Ecosystem health assessment of three inland water bodies in South-west, Nigeria based on fish diversity, pollution status, ecological and health risk indices

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Ecosystem health assessment of three inland water bodies in South-west, Nigeria based on fish diversity, pollution status, ecological and health risk indices

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Abstract

This study was conducted to determine the health status of three water bodies (Badagry Creek, Ologe Lagoon and River Owo) because of the large amount of effluent they receive from industries around Lagos as well as the services they provide to sustain the large human population in an emerging mega city like Lagos. Water, sediment and fish samples were collected monthly from the three water bodies between January and December, 2018. Standard methods were used for the analysis of physico-chemical parameters, heavy metals, length-weight relationship, condition factor, fish diversity indices, sediment pollution indices, ecotoxicology of heavy metals in sediment and potential ecological risks as well as health risk assessment of heavy metals. The geoaccumulation index (Igeo) of heavy metals in sediments of the sampling sites ranged from -12.14 to -0.38. The mean quotients using the probable effect level (m-PEL-Q) are 3.91 x10-4, 4.77 x10-4 and 7.87 x10-4 for Ologe Lagoon, Badagry Creek and River Owo respectively. The trend was the same with mean quotients using effect range-median (m-ERM-Q). The estimated daily intake (EDI) ranged from 0.00 mgkg-1day-1 in Pb from River Owo to 1.15 x10-3 mgkg-1day-1 in Fe still from River Owo. The range of values of the target hazard quotient (THQ) of the metals in Badagry Creek, River Owo and Ologe Lagoon are 1.23x10-4 - 1.65x10-2, 0.00 - 1.64x10-2 and 5.76x10-5 - 1.65x10-2 respectively. The study showed that the three aquatic ecosystems are healthy but require regular monitoring to promptly detect sudden changes in their health status.

Findings: The three aquatic ecosystems are healthy but they require regular monitoring to promptly detect sudden changes in their health status.

Keywords: Ecosystem health, ecotoxicology, health risk, physico-chemistry, condition factor

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1.0 INTRODUCTION

Nigeria has maintained a reasonable level of industrialization despite the unfavourable conditions prevalent in the country. About 60% of the populace are without electricity (Aliyu *et al.,* 2015), the transport system is poor and the roads are in deplorable conditions. This minimal industrial growth is propelled by government's policy to diversify the country's mono-economy which depends largely on crude oil. The result is increase in agricultural and industrial activities in the country. This industrial growth is not widespread but is concentrated in some cities in the country like Abia, Anambra, Kano, Ogun and Lagos states (Oyelaran-Oyeyinka, 1997). Until recently, Lagos state accounts for about 60% of industrial activities in Nigeria. However, the neighbouring Ogun state is the emerging industrial hub in the country and has equaled or even surpassed industrial activities in Lagos state. The wastes generated by these companies are a major concern for ecologists and environmentalists because of inappropriate waste disposal mechanisms. In most cases, the wastes are emptied into natural water bodies without treatment, and this could endanger the lives of man and aquatic organisms that live in these aquatic ecosystems and depend on them for sustenance. The implication of this is that the ecosystem services provided by these water bodies are threatened and can actually be lost. One of the main components of industrial effluent is heavy metal.

Heavy metals are elements that occur naturally at different concentrations in all ecosystems (Ndimele and Kunolu-Johnson, 2012). They occur in both elemental forms and as components of chemical compounds. Volatile heavy metals and those that adsorb to particles can be transported widely across food chains and ecosystems. Heavy metals can have dietary role in which case they are important in enzymatic and biological processes in animals at low concentration but becomes toxic at high concentration (Kumolu-Johnson *et al.,* 2010). Examples are Cu, Co, Zn, Fe and Mn. The non-dietary heavy metals play no known function in biological systems and are toxic even at low concentration. Metals in this category are Hg, As, Cd and Pb. The toxicity of metal is influenced by its chemical form (Ndimele *et al*., 2009). For instance, elemental (inorganic) mercury is not as toxic as the organic forms. The methylation of mercury makes it fat-soluble and in this form, it is able to penetrate biological systems, consequently becoming more toxic and harmful. Heavy metals are non-biodegradable substances and as such persist in different compartments (water, sediment and biota) of the aquatic ecosystem causing various ailments like congenital malformation (Iavicoli *et al*., 2009), low intelligent quotient in children (Ndimele *et al*., 2009), cancer (Yoshida *et al*., 2004) and genetic alteration (Asano *et al*., 2000). Therefore, heavy metals are major threat to the integrity or health of aquatic ecosystems.

Since the emergence of the concept of ecosystem health in the 1980s, various attempts have been made to define and quantify it. Definition of the concept has not been particularly easy because of the dynamic nature of aquatic ecosystems. However, there is a consensus opinion on what a healthy ecosystem should be (Palmer and Febria, 2012). Ecosystem health assessment methods have also varied and in most cases depended on research objectives, available resources and the discipline of the authors, with the last factor being the most influential of the three. Ecosystem health can be measured using physical, chemical or biological indices either singly or in combination (O'Brien *et al*., 2016). Examples of physical and chemical indices of ecosystem integrity are flow and channel morphology/dimension (in freshwater studies only), physico-chemistry and nutrient status (estuarine and freshwater studies), while biological indices used are species abundance, biodiversity and tolerance (Vilmi *et al*., 2016). Ecosystem health can also be measured by the ability of the ecosystem to maintain its structure and function (respiration, primary productivity, metabolism and decomposition) in the face of external stressors (O'Brien *et al*., 2016). Still, others view ecosystem health as the capacity of the ecosystem to provide services (nutrient recycling, drinking water, supply of food, etc) to humans (Keeler *et al*., 2012).

In recent times, there has been increased pressure on maintaining aquatic ecosystem health by adopting sustainable exploitation approaches because of the enormous roles played by water bodies to sustain human lives. This renewed interest stem from the fact that over 50% of the global population live within three kilometers of freshwater ecosystems (Kummu *et al*., 2012) and most of the mega cities in the world are situated on estuaries (Johnston *et al*., 2015). However, in Sub-Saharan Africa, very few studies have been conducted to measure ecosystem health (O'Brien *et al*., 2016). The present study is an attempt to bridge this gap by using multiple indices to determine the health status of Lagos Lagoon complex, which receives effluents from industries located in Lagos State, Nigeria.

2.0 MATERIALS AND METHODS

2.1 Study Area:

In order to assess the ecosystem health of part of Lagos Lagoon complex, three sites were selected based on proximity to industrial site, presence of the test organism (*Coptodon zillii*), domestic and fishing activities. The three sites are Ologe Lagoon, Badagry Creek and River Owo (Figure 1). Ologe Lagoon is a freshwater body with surface area of 64.5 km^2. It lies between latitudes 6° 27′N and 6° 30′N; and longitudes 3° 02′E and 3° 07′E (Ndimele and Kumolu-Johnson, 2011). Badagry Creek lies between latitudes 6° 22′N and 6° 42′N; and longitudes 2° 42′E and 3° 42′E (Ndimele, 2012). River Owo is a stream located in South-west, Nigeria. Its estimated elevation above sea level is 6.0 m and its coordinates are: latitude 6° 12′ N and 6° 33′ N and longitude 3° 12′ E and 3° 48′ E (Ndimele *et al*, 2017).

2.2 Methodology

2.2.1 Physico-chemistry: Water sampling was carried out once every month for twelve months (January to December, 2018) at the sampling sites. The water samples were collected in 1.5 litre plastic bottles previously cleaned by soaking in nitric acid solution. Samples were stored immediately after collection in a cooler to ensure that the physical properties of the water samples were maintained. Temperature, pH, conductivity, salinity, turbidity and dissolved oxygen of samples were measured *in-situ* using a mercury-in-glass thermometer, digital pH meter (model:

Hanna HI98107), HACH-HQ40D portable multi-meter, turbidity meter (HACH 2100Q) and portable dissolved oxygen meter (HI9146) respectively. Ammonia, total suspended solids (TSS), total dissolved solid (TDS), total solid (TS), total alkalinity, biochemical oxygen demand (BOD), carbon dioxide, and chlorophyll were determined in the laboratory using methods described by American Public Health Association (APHA, 1985).

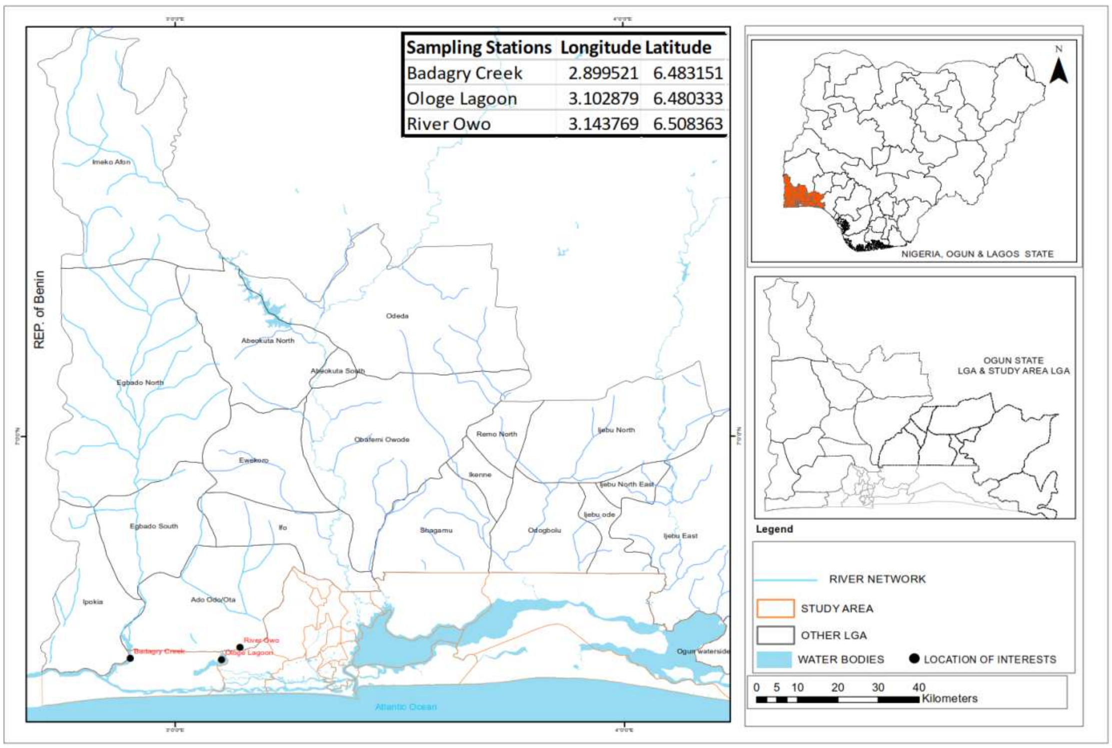

Figure 1: Map of study area showing sampling sites (River Owo, Ologe Lagoon and Badagry Creek)

2.2.2 Length-weight analysis and condition factor

A total of 1,367 fish samples (Badagry Creek = 536; River Owo = 277; Ologe Lagoon = 554) belonging to 15 families (claroteidae, cichlidae, clupeidae. haemulidae, cynoglossidae, mugilidae, lutjanidae, carangidae, clariidae, uranoscopidae, channidae, anabantidae, gymnarchidae, mormyridae, gobiidae) were collected randomly from the three study sites from January – December, 2018. Artisanal fishermen from villages around the study sites deploy surface and bottom-set gillnets, cast-nets, drift-nets and beach-seines for their catches. Fish samples were immediately preserved in 10% formalin and taken to the laboratory for identification using the keys provided by Schneider (1992) and Leveque *et al*. (1990). The total weight (g) of each fish was measured on a top loading Metler balance after bolt drying while the total body lengths (TL) were measured to the nearest centimeter (cm) with a ruler. Parameters of the length-weight relationship of identified fish species were estimated using the equation:

$W = aL^b$ (Rickter, 1973) (1)

Where W = weight (g), L = length (cm), a (y-intercept) = the initial growth coefficient, and b (slope) = the growth coefficient.

The values of constants a and b were estimated after logarithmic transformation of Eq. (1) using least square linear regression (Zar, 1984) to give:

$\log W = \log a + b \log L$ (2)

Before the regression analysis of log W on log L, log–log plots of length and weight values were performed for visual inspection of outliers (Froese, 2006). Extreme outliers which could be attributed to data error were not used for the analyses. The 95% confidence interval (CI) of b was calculated using the equation:

$CI = b \pm (1.96 \times SE)$ (3)

Where SE is the standard error of b.

In order to confirm whether b values obtained in the linear regressions were significantly different from the isometric value of ±95% CI of b at $\alpha = 0.05$, t-test was applied as expressed by the equation according to Sokal and Rohlf (1987):

$t_s = (b-3) / SE$ (4)

where t_s is the t-test value, b = slope and SE = the standard error of the slope (b).

All the statistical analyses were considered at significance level of 5% ($p<0.05$). The condition factor was computed by the formula:

Condition Factor $(K) = 100W/ L^3$ (Pauly, 1983) (5)

2.2.3 Heavy Metal Analyses

2.2.3.1 Collections of samples: Water samples were collected in 0.5L plastic bottles. After collection, samples were properly covered and were refrigerated at 4º C to inactivate microbes and thus preserve the integrity of the samples in the Ecotoxicology and Ecosystem Modelling laboratory, Department of Fisheries, Faculty of Science, Lagos State University, Ojo, Lagos State, Nigeria. Immediately after collection, 5 ml nitric acid (Analar grade, Merck, Darmstadt, Germany) was added to the water samples to minimize metal adsorption onto the inner sides of the sample bottles (APHA 1985).

Grab samples of sediment were collected with a 2-inch diameter steel pipe pressed through the water column to obtain a sediment core of 60 cm below the water surface (Ali and Fishar, 2005). The sediment was emptied into polythene bags previously treated with 10% nitric acid (Analar grade, Merck, Darmstadt, Germany) and sealed (Ndimele *et al,* 2017). About three to five composite samples were collected from each station on each day of sampling. All samples were stored in a deep freezer at -10ºC. *Coptodon zillii* were caught monthly from each site with fishing gears like gill net, cast net and hook and identified using the identification key by Schneider, 1992 and Leveque *et al*. (1990). The total lengths and body weights of the fish were determined using meter rule and digital scale (OHAUS Scout pro, USA) respectively. The fish were preserved immediately after capture in a refrigerator (-10ºC). The mean weight of the fish was 234.48±42.11 g to the nearest 0.1 g while the mean total length was 15.19±4.08 cm to the nearest millimeter. About 4 - 5 *C. zillii* were collected from each site on the sampling days, giving a total of 48 – 60 fish samples obtained from each sampling site. Triplicate samples of water, sediment, and *C. zillii* were collected from each sampling station on every sampling day.

2.2.3.2 Sample treatment

Sample treatment

Frozen samples of sediment, water, and fish (*Coptodon zillii*) were allowed to melt at room temperature (~27 °C). There was no further treatment on water samples but they were mixed vigorously before aspiration into the flames of an atomic absorption spectrophotometer. Sediment samples were oven-dried to constant weight at 105±20°C, and sieved through a 2 mm mesh screen to remove plant materials, stones, and other unwanted particles (Varol, 2011). In order to obtain fine sediment particles used for analyses, the sediment samples were grinded in an agate mortar and passed through a 500-µm stainless steel sieve after which they were stored in pre-washed glass bottles (Oliva *et al*. 2012). The level of heavy metal in sediment was determined by digesting 0.25 g sediment in a Teflon vessel with 12 ml HNO_3 (65% Suprapur, Merck, Darmstadt, Germany)/HCl (37% Suprapur, Merck, Darmstadt, Germany) in the ratio 3:1. A microwave oven (MARSX-Press, CEM) (USEPA, 2007) was used for the digestion. The digested samples were filtered, adjusted to appropriate volumes with Milli-Q deionized water (Millipore, USA), and stored until heavy metal analysis. The fish samples were digested by drying them at 105±5°C and pulverizing in a mortar. The powdered fish sample (0.5 g) was added to a mixture of 6 ml HNO_3 (65% Suprapur, Merck, Darmstadt, Germany) and 2 ml H_2O_2 (30% Suprapur grade, Merck, Darmstadt, Germany) (Sary and Mohammadi, 2012). High-performance microwave (MLS-1200 MEGA, MLS GmbH, Germany) was used for the digestion of the fish samples. The conditions of the microwave were set according to the description in Mendil *et al*. (2005): 2 min at 250 W, 2 min at 0W, 6 min at 250W, 5 min at 400W, and 8 min at 550W and then vented for 8 min. The samples were allowed to cool after which, they were transferred to 20 ml volumetric flasks, made up to the mark with distilled water and stored until metal analysis. The concentrations of metals in procedural blanks were negligible.

2.2.3.3 Heavy Metal Determination: Six metals (zinc, lead, copper, iron, arsenic, and cadmium) were analysed in water, sediment and fish. The samples were filtered with a nitrocellulose membrane filter (0.45 µm) before analysis. In the laboratory, sample blanks were prepared in the same way as the field samples (Maceda-Veiga *et al*., 2012; Türkmen *et al*., 2009). The samples were analysed three times for the six heavy metals by Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES) Varian Liberty Series II (operating conditions: RF power, 1000W; plasma gas flow, 12L/min; torch configuration, radial; nebulizer, V-groove; spray chamber, double-pass cylindrical; detector, photomultiplier). Standard solutions were prepared by diluting stock solutions (Merck, multi-element standard) and the latter were used for system calibration and control of analytical accuracy. All samples were run in batches composed of two spiked samples, a standard calibration curve, one duplicate and blanks (Türkmen *et al.*, 2008). Method accuracy and precision were validated by analyzing (n=6) dogfish muscle (DORM-2, National Research Council, Canada) as a certified reference material. The recovery rate (% mean recovery±S.E.) was also analyzed (n=6) (Zrnčić *et al.*, 2013). The correlation between the analytical and certified values was strong. The recovery was 97.2±2.3% for Cu, 96.5±3.8% for Fe, 97.6±3.6% for Pb, 98.6±2.8% for Ar, 97.4±3.3% for Cd and 97.8±3.5% for Zn. The analytical procedure had good precision, which was calculated as the relative standard deviation (RSD) and the values obtained ranged from 6 and 9%. 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. Metal contents were expressed as mg/kg dry weight.

2.2.4 *Fish Diversity Indices*

The fish assemblage structure was estimated for each site and it included: Simpson's dominance index (D), Simpson index of diversity (1-D), Simpson's reciprocal index (1/D), Shannon diversity index (H'), evenness index (E^1), Brillouin (HB), Menhinick's Index of Species Abundance, Margalef's index of species richness (S), equitability (J), fisher alpha and Berger-parker (d).

Simpson's dominance index is based on this formula:

$$\text{Simpson's dominance index (D)} = \sum_{i=1}^{S} \frac{n_i(n_i-1)}{N(N-1)} \quad \text{(Simpson, 1949)} \qquad (6)$$

Where n_i = the number of individuals in the ith species;

N = the total number of individuals

S = the total number of species

Simpson's indices of diversity (1-D) and reciprocal (1/D) are obtained from Simpson's dominance index by subtracting dominance index from 1 and dividing 1 by dominance index respectively.

$$\text{Therefore, Simpson's index of diversity} = 1 - D \qquad (7)$$

$$\text{Simpson's reciprocal index} = 1/D \qquad (8)$$

Shannon's diversity index is based on the equation below:

$$\text{Shannon's diversity index } (H^1) = -\sum_{i=1}^{S} P_i . \text{Loge}P_i \quad \text{(Shannon and Wiener, 1949)} \qquad (9)$$

Where $P_i = n_i/N$

Evenness index (E) = $\frac{H^1}{\text{LogeS}}$ (Pielou, 1966) (10)

Brillouin's index (H) is defined as:

$$H = \frac{1}{n}\log\frac{n!}{\prod_{i=1}^{k} n_i\,!} = \frac{\log n! - \sum_{i=1}^{k}\log n_i!}{n} \quad (11)$$

where n_i is the number of observations from the sample in the i^{th} of k (non-empty) categories and n is the sample size.

Fish species richness in the sites was evaluated using two indices; menhinick's and margalef's indices.

Menhinick's Index of Species Abundance = S/√N (12)

Margalef's Index of Species Abundance = S – 1/ LogeN (13)

Where S is the total number of species and N is the total number of individuals.

Fisher's alpha is a diversity index, defined implicitly by the formula:

S = a*Loge(1+ n/a) (14)

where S is number of species, n is number of individuals and a is the Fisher's alpha.

The Berger–Parker index equals the maximum p_i value in the dataset or sampling station, i.e. the proportional abundance of the most abundant species.

Where $p_i = n_i/N$ as has been earlier expressed.

2.2.5 *Sediment pollution indices*

2.2.5.1 Enrichment factor: Enrichment Factor (EF) was calculated following the method of Adaikpoh (2013). The EF normalizes the level of the measured potentially harmful elements with respect to a reference metal such as Fe, Al or Zn (Mediolla *et al*, 2008). In this study, Fe was used as the reference metal or normalizer because of its abundance in Nigerian soils and natural sources (98%) vastly dominate its input (Ndimele and Kumolu-Johnson, 2012; Nasir and Harikumar, 2011). The crustal abundance data of Bowen (1979) were used for all EF values.

The EF of heavy metal in sediment was calculated as:

$$EF = C_{metal}/C_{normalizer}\ (sediment)\ /\ C_{metal}/C_{normalizer}\ (earth's\ crust) \quad (15)$$

where C_{metal} and $C_{normalizer}$ are concentrations of heavy metal and normalizer (Fe) in the sediment and in the earth's crust. The EF value is used to distinguish the magnitude of contamination resulting from either the natural or anthropogenic influence (Nasir and Harikumar, 2011).

2.2.5.2 Geoaccumulation index (Igeo): Igeo was calculated for different metals according to the formula introduced by Muller (1969):

$$Igeo = Log_2(C_n/1.5*B_n) \quad (16)$$

where C_n is the measured concentration of the metals in the sediment samples and B_n is the geochemical background concentrations in soils derived from rocks of average shale composition (Muller, 1969). The factor 1.5 was introduced to minimise the possible variation of the background values attributable to lithological variations.

2.2.5.3 Contamination factor: The Contamination Factor (CF) was calculated according to Hakanson (1980):

$$CF = C_m\ (sample)/C_m\ (background) \quad (17)$$

where, C_m (sample) is the concentration of metals in the sediments of the sampling sites and C_m (background) is the concentration of metals in a control or background sediment sample. The CF is defined according to 4 categories: Low contamination ($CF<1$), moderate contamination ($1\leq CF<3$), considerable contamination ($3\leq CF<6$), and very high contamination ($CF>6$) (Wang *et al*, 2006).

2.2.5.4 Pollution load index (PLI) is given by the equation;

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n} \quad \text{(Tomlinson } et\ al\text{, 1980)} \quad (18)$$

where CF is the contamination factor, n is the number of metals studied.

2.2.5.5 The modified degree of contamination (*mCd*) is a generalized form of the Håkanson (1980) equation proposed by Abrahim (2005) for the calculation of the combined contaminations of a given study site:

$$mCd = \frac{\sum_{i=1}^{n} CF_i}{n} \quad (19)$$

The following classification of modified degree of contamination in sediments has been proposed: very low contamination ($mCd < 1.5$); low degree of contamination ($1.5 \leq mCd < 2$); moderate degree of contamination ($2 \leq mCd < 4$); high degree of contamination ($4 \leq mCd < 8$); very high degree of contamination ($8 \leq mCd < 16$); extremely high degree of contamination ($16 \leq mCd < 32$) and ultra high degree of contamination ($mCd \geq 32$).

2.2.6 *Ecotoxicology of heavy metals in sediment and potential ecological risks*

Two sets of standard quality guidelines (SQGs) developed for aquatic environments were applied in this study to evaluate the ecotoxicological potentials of heavy metals in sediments. The SQGs are the effect range-low (ERL)/effect range-median (ERM); and the threshold effect level (TEL)/probable effect level (PEL) values (MacDonald *et al*, 2000; Long and MacDonald, 1998). The low range values (ERLs/TELs) are concentrations below which adverse effects on animals living in sediment would infrequently be observed. In contrast, the ERMs and PELs are concentrations above which adverse effects are likely to occur (Long and MacDonald, 1998). The comparison method used in this study is the mean quotients (m-PEL-Q, m-ERM-Q) calculated from PEL and ERM values according to Long *et al* (1995) as follows:

$$\text{m-PEL-Q} = \left(\sum_{i=1}^{n} \frac{C_i}{PEL_i}\right)/n \quad (20)$$

$$\text{m-ERM-Q} = \left(\sum_{i=1}^{n} \frac{C_i}{ERM_i}\right)/n \quad (21)$$

The potential ecological risk posed by the metals was assessed by the method described by Håkanson (1980). The formulae are:

$$R_I = \sum E_r^i \quad (22)$$

$$E_r^i = T_r^i C_f^i \quad (23)$$

$$C_f^i = C_0^i / C_n^i \quad (24)$$

where R_I is the sum of all risk factors for all metals in sediments, E^i_r is the monomial potential ecological risk factor, T^i_r is the toxic-response factor for a given metal/substance, C^i_r is the contamination factor, C^i_0 is the concentration of metals in the sediment samples, and C^i_n is a reference/background value for metals.

2.2.7 *Health risk assessment of heavy metals*

The assessment of the risks associated with the consumption of a fish (*Coptodon zillii*) from the sampling stations was done with two indices; estimated dietary intake (EDI) and target hazard quotients (THQ). The daily intake of contaminant depends on factors like the concentration of the contaminant in food, rate of food consumption and body weight of the food consumer (Zhao *et al*, 2012; Wang *et al*, 2005).

$$\text{EDI} = C_{metal}\ x\ DNI\ x\ C_f / B_w \quad (25)$$

where C_{metal} is the concentration (mg kg^{-1}) of the heavy metals in the muscle tissue of *C. zillii*, DNI is the daily nutritional intake in (g day^{-1}), and C_f is the factor for conversion of fresh fish tissues to dry constant weight. The average moisture content in *C. zillii* was 70.56% and the C_f (0.2944) was calculated using the equation reported by Abubakar *et al* (2015). The average body weight for adults in Nigeria is 70 kg. The daily nutritional intake of *C. zillii* was evaluated by adopting the ingestion rate for Nigeria based on 2011 estimate by FAO. The DNI for adults is 62.60 g $capita^{-1}$ day^{-1} (FAO, 2015).

Chen *et al* (2002) model for estimating target hazard quotient was used in this study:

$$THQ = \frac{\text{EFr x EDtot x FIR x C x } 10^{-3}}{RfDo\ x\ Bw\ x\ ATn} \quad (26)$$

where THQ is the target hazard quotient; EFr is exposure frequency (365 days/year); EDtot is the exposure duration (55.2 years, average lifetime of Nigerians); FIR is the food ingestion rate (g/day); C is the heavy metal concentration in fish (mg/g); RfDo is the oral reference dose (mg/kg/day); Bw is the average adult body weight of Nigerians (60.75 kg); and ATn is the average exposure time for non-carcinogens (365 days/year x number of exposure years, assuming 55.2 years).

Hallenbeck (1993) reported that multiple exposure to pollutants can results in additive and/or interactive effects. In this study, the total THQ is calculated as the arithmetic sum of the individual metal THQ values:

$$\text{Total THQ} = \text{THQ (toxicant 1)} + \text{THQ (toxicant 2)} + \ldots + \text{THQ (toxicant n)} \quad (27)$$

2.5 Statistical Analysis: One way analysis of variance (ANOVA) was used to assess significant differences among the sampling stations. The comparison of mean using the Least Significant difference (LSD) test was calculated for p-values. A value of ($p<0.05$) was considered significant.

3.0 RESULTS

3.1 Physicochemical analysis of water samples

The summary of data on the physicochemical parameters of water in the sampling stations is presented in table 1. There were no significant difference ($p>0.05$) in the temperature, salinity, total suspended solids (TSS), dissolved oxygen (DO), and chlorophyll-a among the sampling stations. However, pH, turbidity, conductivity, total dissolved solids (TDS), total solids (TS), biochemical oxygen demand (BOD), carbon dioxide, total alkalinity and ammonia (NH_3) varied significantly ($p<0.05$) among the sampling stations. The highest values in turbidity (18.90±3.3 NTU), conductivity (512.85±233.41 µS/cm), total dissolved solids (298.70±124.78 mg/L), total solids (338.47±122.84 mg/L), biochemical oxygen demand (29.50±9.89 mg/L) and ammonia (0.18±0.03 mg/L) were recorded in Badagry Creek while the lowest values in these parameters {turbidity (10.54±1.44 NTU), conductivity (133.22±10.80 µS/cm), total dissolved solids (72.25±5.84 mg/L), total solids (93.33±5.56 mg/L), biochemical oxygen demand (7.35±1.18 mg/L) and ammonia (0.04±0.01 mg/L)} were recorded in River Owo. River Owo had the highest values in carbon dioxide (81.67±16.64 mg/L) and total alkalinity (80.38±5.95 mg/L) but their lowest values were obtained in Ologe Lagoon (56.85±5.91 mg/L) and Badagry Creek (48.12±3.55

mg/L) respectively. The highest value for pH (6.48±0.18) was recorded in Ologe Lagoon and the lowest value (5.43±0.48) in Badagry Creek.

PARAMETERS	Badagry Creek	River Owo	Ologe Lagoon	WHO Standard
Temperature (°C)	25.78±0.16[a]	25.85±0.11[a]	25.77±0.19[a]	<40
pH	5.43±0.48[a]	6.38±0.25[a]	6.48±0.18[b]	5.5 – 9.0
Turbidity (NTU)	18.90±3.3[a]	10.54±1.44[b]	15.92±1.70[a]	5.0
Salinity (ppt)	0.29±0.12[a]	0.10±0.01[a]	0.23±0.04[a]	NS
Conductivity (µS/cm)	512.85±233.41[a]	133.22±10.80[b]	377.78±83.03[ab]	250
TDS (mg/l)	298.70±124.78[a]	72.25±5.84[c]	210.52±45.32[b]	2100
TSS (mg/l)	40.62±12.44[a]	21.10±4.20[a]	39.57±5.745[a]	100
Total Solids (mg/l)	338.47±122.84[a]	93.33±5.56[b]	246.92±48.44[a]	2200
Dissolved oxygen (mg/l)	4.52±0.38[a]	4.78±0.13[a]	4.57±0.34[a]	>2.0
BOD (mg/l)	29.50±9.89[a]	7.35±1.18[b]	26.00±14.05[a]	50
Carbon dioxide (mg/l)	57.17±36.30[a]	81.67±16.64[b]	56.85±5.91[a]	-
Total alkalinity (mg/l)	48.12±3.55[a]	80.38±5.95[b]	56.85±5.91[a]	120
Ammonia (mg/l)	0.18±0.03[a]	0.04±0.01[b]	0.15±0.04[a]	-
Chlorophyll-a (µ/L)	7.60±0.41[a]	7.08±0.41[a]	8.83±0.87[a]	NS

Table 1: Physicochemical parameters of water in the sampling stations

BOD = biochemical oxygen demand; TDS = total dissolved solids; TSS = total suspended solids

Values in the same row and with the same superscript are not significantly ($p>0.05$) different. All values are expressed as mean±S.E

Table 2: Length-weighted regression analysis of fish species in Badagry Creek, River Owo and Ologe Lagoon

Source	Fish species	N	a	b	K	95% CI for b	r	Growth Pattern
Badagry Creek	*Chrysichthys nigrodigitatus*	96	0.015	2.901	0.87	2.751 – 3.051	0.96	-
	Coptodon zillii	58	0.019	3.081	4.51	2.867 – 3.295	0.92	1
	Sardinella maderensis	21	0.024	2.716	1.62	2.381 – 3.051	0.95	-
	Pellonula leonensis	15	0.004	3.183	1.73	3.164 – 3.202	0.96	+
	Pomadasys jubelini	22	0.018	2.875	1.21	2.652 – 3.098	0.97	-
	Sarotherodon melanotheron	18	0.023	2.776	2.18	2.522 – 3.030	0.98	-
	Cynoglossus senegalensis	46	0.006	2.815	0.94	2.806 – 2.824	0.95	-
	Mugil cephalus	41	0.008	3.042	0.84	3.033 – 3.052	0.96	1
	Lutjanus agennes	19	0.007	3.058	3.24	2.553 – 3.563	0.93	1
	Caranx hippos	18	0.027	2.844	2.12	2.664 – 3.024	0.96	-
	Ethmalosa fimbriata	72	0.008	3.088	1.14	3.083- 3.093	0.95	1
	Clarias gariepinus	29	0.016	2.901	0.92	2.488 – 3.314	0.98	-
	Uranoscopus polli	81	0.018	2.914	3.13	2.704 – 3.124	0.97	-
River Owo	*Chrysichthys nigrodigitatus*	33	0.018	2.941	2.62	2.932 – 2.950	0.85	-
	Coptodon zillii	43	0.022	2.824	4.43	2.644 – 3.004	0.92	-
	Sarotherodon melanotheron	31	0.028	2.813	4.18	2.623 – 3.003	0.88	-
	Oreochromis niloticus	60	0.018	2.941	3.92	2.916 – 2.966	0.80	-
	Parachanna obscura	24	-1.893	2.905	2.13	2.885 – 2.925	0.81	-
	Ctenopoma petherici	27	0.036	2.855	2.08	2.735 – 2.975	0.79	-
	Clarias gariepinus	38	0.014	2.993	1.26	2.843 – 3.143	0.94	1
	Gymnarchus niloticus	21	-0.950	2.348	1.12	2.168 – 2.528	0.76	-
Ologe Lagoon	*Chrysichthys nigrodigitatus*	78	0.013	2.962	2.11	2.955 – 2.969	0.95	-
	Coptodon zillii	52	0.024	2.716	3.52	2.704 – 2.728	0.81	-
	Sardinella maderensis	41	0.030	2.543	3.95	2.403 – 2.728	0.87	-
	Cynothrissa mento	48	0.023	2.478	6.26	2.438 – 2.518	0.80	-
	Hyperopisus bebe	65	0.021	2.684	2.61	2.679 – 2.689	0.75	-
	Sarotherodon melanotheron	45	0.032	2.605	2.32	2.575 – 2.635	0.80	-
	Oreochromis niloticus	75	0.021	2.812	2.78	2.803 – 2.821	0.85	-
	Mugil cephalus	24	0.017	2.868	2.63	2.843 – 2.893	0.92	-
	Bathygobius soporator	20	0.020	2.651	4.86	2.636 – 2.666	0.83	-
	Liza falcipinnis	86	0.018	2.996	1.54	2.980 – 3.012	0.96	I
	Ethmalosa fimbriata	20	0.034	2.835	2.12	2.817 – 2.853	0.87	-

* N = number of specimen, *a* = intercept of regression line, *b* = slope of regression line, K = condition factor; r = correlation coefficient, - = negative allometric; + = positive allometric; I = isometric.

3.2 Length-weight relationship and condition factor

A total of 1,367 individuals belonging to 21 genera were analysed in this study. In Badagry Creek, 13 genera were encountered while River Owo and Ologe Lagoon recorded 8 and 11 genera respectively. Three species were common to the 3 sampling stations; *Chrysichthys nigrodigitatus, Coptodon zillii* and *Sarotherodon melanotheron*. The species, number of specimens, length-weight relationship parameters a and b, condition factor (K), 95% confidence interval for b, correlation coefficient (r), and growth type (allometric or isometric) are presented in Table 2. The sample size varies from 18 (*Sarotherodon melanotheron, Caranx hippos*) to 96 (*Chrysichthys nigrodigitatus*) in Badagry Creek, 21 (*Gymnarchus niloticus*) to 60 (*Oreochromis niloticus*) in River Owo and 24 (*Mugil cephalus*) to 86 (*Liza falcipinnis*) in Ologe Lagoon. The value of b ranges from 2.716 (*Sardinella maderensis*) to 3.183 (*Pellonula leonensis*), 2.813 (*Sarotherodon melanotheron*) to 2.993 (*Clarias gariepinus*) and 2.478 (*Cynothrissa mento*) to 2.996 (*Liza falcipinnis*) in Badagry Creek, River Owo and Ologe Lagoon respectively. The correlation coefficient (r) varies from 0.92 (*Coptodon zillii*) to 0.98 (*Sarotherodon melanotheron, Clarias gariepinus*) in Badagry Creek, 0.76 (*Gymnarchus niloticus*) to 0.94 (*Clarias gariepinus*) in River Owo and 0.75 (*Hyperopisus bebe*) to 0.96 (*Liza falcipinnis*) in Ologe Lagoon. Most of the growth pattern in River Owo and Ologe Lagoon were negatively allometric except *Clarias gariepinus* that had isometric growth in River Owo and *Liza falcipinnis* that also had isometric growth in Ologe Lagoon. All the growth patterns were represented in Badagry Creek but most of them were negatively allometric as it occurred in the other two sampling stations. Only *Pellonula leonensis* had positive allometric growth while *Coptodon zillii*, *Mugil cephalus*, *Lutjanus agennes* and *Ethmalosa fimbriata* recorded isometric growth type. In Badagry Creek, the condition factor varied from 0.84 in *M. cephalus* to 4.51 in *C. zillii*. *Coptodon zillii* also had the highest condition factor (4.43) in River Owo but the lowest (1.12) was recorded in *G. niloticus*. The lowest (1.54) and highest (4.86) condition factor values in Ologe Lagoon were recorded in *L. falcinnis* and *B. soporator* respectively.

3.3 Ecological indices of the sampling stations

The ecological indices of the three sampling stations are presented in Table 3. Badagry Creek and Ologe Lagoon had the same Simpson's dominance index (D) (0.11) and Simpson's index of diversity (0.89), which is lower than the values recorded in River Owo (Simpson's dominance index = 0.14; Simpson's index of diversity = 0.86). About 5 diversity indices followed the same trend; the lowest values (Simpson's reciprocal index = 7.18, Shannon's diversity index = 2.03, Brillouin = 1.96, Margalef's index of species abundance = 1.25 and Fisher Alpha = 1.54) were obtained in River Owo while the highest values (Simpson's reciprocal index = 9.23, Shannon's diversity index = 2.37, Brillouin = 2.32, Margalef's index of species abundance = 1.91 and Fisher Alpha = 2.40) occurred in Badagry Creek. Two parameters followed the exact opposite trend of the five previous variables. The lowest values (evenness = 0.83, equitability = 0.93) were recorded in Badagry Creek while the highest values (evenness = 0.95, equitability = 0.97) were found in River Owo. The lowest values for Menhinick's index of species richness (0.47) and Berger-Parker

(0.16) occurred in Ologe Lagoon while the highest value of the former was found in Badagry Creek (0.56) and the latter in River Owo (0.22).

Table 3: Diversity Indices of fish species from Badagry Creek, River Owo and Ologe Lagoon

Diversity Indices	Badagry Creek	River Owo	Ologe Lagoon
Simpson's Dominance Index (D)	0.11	0.14	0.11
Simpson's Index of Diversity (1-D)	0.89	0.86	0.89
Simpson's Reciprocal Index (1/D)	9.23	7.18	9.18
Shannon's Diversity Index (H^1)	2.37	2.03	2.29
Evenness (E^1)	0.83	0.95	0.90
Brillouin (H)	2.32	1.96	2.25
Menhinick's Index of Species Abundance	0.56	0.48	0.47
Margalef's Index of Species Abundance	1.91	1.25	1.58
Equitability (J)	0.93	0.97	0.96
Fisher's Alpha (a)	2.40	1.54	1.95
Berger-Parker (d)	0.18	0.22	0.16

3.4 Sediment pollution indices

The enrichment factors of the heavy metals in sediment of the sampling stations vary from $4.05x10^{-4}$ in Cu from River Owo to $8.65x10^{-1}$ in Cd from Ologe Lagoon (Table 4). The geoaccumulation index (Igeo) of heavy metals in sediments of the sampling sites ranged from -12.14 to -0.38 (Table 4). Contamination factor (CF), pollution load index (PLI) and modified degree of contamination (mCd) of metals in sediments of the 3 sampling stations are also shown in Table 4. The contamination factors of Fe and Cd were higher than the other metals. The CF of Fe ranged from 0.36 in Ologe Lagoon to 1.15 in River Owo and 0.20 in River Owo to 0.38 in Badagry Creek for Cd. For the other metals, the value varied from $3.33x10^{-4}$ to $7.37x10^{-3}$. The PLI was lowest ($6.97x10^{-3}$) in Ologe Lagoon and highest ($1.28x10^{-2}$) in River Owo. The modified degree of contamination followed the same trend as PLI; the lowest (0.11) and highest (0.23) were recorded in Ologe Lagoon and River Owo respectively.

Table 4: Enrichment Factor, Geoaccumulation indices (Igeo), Contamination factor, pollution load index and modified degree of contamination of metals in sediments of Badagry Creek, River Owo and Ologe Lagoon

Sampling Station		Heavy metal						PLI	mCd
		Zn	Pb	Cu	Fe	As	Cd		
Badagry Creek	EF	8.25×10^{-4}	1.07×10^{-2}	1.02×10^{-3}	-	1.31×10^{-3}	6.54×10^{-1}		
	Igeo	-11.6	-7.9	-11.29	-1.36	-10.93	-1.97		
	CF	4.83×10^{-4}	6.28×10^{-3}	6.00×10^{-4}	0.59	7.69×10^{-4}	0.38	8.25×10^{-3}	0.16
River Owo	EF	4.46×10^{-3}	6.39×10^{-3}	4.05×10^{-4}	-	9.34×10^{-4}	1.71×10^{-1}		
	Igeo	-8.19	-7.67	-11.65	-0.38	-10.44	-2.93		
	CF	5.14×10^{-3}	7.37×10^{-3}	4.67×10^{-4}	1.15	1.08×10^{-3}	0.20	1.28×10^{-2}	0.23
Ologe Lagoon	EF	3.28×10^{-3}	1.02×10^{-2}	9.20×10^{-4}	-	1.91×10^{-3}	8.65×10^{-1}		
	Igeo	-10.3	-8.67	-12.14	-2.05	-11.08	-2.26		
	CF	1.19×10^{-3}	3.69×10^{-3}	3.33×10^{-4}	0.36	6.92×10^{-4}	0.31	6.97×10^{-3}	0.11

EF = Enrichment factor; Igeo = Geoaccumulation index; CF = Contamination factor; PLI = Pollution load index; mCd = Modified degree of contamination

Table 5: Mean quotients using the PEL and ERM values and heavy metal potential ecological risk indices for Badagry Creek, River Owo and Ologe Lagoon

	Badagry Creek (E^1_r)	River Owo (E^1_r)	Ologe Lagoon (E^1_r)
Zn	5.75×10^{-4}	6.11×10^{-3}	1.41×10^{-3}
Pb	2.52×10^{-2}	2.96×10^{-2}	1.48×10^{-2}
Cu	4.50×10^{-3}	3.50×10^{-3}	2.50×10^{-3}
As	6.67×10^{-3}	9.33×10^{-3}	6.00×10^{-3}
Cd	6.90	3.54	5.64
R_1	6.94	3.59	5.66
m-PEL-Q	4.77×10^{-4}	7.87×10^{-4}	3.91×10^{-4}
m-ERM-Q	2.49×10^{-4}	4.62×10^{-4}	2.11×10^{-4}

m-PEL-Q = Mean quotient using probable effect level; m-ERM-Q = Mean quotient using effect range-median

3.5 Ecotoxicological assessment of heavy metal concentration in sediments

The sediment contamination and potential ecotoxicological effects associated with the observed level of the metals were evaluated with two sets of standard quality guidelines (SQGs) (ERL/ERM and TEL/PEL) developed for aquatic ecosystems (MacDonald *et al*., 2000). The mean quotients using the PEL (m-PEL-Q) are 3.91×10^{-4}, 4.77×10^{-4} and 7.87×10^{-4} for Ologe Lagoon, Badagry Creek and River Owo respectively. The trend was the same with mean quotients using ERM (m-ERM-Q); Ologe Lagoon = 2.11×10^{-4}, Badagry Creek = 2.49×10^{-4} and River Owo = 4.62×10^{-4} (Table 5).

3.6 Potential Ecological Risks

The potential ecological risk index (PERI) (E^1_r) for each metal at the sampling stations and the integrated ecological risk index (R_1) are shown in Table 5. The PERI of Pb (1.48×10^{-2}) and As (6.00×10^{-3}) were lowest in Ologe Lagoon but highest (Pb = 2.96×10^{-2}, As = 9.33×10^{-3}) in River Owo. The PERI of Zn and Cd followed opposite trend; the lowest (5.75×10^{-4}) for Zn was recorded in Badagry Creek while the highest (6.11×10^{-3}) value occurred in River Owo, Cd had the lowest value (3.54) in River Owo and the highest (6.90) in Badagry Creek. The lowest (2.50×10^{-3}) and highest (4.50×10^{-3}) PERI for Cu were obtained in Ologe Lagoon and Badagry Creek respectively.

The integrated ecological risk index for River Owo, Ologe Lagoon and Badagry Creek are 3.59, 5.66 and 6.94 respectively.

3.7 Health risk assessment of heavy metals

The health risk associated with the consumption of the muscle of *Coptodon zillii* was evaluated by calculating the estimated dietary intake (EDI) and target hazard quotients (THQ) (Table 6). The EDI ranged from 0.00 $mgkg^{-1}day^{-1}$ in Pb from River Owo to 1.15 $x10^{-3}$ $mgkg^{-1}day^{-1}$ in Fe still from River Owo. The EDI for Zn and Cu followed the same pattern as does Pb and Cd but the EDI for As was the same value (8.41 $x10^{-7}$ $mgkg^{-1}day^{-1}$) in all the sampling stations. Table 6 also shows the Total-THQ associated with the consumption of *Coptodon zillii*. The range of values of the THQs of the metals in Badagry Creek, River Owo and Ologe Lagoon are $1.23x10^{-4}$ - $1.65x10^{-2}$, 0.00 - $1.64x10^{-2}$ and $5.76x10^{-5}$ - $1.65x10^{-2}$. The Total-THQs are Badagry Creek ($1.98x10^{-2}$), River Owo ($1.90x10^{-2}$) and Ologe Lagoon ($2.28x10^{-2}$).

Table 6: Estimated daily intake ($mgkg^{-1}day^{-1}$) and estimated target hazard quotients (THQ) for individual metals and total THQ from consumption of *Coptodon zillii* from Badagry Creek, River Owo and Ologe Lagoon

	Badagry Creek		River Owo		Ologe Lagoon	
	EDI ($mgkg^{-1}day^{-1}$)	THQ	EDI ($mgkg^{-1}day^{-1}$)	THQ	EDI ($mgkg^{-1}day^{-1}$)	THQ
Zn	8.83 $x10^{-6}$	$1.73x10^{-4}$	1.26 $x10^{-6}$	$2.47x10^{-5}$	2.94 $x10^{-6}$	$5.76x10^{-5}$
Pb	4.21 $x10^{-7}$	$6.17x10^{-4}$	0.00	0.00	8.41 $x10^{-7}$	$1.23x10^{-3}$
Cu	8.41 $x10^{-7}$	$1.23x10^{-4}$	4.21 $x10^{-7}$	$6.17x10^{-5}$	4.21 $x10^{-7}$	$6.17x10^{-5}$
Fe	1.74 $x10^{-3}$	-	1.15 $x10^{-3}$	-	6.30 $x10^{-4}$	-
As	8.41 $x10^{-7}$	$1.65x10^{-2}$	8.41 $x10^{-7}$	$1.64x10^{-2}$	8.41 $x10^{-7}$	$1.65x10^{-2}$
Cd	4.21 $x10^{-7}$	$2.47x10^{-3}$	4.21 $x10^{-7}$	$2.47x10^{-3}$	8.41 $x10^{-7}$	$4.94x10^{-3}$
Total THQ		$1.98x10^{-2}$		$1.90x10^{-2}$		$2.28x10^{-2}$

4.0 DISCUSSION

4.1 *Physicochemical parameters in water*

One of the indices used to assess aquatic ecosystem health is the physico-chemistry of the environment (O'Brien *et al*., 2016). A lot of the processes in aquatic ecosystem are driven by these water quality variables, which must be maintained within specific limits; otherwise the water body would be unable to provide its traditional services to man and its environment. The results of the physico-chemical parameters of this study conform to earlier studies on Badagry Creek and Ologe Lagoon in the Lagos Lagoon complex (Agboola *et al.,* 2016, Kumolu-Johnson *et al.,* 2010). Some of the water quality variables showed significant ($p<0.05$) variation among the sampling stations. These parameters are turbidity, electric conductivity, total dissolved solids, total solids and ammonia. Indeed, the values of turbidity and conductivity in this study have exceeded the World Health Organisation (WHO, 2008) standards for the culture of fish and other aquatic organisms. This observation might have been caused by sand mining activities in the sampling stations especially in Badagry Creek and Ologe Lagoon. Clarke *et al.* (2019) reported that the conductivity value is an indication of the quantity of dissolved ionic or dissolved organic substances in aquatic ecosystem, which can increase due to anthropogenic activities like sand dredging. Most of the water quality variables in this study are within the limits of the values recommended for the growth and survival of fish in tropical environment. Boyd (1998) suggested a temperature range of 20 - 30^0C and dissolved oxygen range of 3 - 4 mg/l. World Health Organisation (2008) recommended pH of 5.5 - 9.0. Chlorophyll-a concentration is a measure of phytoplankton abundance and biomass (primary productivity) in water bodies. Badagry Creek and River Owo can be described as mesotrophic and Ologe Lagoon as eutrophic (Lang, 1985). The intense sand mining activity in Badagry Creek might have been responsible for the low chlorophyll-a (primary productivity) level observed in that station, although it was not significantly ($p>0.05$) different from the values obtained in the other stations. Sand mining will increase turbidity which will result in increased extinction coefficient of the water body, and consequently light penetration will be reduced causing low primary productivity and low fisheries output. The physico-chemical variables of the sampling stations indicate that the water bodies have favourable conditions for occurrence, survival, growth and multiplication of most tropical fish species.

4.2 *Length-weight relationship and condition factor*

Length-weight relationship (LWR) and condition factor (K) are indices that are importance in aquatic ecosystem health assessment although they might not be in frequent use. Many fish stock assessment models use length and weight data. The growth coefficient (b) obtained from LWR is a reflection of the general condition of appetite and gonad content of fish (Pervin and Mortuza, 2008). Fish experiences increase in weight due to the utilization of food items that are available for growth and energy (Kamaruddin *et al*. 2012). The growth coefficient may also vary in response to other factors like growth phase, sex, gonad development and stomach contents (Hossain *et al*. 2006; Leunda *et al*. 2006). In the same vein, condition factor reflects the physiological state of fish in relation to its welfare (Kumolu-Johnson and Ndimele, 2010). The K value has very strong correlation with the LWR and as such, b is important in the assessment of the well-being of fish, which is a reflection of the state of the environment of the fish. In the present study, the b value of all the fish species from the three sampling stations were within the expected range of 2.5 to 3.5 (Froese, 2006). About 78% of the fish had negative allometric growth, 19% isometric and 3%

positive allometric growth. The range of value of b (2.478 – 3.183) obtained in this study is similar to the values (2.607-3.254) recorded by Agboola and Anetekhai (2008), which studied the length-weight relationships of 35 fish species from Badagry Creek, Lagos. It is also similar to the b values (2.012 - 2.991) obtained by Kumolu-Johnson and Ndimele (2010) who worked on 21 fish species from Ologe Lagoon. Most of the fish species have K values outside the range (2.9 – 4.8) recommended as suitable for matured fresh water fish by Bagenal and Tesch (1978). The percentage of conformity to this standard is 23%, 38% and 27% for Badagry Creek, River Owo and Ologe Lagoon respectively. However, most of the K>1.0 except *Chrysichthys nigrodigitatus, Cynoglossus senegalensis, Mugil cephalus* and *Clarias gariepinus* from Badagry Creek. Ogunola *et al* (2018) reported that fish with high K values (> 1) are in a better environmental condition than those with low K values (< 1). High K values have been linked to several factors; availability and abundance of food or prey, high feeding intensity, good environmental conditions such as optimum temperature, high dissolved oxygen level, low or absence of predators, sustainable fishing practices, genetic and immunity, and self-regulatory systems (Idowu 2017; Guidelli *et al*. 2011; Abdul *et al*. 2016). The good condition of the fish species from the sampling stations could be due to the good quality of the water bodies evidenced in the reported physico-chemical parameters, which are within the limits considered adequate for tropical fish.

4.3 *Ecological indices of the sampling stations*

Biological diversity, abundance, tolerance and composition are community metrics frequently used in aquatic environment to assess ecosystem health. They have been used as either single or multi-metric indices to ascertain ecosystem integrity and guide management decisions (e.g. Chiu *et al*., 2011). Most of the diversity indices used in this study did not show much variation among the sampling stations, and they are similar to values reported in previous studies (Lawson and Olusanya, 2010; Alam *et al*., 2007; Jewel *et al*., 2018). The range of Shannon's diversity index (2.03 – 2.37) recorded in this study is higher than the values (0.74 – 0.85) reported by Lawson and Olusanya (2010) who worked on River Ore, South-west, Nigeria. However, the number of fish species reported in previous studies in these water bodies is higher than the values observed in this study. Agboola and Anetekhai (2008) reported 35 fish species from Badagry Creek against 13 species in this study. Kumolu-Johnson and Ndimele (2010) encountered 21 fish species, 11 was observed in the present study. Although, these previous studies did not use ecological indices to analyse their results, the absence of a good number of these species (more than 50%) indicates that the environment may not be as conducive as it used to be or the fish stock has been over-exploited. Oral evidence from fishers in the sampling stations states that their catches have progressively dwindled over time forcing some of them to take up alternative or additional sources of livelihood. They attributed this to intense sand mining activities in the sampling stations. In addition, the presence of Agbara Industrial Estate in Ogun State, which empties its effluent into Ologe Lagoon and Badagry Creek could also be responsible for the loss in fish species and reduction in catch by fishers. Ndimele *et al*. (2017) reported that since 2013, there has been an increase in industrial effluent discharged into Ologe Lagoon and Badagry Creek from Agbara Industrial Estate because about 45 companies, each with a minimum investment of US$100 million, have made Ogun state their abode with majority of them located in Agbara Industrial Estate.

4.4 *Sediment pollution indices*

Sediment is very important in pollution studies because it acts as sink or reservoir of heavy metals in aquatic ecosystem (Ndimele and Kumolu-Johnson, 2012). The level of heavy metals in different compartments (water, sediment and biota) of the water bodies in Lagos metropolis has been increasing in the last twenty five years (Ndimele and Kumolu-Johnson, 2012). Agboola *et al* (2008) did not detect Pb in Badagry Creek. So, the presence of Pb in Badagry Creek and other wetlands in Lagos now suggest that metal levels are on the increase. This could be as a result of natural processes like weathering, biogenic sources, wind-borne soil particles, etc. Another factor that could be responsible for the observed metal increase in aquatic ecosystems in Lagos Lagoon complex is anthropogenic sources. Lagos and Ogun States are the industrial hubs in Nigeria, accounting for over 70% of industrial activities in the country (Ndimele *et al*, 2017). These industries discharge effluent into nearby water bodies, thus polluting them and rendering them unfit to provide services to man and his environment. Sediment pollution indices are used for assessment and classification of aquatic ecosystem for effective management. In the present study, enrichment factor (EF), geoaccumulation index (Igeo), contamination factor (CF), pollution load index (PLI) and modified degree of contamination (mCd) were used. Based on the standard provided by Acevedo-Figueroa *et al* (2006), the three sampling stations have no enrichment since the EF of the metals are less than 1. The indices of geoaccumulation for the metals in the sediments of the sampling stations were all below 1 indicating that the water bodies are uncontaminated according to the classification of Muller (1969). The health status of the water bodies were further investigated by CF, PLI and mCd. Tomlinson's contamination factors, pollution load indices and modified degrees of contamination of the metals in the sediments of the sites were <1. Håkanson (1980) opined that the degree of sediment metal contamination varies with location in any ecosystem. According to Håkanson classification, the water bodies have low contamination because the CF, PLI and mCd of all the metals were < 1. They are similar to the values reported by Benson *et al* (2016) who worked on Douglas Creek, Qua Iboe estuary, Akwa-Ibom state, South-south, Nigeria. The low levels of CF, PLI and mCd in the sites imply that the aquatic ecosystems might not have been significantly contaminated by anthropogenic sources (Benson *et al*, 2016).

4.5 *Ecotoxicological assessment of heavy metal concentration in sediments*

The mean quotients calculated from the two SQGs using PEL and ERM values are used to compare metal pollution of the sediments of the water bodies. Long and MacDonald (1998) reported that mean ERM quotients are related to the degree or probability of toxicity. Mean ERM quotient of <0.1 has a 12% probability of toxicity; mean ERM quotient of 0.11- 0.5 has a 30% probability of being toxic; mean ERM quotient of 0.51- 1.5 has a 40% probability of toxicity and a mean ERM quotient of >1.50 has a 74% probability of toxicity. Going by this classification, all the sediment samples can be described as low priority sites with 12% probability of being toxic. Mean PEL quotient has a similar classification as mean ERM quotient. Low degree of contamination (≤0.1), medium-low degree of contamination (0.11–1.5), high-medium degree of contamination (1.51–2.3), and high degree of contamination (>2.3) has 8%, 21%, 49% and 73% probability of being toxic respectively (Long *et al*, 2000). The mean PEL quotients (3.91×10^{-4} - 7.87×10^{-4}) obtained in the sediments of the studied sites are <0.1. Therefore, the sediments would have low degree of contamination with 8% probability of being toxic.

4.6 *Potential Ecological Risks*

The risk factor R_I introduced by Hakanson (1980) used eight parameters (Zn, Pb, Cu, As, Cd, Cr, Hg and PCB) but only five (Zn, Pb, Cu, As and Cd) were applied in this study. According to the Hakanson (1980) criteria for evaluation of ecological risk, none of the metals posed any threat at the studied sites because their potential ecological risk indices (E^1_r) ($5.75x10^{-4}$ – 6.90) are <40. However, E^1_r for Cd was considerably higher than the values obtained for other metals. Yi *et al* (2011) opined that the high ecological risk of Cd in aquatic ecosystems is due to its high toxic-response factor. The potential ecological risk indices for individual metals stressors (E^1_r) indicated that intensity of pollution of the five metals decreased in the following order: Cd>Pb>As>Cu>Zn. R_I is a measure of the sensitivity of biological communities to toxic substances and shows the potential ecological risk caused by the metals combined. In the present study, R_I of the three sampling stations (3.59 – 6.94) was <95, which implies that these aquatic ecosystems exhibited low ecological risks according to the standard by Hakanson (1980).

4.7 *Health risk assessment of heavy metals*

Two indices {estimated dietary intake (EDI) and target hazard quotients (THQ)} were used to assess the health risk associated with the consumption of *Coptodon zillii* from the sampling stations. The ranges of the EDIs for the metals across the sampling sites are: Zn ($1.26 x10^{-6}$ - $8.83 x10^{-6}$ $mgkg^{-1}day^{-1}$), Pb (0.00 - $8.41 x10^{-7}$ $mgkg^{-1}day^{-1}$), Cu ($4.21 x10^{-7}$ - $8.41 x10^{-7}$ $mgkg^{-1}day^{-1}$), As ($8.41 x10^{-7}$ $mgkg^{-1}day^{-1}$) and Cd ($4.21 x10^{-7}$ - $8.41 x10^{-7}$ $mgkg^{-1}day^{-1}$). These values are lower than the oral reference doses (RfDo) of the metals; Zn ($3x10^{-1}$ $mgkg^{-1}day^{-1}$), Pb ($4 x10^{-3}$ $mgkg^{-1}day^{-1}$), Cu ($4 x10^{-2}$ $mgkg^{-1}day^{-1}$), As ($3 x10^{-4}$ $mgkg^{-1}day^{-1}$) and Cd ($1 x10^{-3}$ $mgkg^{-1}day^{-1}$) (USEPA, 2009), indicating that the consumption of *Coptodon zillii* from the studied sites is not likely going to cause a non-cancer health risk. In the same vein, THQs of the metals in all the sites was <1, also suggesting that people who consume the fish would not experience significant health risks due to intake of individual metals. The THQs were also lower than the RfDo further buttressing the non-toxic status of the *Coptodon zillii* from these water bodies. The estimated daily intakes for individual metals decreased in the following order: Zn>As>Cu>Cd>Pb while estimated target quotients followed this sequence: As>Cd>Cu>Zn>Pb. The total THQ for the populace in each sampling location did not exceed 1. This further affirms the safety level of *Coptodon zillii* from the sites and their healthy nature.

Conclusion

Heavy metal pollution continues to present significant environmental challenge to communities around Lagos Lagoon Complex, Lagos, Nigeria because of the growing number of companies that discharge effluents into the lagoons. The implication is that the ecosystem services provided by these water bodies are threatened. More worrisome is the threat to the lives of the communities around the aquatics who depend on the lagoons for sustenance. In order to ascertain the health status of the aquatic ecosystems, a multi-indices approach is adopted because of the deficiency of single index methods. These indices include physico-chemistry, length-weight relationship, condition factor, fish diversity indices, sediment pollution indices, ecotoxicology of heavy metals in sediment and potential ecological risks as well as health risk assessment of heavy metals. This study showed that the three water bodies (Badagry Creek, Ologe Lagoon and River Owo) are healthy but regular monitoring is necessary for prompt detection of sudden changes that could affect aquatic and human lives around the areas.

Declarations:

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Consent for publication: Not Applicable

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Authors' contributions:

Activities	Personnel
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Data curation	Ndimele, P.E; Owodeinde, F.G.; GiwaAjeniya, A.O.; Moronkola, B.A.; Adaramoye, O.R.; Ewenla, L.O. and Kushoro, H.Y.
Formal analysis	Ndimele, P.E; Owodeinde, F.G.; GiwaAjeniya, A.O.; Moronkola, B.A.
Investigation	Ndimele, P.E; Owodeinde, F.G.; GiwaAjeniya, A.O.; Moronkola, B.A.; Adaramoye, O.R.; Ewenla, L.O. and Kushoro, H.Y.
Methodology	Ndimele, P.E; Owodeinde, F.G.; GiwaAjeniya, A.O.; Moronkola, B.A.
Project administration	Ndimele, P.E; Owodeinde, F.G.
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Software	Adaramoye, O.R.; Ewenla, L.O. and Kushoro, H.Y.
Supervision	Ndimele, P.E; Owodeinde, F.G.
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Figures

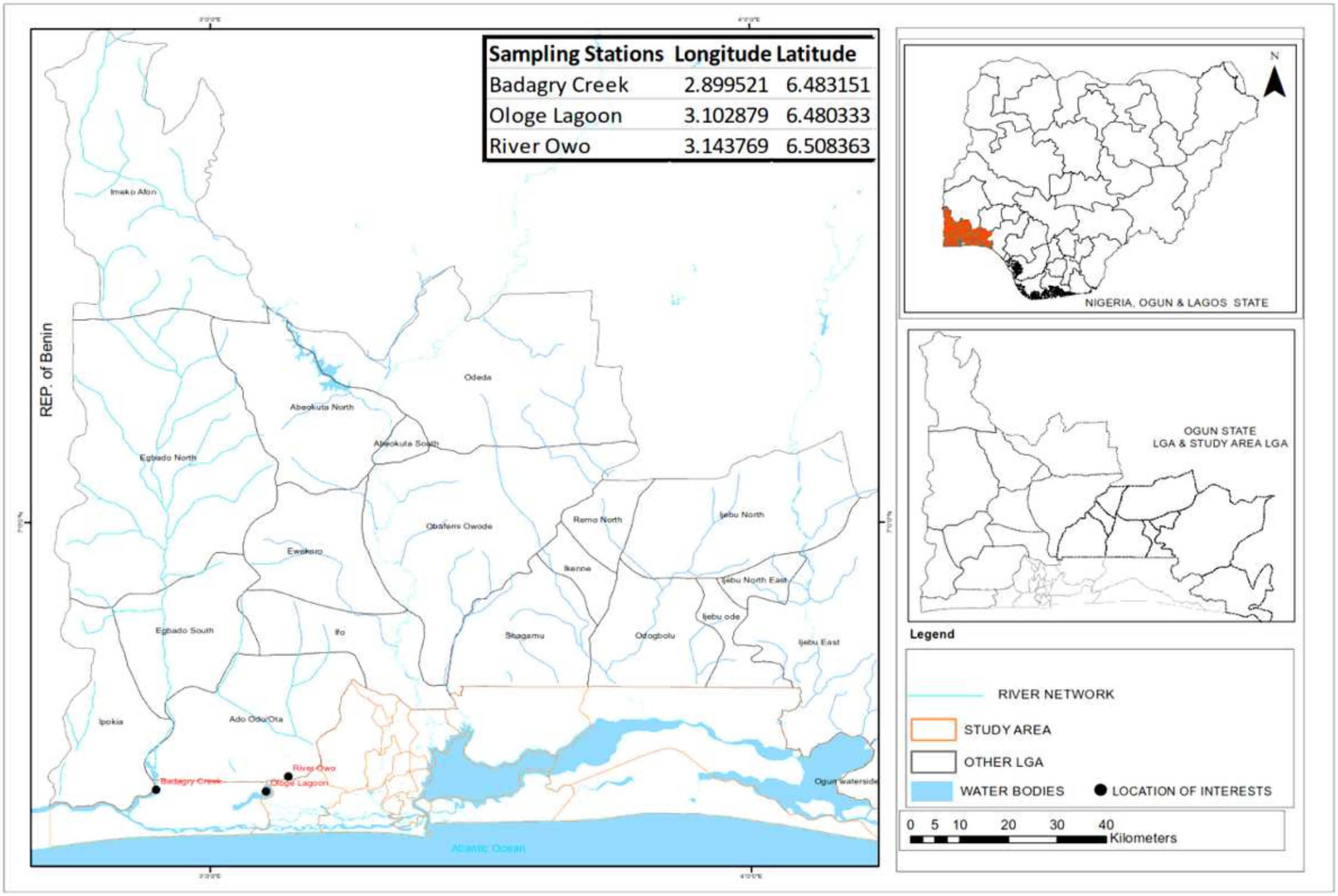

Figure 1

Map of study area showing sampling sites (River Owo, Ologe Lagoon and Badagry Creek)