ml volumetric flask and made up to the mark with de-ionized water. Heavy metals content of the digested sediment samples was determined using atomic absorption spectrophotometer (Buck scientific 210 VGP model).

Twenty samples each of water hyacinth and whole fresh fish were selected from each station, weighed and dried in an oven at 105°C for 28 hours until a constant weight was obtained. Dried samples were grounded into powdery form (with ceramic mortar and pestle) and 2g of each sample was digested according to APHA (2005). Zn, Fe, Cu, Cd and Pb contents were determined with atomic absorption spectrophotometer (Buck scientific 210/211 VGP model). The concentration of the metals in sediment, water hyacinth and fish was recorded in mg/kg.

Standard solutions prepared by diluting stock solutions (Merck, multi element standard) were used for system calibration and control of analytical accuracy. All samples were run in clusters composed of blanks, two spiked samples, a standard calibration curve, and one duplicate (Türkmen *et al* 2008). Dogfish muscle (DORM-2, National Research Council, Canada) was analysed (n=5) as a certified reference material for validation of method for accuracy and precision. The recovery rate (% mean recovery ± S.E.) was also analysed (n=5) (Zrnčić *et al* 2013). There was strong correlation between analytical and certified values. The recovery rate for the metals were 98.4±2.7%, 96.5±3.6%, 97.8±3.5%, 98.2±2.8%, 97.8±3.4% for Fe, Zn, Cu, Pb and Cd, respectively. The precision of the analytical procedure (relative standard deviation) varied between 5 and 8%. The analysis of standard solution had precision value that is better than 5%. Each of the analyses was repeated twice, and the results obtained were reported as the average.

Statistical analyses

Spatial variation was tested by one-way analysis of variance (ANOVA) and Duncan multiple range test was used to separate the means when the difference is significant. In addition, the seasonal variations were determined by t-test. The level of significance was set at $p<0.05$ and all statistical analyses were carried out with statistical package for social sciences (SPSS windows version 17.0, Chicago, USA).

Results

Physico-chemical parameters of water

The results of the physico-chemical parameters of water samples are presented in Table 1. Out of all the physico-chemical parameters, only hardness and turbidity showed significant ($p<0.05$) spatial variation (Table 1). The highest hardness value was recorded in Era (868±96.0mg/l) and lowest in Imude (64.5±12.9mg/l). The highest (32.5±13.2NTU) and lowest (15.6±4.86NTU) turbidity values were observed in Imude and underbridge, respectively.

Heavy metals content of water, sediment, water hyacinth and *Bathygobius soporator*

The spatial variation of heavy metal in water is shown in Table 2. All the five heavy metals (Fe, Zn Cu Pb and Cd) investigated were detected in measurable quantities in the water column of the six sampling stations and none of them exhibited significant ($p>0.05$) spatial variation. Table 3 shows the concentration of heavy metals in the sediment of the sampling stations. Iron (Fe), Zn and Cu varied significantly ($p<0.05$) between sampling sites but Pb and Cd did not. The highest concentrations of Fe (2756±1213mg/kg) and Cu (36.8±16.9mg/kg) were observed in Underbridge while their lowest values (Fe, 454±112mg/kg; Cu, 7.68±5.65mg/kg) occurred in Era and Morogbo, respectively. The concentration of Zn in sediment was highest in Imude (18.7±6.83mg/kg) and lowest in Era (3.89±3.08mg/kg). The concentrations of heavy metals in water hyacinth from the six sampling stations exhibited significant ($p<0.05$) spatial variation (Table 4) except Cd. The highest (Cu, 6.54±1.45mg/kg; Pb, 12.2±4.71mg/kg) and lowest (Cu, 0.56±0.25mg/kg; Pb, 5.06±2.41mg/kg) values of Cu and Pb were recorded in Agbara and Ologe Jetty, respectively. The highest concentration of Fe (987±86.8mg/kg) in water hyacinth from the sampling stations occurred in Ologe Jetty while the highest Zn values (162±46.2mg/kg) was obtained in Agbara but the lowest concentrations for these two metals (Fe, 68.5±16.5mg/kg; Zn, 13.2±6.40mg/kg) were recorded in Era. The seasonal variation of heavy metals in frillfin goby (*B. soporator*) is shown in Table 5. Iron (Fe), Zn and Cu were significantly ($p<0.05$) affected by difference in seasons while Pb and Cd showed no significant ($p>0.05$) seasonal variations.

Table 1: Physico-chemical parameters of Ologe Lagoon and its tributaries

STATIONS	**Temp (°C)**	**DO (mg/L)**	**pH**	**Alkalinity (mg/L)**	**Salinity (ppt)**	**Hardness (mg/L)**	**Turbidity (NTU)**
Agbara	26.70±1.45^{a}	4.68±0.87^{a}	5.67±0.46^{a}	31.10±4.04^{a}	0.02±0.04^{a}	263.00±42.9^{a}	31.40±14.5^{a}
Ologe Jetty	27.90±2.68^{a}	4.15±0.75^{a}	6.78±0.45^{a}	42.20±5.34^{a}	0.01±0.01^{a}	119.00±58.4^{b}	18.90±5.68^{b}
Imude	28.30±2.18^{a}	3.78±0.57^{a}	5.85±0.98^{a}	36.50±2.48^{a}	0.01±0.03^{a}	64.50±12.9^{c}	32.50±13.2^{a}
Morogbo	28.00±2.69^{a}	3.48±0.78^{a}	5.86±0.36^{a}	35.00±2.60^{a}	0.02±0.03^{a}	278.00±65.2^{a}	22.20±10.6^{b}
Era	28.10±2.34^{a}	3.73±0.67^{a}	6.68±0.56^{a}	31.70±1.89^{a}	0.01±0.02^{a}	868.00±96.0^{d}	29.00±15.5^{a}
Underbridge	28.50±2.88^{a}	3.46±0.98^{a}	5.78±0.78^{a}	38.10±3.42^{a}	0.01±0.02^{a}	106.00±28.7^{b}	15.60±4.86^{b}
WHO (2004)	-	>2.0	6.5 – 8.5	-	-	75.00	5.00
NESREA (2011)	-	-	6.5-8.5	-	-	150.0	5.00

Values in the same column and with the same superscript letters are not significantly ($p>0.05$) different.

All the values are expressed as mean±SE; NESREA = National Environmental Standards and Regulations Enforcement Agency; n=10.

Table 2: Concentrations of heavy metals in water samples from Ologe Lagoon and its tributaries

STATIONS	**Fe (mg/l)**	**Zn (mg/l)**	**Cu (mg/l)**	**Pb (mg/l)**	**Cd (mg/l)**
Agbara	0.48±0.11^{a}	0.01±0.01^{a}	0.10±0.06^{a}	0.09±0.05^{a}	0.01±0.01^{a}
Ologe Jetty	0.80±0.30^{a}	0.02±0.02^{a}	0.06±0.05^{a}	0.01±0.01^{a}	0.01±0.01^{a}
Imude	0.57±0.20^{a}	0.02±0.01^{a}	0.03±0.02^{a}	0.41±0.04^{a}	0.01±0.02^{a}
Morogbo	0.58±0.13^{a}	0.06±0.05^{a}	0.03±0.03^{a}	0.05±0.03^{a}	0.01±0.01^{a}
Era	0.43±0.21^{a}	0.03±0.03^{a}	0.07±0.06^{a}	0.01±0.01^{a}	0.01±0.01^{a}
Underbridge	0.26±0.07^{a}	0.03±0.02^{a}	0.05±0.04^{a}	0.01±0.01^{a}	0.02±0.01^{a}
MDL	0.00120	0.00132	0.00106	0.00186	0.00190

values in the same column and with the same superscript letters are not significantly ($p>0.05$) different.

All the values are expressed as Mean±SE; MDL = method detection limit; n = 10.

Table 3: Heavy metals content in sediment of Ologe Lagoon and its tributaries

STATIONS	**Fe (mg/kg)**	**Zn (mg/kg)**	**Cu (mg/kg)**	**Pb (mg/kg)**	**Cd (mg/kg)**
Agbara	1877.00±976^{a}	15.10±5.45^{a}	11.90±8.67^{ab}	7.53± 1.48^{a}	0.65±0.32^{a}
Ologe Jetty	1868.00±678^{a}	16.20±6.82^{a}	15.10±12.51^{a}	6.24± 2.56^{a}	0.43±0.15^{a}
Imude	1912.00±856^{a}	18.70±6.83^{a}	10.20±7.56^{ab}	10.89±3.45^{a}	0.61±0.33^{a}
Morogbo	1236.00±424^{a}	13.90±4.12^{a}	7.68±5.65^{b}	9.38± 3.42^{a}	0.83±0.41^{a}
Era	454.00±112^{b}	3.89±3.08^{b}	18.50±10.23^{a}	8.41±3.60^{a}	0.42±0.17^{a}
Underbridge	2756.00±1213^{c}	16.70±6.06^{a}	36.80±16.9^{c}	11.20±4.45^{a}	0.92±0.42^{a}
WHO (2008)	40	123	25	30	0.5
USEPA (1999)	-	121	31.6	35.8	0.99

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

Table 4: Concentration of heavy metals in water hyacinth (*E. crassipes)* from Ologe Lagoon and its tributaries

STATIONS	**Fe (mg/kg)**	**Zn (mg/kg)**	**Cu (mg/kg)**	**Pb (mg/kg)**	**Cd (mg/kg)**
Agbara	381.00±59.6^{a}	162.00±46.2^{a}	6.54±1.45^{a}	12.20±4.71^{a}	0.81±0.39^{a}
Ologe Jetty	987.00±86.8^{b}	78.60±25.8^{b}	0.56±0.25^{b}	5.06±2.41^{b}	0.28±0.22^{a}
Imude	96.60±29.0^{c}	88.60±35.2^{b}	4.67±0.96^{a}	10.80±3.66^{a}	0.94±0.45^{a}
Morogbo	268.00±64.5^{d}	17.30±7.17^{c}	0.86±0.31^{b}	8.58±3.12^{ab}	0.61±0.33^{a}
Era	68.50±16.5^{c}	13.20±6.40^{c}	1.39±0.38^{b}	7.18±2.56^{ab}	0.64±0.31^{a}
Underbridge	144.00±34.4^{d}	76.60±23.1^{b}	6.47±1.63^{a}	10.90±4.14^{a}	1.21±0.49^{a}
WHO (1996)	-	0.6	10.0	2.0	0.02

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

Table 5: Seasonal Variation of heavy metals in Frillfin Goby (*B. soporator)* from Ologe Lagoon and its tributaries

SEASONS	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Cd (mg/kg)
WET	8.30±2.29^{a}	0.78±0.28^{a}	16.20±6.20^{a}	2.21±0.33^{a}	0.16±0.05^{a}
DRY	27.20±7.28^{b}	24.50±6.27^{b}	0.18±0.16^{b}	1.72±0.07^{a}	0.19±0.03^{a}
FAO/WHO (1989)	-	40	30	0.5	0.5

Discussion

Physico-chemical parameters are very important in the study of aquatic ecosystem. They determine among other things, the health of the water body and their carrying capacity. The water quality variables measured in this study exhibited different trends compared to previous studies on Ologe Lagoon and adjoining water bodies. Temperature and alkalinity values were similar to those reported by Agboola *et al* (2008) who worked on Badagry Creek, which directly empties into Ologe Lagoon.

However, turbidity (15.6±4.86-32.5±13.2 NTU) and hardness (64.5±12.9-868±96.0 mg/L) values were higher than previously reported by Agboola *et al* (2008) turbidity, 13.50±4.0-15.0±4.6 NTU and Kumolu-Johnson *et al* (2010); hardness, 43±14-48±16mg/L. Hardness and turbidity showed significant ($p<0.05$) spatial variations in this study. The range of pH recorded in this study was 5.67±0.46 - 6.78±0.45. The recommended range of pH for the growth and survival of tropical fishes is 6.5-7.5 by Onolaja (2000), and 7.0-8.0 by Huet (1972). These recommendations suggest that tropical fishes may prefer slightly alkaline environment. World Health Organization (WHO 2004) standard range for pH in drinking water is 7.0-8.5. The mean value of pH obtained in this study is within the limits required for the growth and survival of tropical fishes but slightly lower than the standards set by the above regulatory agency for drinking water. This implies that the water from the Ologe Lagoon and its tributaries may not be drinkable because of the acidic level of the water. The leaching of metals from acidic water often leads to serious health risks like gastrointestinal upset, congenital malformation, etc (Ndimele *et al* 2011).

Although, alkalinity did not vary significantly ($p>0.05$) among the sampling stations, the values in this study (31.1±4.04-42.2±5.34mg/l) were higher than the recommended limit (20mg/l as $CaCO_3$) set by Federal Environmental Protection Agency (FEPA 2003). On the contrary, hardness values (64.5±12.9-868±96.0mg/l) differed significantly ($p<0.05$) among the sites and they are higher than FEPA limits (75mg/l). The salinity of the six sampling stations was below 0.5ppt, which is an indication that all the sampling stations are freshwater ecosystems and only freshwater organisms can survive in these environment. Turbidity is the haziness or cloudiness of an aquatic ecosystem as a result of suspended solids that are generally invisible to the unaided eyes. Barnes *et al* (1998) categorized water bodies into different groups using turbidity values; clear water (<10 NTU), cloudy water (50 NTU), very cloudy water (100-500 NTU). High turbidity affects photosynthesis by reducing light penetration into water column. This reduces food availability, growth and survival of organisms high in aquatic food chain, which depend on photosynthetic plants. The consequences may be migration if they are motile or mass mortality and in severe cases extinction. The range of turbidity (15.6±4.86-32.5±13.2 NTU) in this study is higher than WHO limit (5.0 NTU). The high values from all the sampling stations might be due to organic load from domestic wastes and intense sand mining activities in Lagos Lagoon Complex of which Ologe Lagoon and its tributaries belong. Clarke *et al* (2019) reported that sand extraction in Lagos Lagoon has impaired the quality of the water body.

The concentrations of metals in the water column of the sampling sites did not show significant spatial variation ($p>0.05$). The values of the metals were all within WHO acceptable limits (Fe=2mg/l, Zn=3mg/l, Cu=2mg/l, Pb=0.01mg/l and Cd=0.003mg/l) recommended by WHO for drinking water. The results of the present work agree with previous studies; Adeboyejo *et al* (2011) did not detect Cd, and Agboola *et al* (2008) did not detect Cd and Cr in Badagry Creek. Adefemi *et al* (2008) did not detect Cu but reported mean Zn and Fe concentrations of 30µg/l and 80µg/l, respectively, in Ureje Dam in south-western Nigeria. Obasohan and Eguavoen (2008) reported Cu and Zn ranges of 1.0–63µg/l and 1.0–110µg/l, respectively, in Ogba River, Benin City, Nigeria. The detection of these metals in the present study suggests that their concentration is increasing. This can be attributed to increasing industrial activities in Agbara Industrial Estate caused by the relocation of more companies to this estate. Some of the companies discharge their wastes into Ologe Lagoon without prior treatment, which is harmful to man and the environment (Kumolu-Johnson *et al* 2010).

The concentrations of Fe and Cd in the sediments are higher than the WHO (2008) limits (Fe, 40mg/kg; Cd, 0.5mg/kg). However, the values of the metals in the sediment are lower than those reported by Anetekhai *et al* (2007) for Ologe Lagoon. They reported Cu (1300±22mg/kg) and Zn (2920±23mg/kg). The high Fe level observed in the sediment have been reported in earlier studies by Kumolu-Johnson *et al* (2010) and Kakulu and Osibanjo (1988). Similar observation was made by Asaolu and Olaofe (2005) and they opined that background Fe content in Nigerian soil and other parts of the globe is naturally high. The concentrations of Cu and Cd in water hyacinth (*E. crassipes*) in the present study are similar to those reported by Nnamonu *et al* (2015) on River Benue but Fe and Zn values were higher. The concentrations of Zn, Pb and Cd are higher than the WHO permissible limits of metals in plants (WHO 1996). High concentration of heavy metals in *E. crassipes* can be caused by unregulated disposal of industrial wastes into surrounding water bodies (Asuquo *et al* 1999). The observed low concentrations of Cu in the *E. crassipes* could be due to the efficient mechanism of elimination by this plant.

All the investigated metals (Fe, Zn, Cu, Pb and Cd) were found in measurable quantities in the muscle of *B. soporator* but only Fe, Zn and Cu were affected by seasonal dynamics. Anetekhai *et al* (2007) did not detect Pb and Cd in the flesh of *Macrobrachium vollenhovenii* from Ologe Lagoon but Ndimele *et al* (2009) found Pb in the tissue of *Chrysichthys nigrodigitatus* from the same water body. In the same vein, Fe, Zn and Cu concentrations have also increased when compared to the values reported in previous studies in Ologe Lagoon and other water bodies in Nigeria. Kumolu-Johnson *et al* (2010) reported 1.19±0.23-1.53±0.26mg/kg of Cu in the muscle of *Cynothrissa mento* from Ologe Lagoon while Obasohan *et al* (2006) reported a range of 4.17-6.46mg/kg of Cu in *Malapterurus electricus* from Ogba River, Benin city, Nigeria. Adefemi *et al* (2008) reported 2.21-10.10 mg/kg of Fe in the muscle of *Tilapia mossambica* from Ureje Dam, South-west while Oguzie (2009) reported Zn concentration of 0.15±0.05-2.80±0.05mg/kg in *Parachanna obscura* from Ikpoba River, Benin city, South-west, Nigeria.

The increase in heavy metals concentration in different water bodies in Nigeria might be due to the discharge of industrial effluents into them. Unfortunately, most of these wastes are emptied into these aquatic ecosystems untreated, thereby endangering the lives of coastal communities that depend on services by these water bodies for sustenance.

The concentrations of heavy metals in the water, sediment and water hyacinth of Ologe Lagoon during this study were below the FAO/WHO maximum permissible limit (MPL). However, the concentration of Pb in the muscles of *B. soporator* was above (FAO/WHO 1989), which makes regular monitoring of the lagoon and its tributaries an essential necessity.

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