Original Research Article

Bioaccumulation of Heavy Metal in Water, Sediment and Fish (*Chrysichthys nigrodigitatus*) of Lower Ogun River, Ogun State, Nigeria

***[1]Ojelade, O.C., [2]Oyebanji, F.F., [3]Ayantobo, O.O., [1]Adeleke, A.J., [1]Akinremi, S.A., [1]Fatoke, S.O., [1]Mafolasere, M.K. and [1]Okeowo, V.O.**

[1]Department of Aquaculture and Fisheries Management
Federal University of Agriculture, Abeokuta, Nigeria

[2] Department of Environmental Management and Toxicology
Federal University of Agriculture, Abeokuta, Nigeria

[3]Department of Water Resources Management and Agro-meteorology
Federal University of Agriculture, Abeokuta, Nigeria

*Corresponding author: ojeladeoc@funaab.edu.ng, +2348032255000

Received 26th September, 2018; Accepted 4th October, 2018; Corrected 11th October, 2018

Abstract

The concentrations of some heavy metals (Lead, Cadmium, Zinc and Copper) were determined in water, sediment and tissue (*Chrysicthys nigrodigitatus*) samples collected from three (3) locations in the Lower Ogun River, Akomoje, Ogun state, Nigeria. Samples of silver catfish (*Chrysicthys nigrodigitatus*) were collected monthly from fish farmers at the landing site early in the morning from January to June 2017. The specimens were transported in an ice-chest to the laboratory within 30 minutes of collection for subsequent laboratory analysis. The concentrations of heavy metals were identified and analyzed using Flame Atomic Absorption Spectrophotometer. Heavy metals in the water, sediment and tissue fluctuated throughout the sampling months, in which the highest and lowest values were recorded during the wet and dry seasons respectively. The concentration of different metals in water, sediment and tissues followed the same order: Zn > Cu > Pb> Cd. The mean concentrations of heavy metals in soft tissues of *Chrysichthys nigrodigitatus* were as follows: Zn: 12.341 µg/kg; Cu: 3.876 µg/kg; Pb: 2.890 µg/kg and Cd: 2.606 µg/kg. Gills (7.606 µg/kg) of the examined fish contained the highest concentrations of all of the measured metals, while the flesh (2.390µg/kg) retained the lowest. However, despite the level of contamination of Ogun River by heavy metals, the level of the metals in the tissue (edible part) of *C. nigrodigitatus* did not exceed the recommended permissible limit thus implying that fish in the Lower Ogun River is considered safe for human consumption.

Keywords: Heavy metal, *Chrysicthys nigrodigitatus*, sediment, tissue, Lower Ogun River

Introduction

Fish and other edible aquatic organisms provide at least 20% of protein intake for over one-third of the world's population, and the dependence on fish and other edible aquatic organisms is highest in the developing countries (Bene *et al.*, 2007). Small-scale fisheries represent the most important and reliable source of fish. Jahan *et al.* (2009) reported that the small-scale fisheries sector supplies a large percentage of nutrients required for over 400 million people in the poorest areas of developing countries. Furthermore, the aquaculture and fisheries sectors employ over 36 million fisherfolks across the world and indirectly support half a billion people as dependents or in ancillary occupations (Akinrotimi *et al*., 2007).

In aquatic ecosystems, research on bioaccumulation of heavy metals has received greater attention due to their bioaccumulation effect. However, accumulation of these heavy metals is caused principally by erosion and anthropogenic activities (Stephen *et al.,* 2000; Fernandez and Olalla, 2000; Ogoyi *et al*., 2009).

Thus, the heavy metal pollution of most aquatic environments poses a serious challenge to fisheries managers across the globe due to the non-breakable nature of these metals, and their harmful effects on aquatic organisms (Macfarlane and Burchett, 2000). Out of the several available environmental pollutants, metals are of greater threat due to their toxicity and bioaccumulation effect over time (Censi *et al.,* 2006).

Heavy metal accumulation in aquatic ecosystems occurs mostly in water, sediments and tissues (Camusso *et al.,* 1995). Most times, the lowest concentrations are found in water, with increased levels in sediments and biota (Storelli *et al.,* 2005).

Canli and Atli (2003) stated that heavy metals descend into aquatic sediments, thus justifying the use of sediments as reliable indicators in the assessment of heavy metal contamination. Beyond this level, sediments also release these metals back into the aquatic medium through natural human-induced processes, thus increasing the bioaccumulation and toxicity effect within the aquatic ecosystem (Ali and Abdel-Satar, 2005).

In Nigeria, all water bodies are utilized by the industrial, domestic, agricultural and urban sectors (Fafioye *et al.,* 2008). This has made such water bodies, including Ogun River, to be of serious worry due to their commercial significance in the supply of aquatic foods for the growing population. Thus, it is important to monitor heavy metals in the aquatic environment via water, sediments and biota to prevent the hazardous effect of the utilization of adulterated food by human. Thus, the assessment of these heavy metals will give a better understanding of current status of the river and its aquatic life, and the possible health risks associated with the utilization of these aquatic products in the study area.

Materials and Methods

Description of Study Area

The research was carried out in the Lower Ogun River, Akomoje situated within Ogun State, Nigeria. The river is a perennial river in Nigeria, with coordinates of 3° 28 'E and 8° 41 'N from its source in Oyo state to 3° 25 'E and 6° 35 'N in Lagos state where it enters Lagos lagoon (Figure 1). The area experiences a dry season from November to March each year, and a wet season from April to October. Iganran hill, which is about 540m above sea level, is the source of the river. The river flows over a distance of 480km southwards before it enters into the Lagos lagoon (Adeosun *et al.*, 2011).

Selection of Sampling Sites, and Duration of the Study

Reconnaissance survey was carried out at the Lower Ogun River to get familiar with the people and fisherfolks within the study area. Three (3) sampling stations were purposively selected across the length of the river to represent various degrees of human activities within the study area. Sediment, water and fish samples of *Chrysicthys nigrodigitatus* were collected during the wet and dry months from January to June, 2017 from the three different sampling stations.

Sampling Technique

Water samples were collected on a monthly basis at a depth of 50cm in two polyethylene bottles acidified with nitric acid, and kept for analysis. The samples were filtered through a 0.45µm micropore filter, and kept at 4°C until further analysis. A grab sampler was used to collect sediment samples from the three locations, and conveyed to the laboratory. The samples were air-dried in the laboratory at room temperature; samples were stored at -2°C, and kept in polyethylene bags prior to analysis. The sediment samples were sieved through a 160µm filter before placing in digestion bombs with 10 mL of HNO_3/HCl (1:3 v/v). Sediments and water were analyzed using the procedure of Binning and Baird (2001).

Gills, skin and muscle of *C. nigrodigitatus* obtained from the river were taken from each fish, weighed, put in a flask, dried in an oven at 105°C for about 24h, and acid-digested by nitric acid and perchloric acid (2:1) on a hotplate until the solution became clear. Lead (Pb), Cadmium (Cd), Zinc (Zn) and Copper (Cu) concentrations in the water were determined by the extraction method (APHA, 1998) using an atomic absorption spectrophotometer (Bulk Scientific VGB 211 Model). Fish samples were prepared for heavy metal analysis according to the method described by Monday *et al*. (2007). Two-way Analysis of Variance (ANOVA) was employed to find the significant differences among mean heavy metal concentrations in sediment, water and fish organs of *C. nigrodigitatus* with respect to locations and seasons at 5% level of significance, while descriptive statistical tools such as means, averages and a bar-chart were employed to quantify the levels of heavy metals in the study.

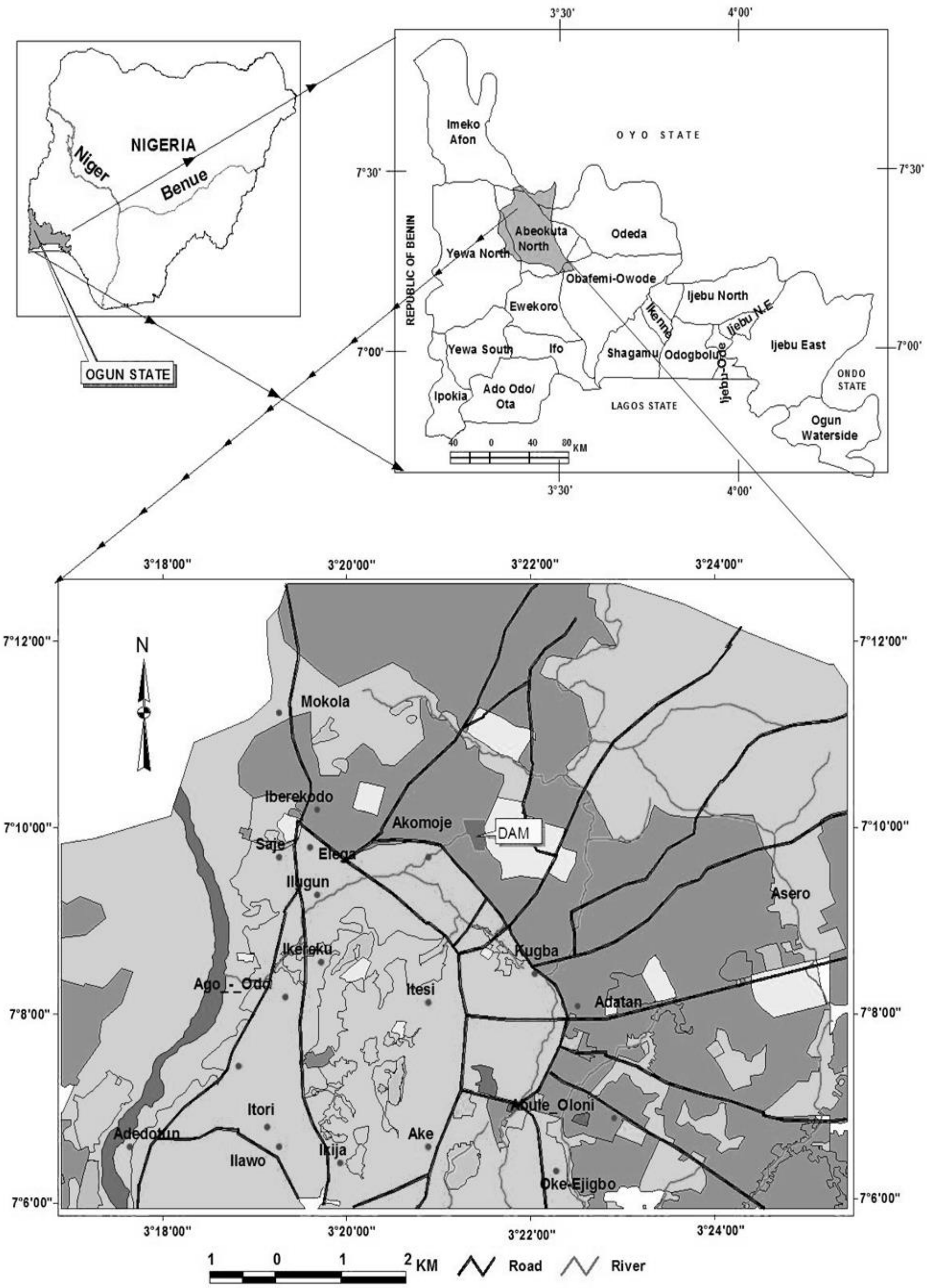

Figure 1: Map of Lower Ogun River (Akomoje)

Results and Discussion

The bioaccumulation of heavy metals in most aquatic ecosystems poses a serious health challenge to man due to its level of toxicity and other effects over time (Aharamwa and Umunnakwe (2014). The mean monthly concentrations of Pb, Cd, Zn and Cu in the collected water samples from the Lower Ogun River are shown in Table 1. The mean concentrations of the metals in their increasing order were: 0.175mg/l (Zn)>0.052mg/l (Pb)>0.029mg/l (Cu)> 0.013mg/l (Cd). This order of concentrations is in line with the results of previous researchers: Al-Yousuf *et al.* (2000), Canli and Atli (2003), Monday *et al.* (2007) and Obaroh *et al.* (2015). Generally, most of the recorded levels of heavy metals were greater at station 3, probably as a result of several anthropogenic activities going on around this location coupled with domestic sewage discharge and agricultural drainage water. Anthropogenic activities have been reported to be an important factor to the increased the level of heavy metals in aquatic ecosystems (Obaroh *et al*., 2012). Station 2, appeared to be the cleanest region of the River, as it contained the lowest concentrations of the investigated metals across the sampling months. This Station probably did not receive many pollutants from agricultural, industrial, and sewage drains compared to Station 3 which had the highest mean values of all the sampled metals.

Monthly variations in the concentration of heavy metals were also observed in the study area during the period, with the rainy season months (April, May and June) having significantly higher concentrations of heavy metals. The increased levels of heavy metal concentration recorded during the wet months could be as a result of increased levels of rainfall and subsequent runoffs, coupled with the introduction of industrial, domestic, metropolitan and agricultural wastes along with pesticides discharged through runoffs (George *et al.,* 2013; Muhammad *et al*, 2014).

In contrast to these findings, Ali and Abdel-Satar (2005) ascribed the high rate of heavy metal concentrations in the water during dry months to the liberation of these metals from the sediments into the water body as a result of the effect of high temperatures and fermentation process resulting from the decomposition of organic matter. Seasonal variations of metals in aquatic ecosystems have also been reported by Yilmaz (2003), Suresh *et al.* (2012) and Muhammad *et al.* (2014) for different bodies of water.

Table 2 presents the spatial as well as the monthly concentrations of heavy metals in gills, skin and muscle of the sampled *C. nigrodigitatus.* The sequence of the concentrations of heavy metal and their mean values in the body organs were; gills>muscle>skin (7.606µg/kg, 5.428µg/kg and 2.390µg/kg respectively).

This study revealed that the level of Pb in *C. nigrodigitatus* was higher in the gills than in the flesh and muscle, thus corroborating the studies of Adeosun *et al.,* (2011) and Aharamwa and Umunnakwe (2014). The mean values of the concentrations of Pb found in the skin (2.309µg/kg) samples of this study were below the maximum permissible limit of 0.5 mg/kg for the consumption and absorption of man (FAO, 1983; WHO, 2004). Meanwhile, the concentration of Pb content found in this study might be strongly related to discharge of industrial wastes, oil leakage, grease

Table 1: Monthly and spatial concentrations (mg/l) of heavy metals in the water of the Lower Ogun River (mean ± standard deviation)

Elements	Station	January	February	March	April	May	June	Mean	p
Pb	1	0.014±0.03	0.033±0.01	0.050±0.02	0.075±0.02	0.081±0.03	0.096±0.03	0.048±0.02	0.03
	2	0.010±0.00	0.017±0.01	0.023±0.01	0.058±0.02	0.072±0.02	0.079±0.03	0.043±0.02	0.02
	3	0.019±0.01	0.025±0.01	0.031±0.01	0.063±0.02	0.073±0.02	0.084±0.02	0.059±0.02	0.01
	Mean	**0.014±0.01**	**0.025±0.01**	**0.035±0.02**	**0.065±0.02**	**0.075±0.02**	**0.086±0.03**	**0.052±0.02**	
Cd	1	0.006±0.00	ND	0.001±0.00	0.012±0.01	0.021±0.01	0.035±0.02	0.015±0.01	0.01
	2	0.002±0.00	0.001±0.00	ND	0.011±0.01	0.018±0.01	0.020±0.01	0.01±0.00	0.00
	3	0.010±0.01	0.004±0.00	0.002±0.00	0.022±0.01	0.031±0.02	0.042±0.02	0.019±0.01	0.00
	Mean	**0.006±0.00**	**0.003±0.00**	**0.002±0.00**	**0.015±0.01**	**0.023±0.01**	**0.032±0.02**	**0.013±0.01**	
Zn	1	0.018±0.01	0.013±0.01	0.010±0.00	0.211±0.02	0.374±0.03	0.471±0.04	0.183±0.01	0.00
	2	0.011±0.00	0.009±0.00	0.003±0.00	0.196±0.01	0.281±0.03	0.352±0.03	0.142±0.01	0.01
	3	0.026±0.01	0.017±0.00	0.015±0.00	0.253±0.02	0.395±0.04	0.486±0.04	0.199±0.02	0.01
	Mean	**0.018±0.01**	**0.013±0.01**	**0.009±0.00**	**0.220±0.02**	**0.350±0.03**	**0.436±0.04**	**0.175±0.02**	
Cu	1	0.014±0.01	0.010±0.00	0.003±0.00	0.029±0.01	0.054±0.02	0.061±0.02	0.029±0.01	0.00
	2	0.009±0.00	0.005±0.00	0.001±0.00	0.019±0.01	0.028±0.01	0.034±0.01	0.016±0.01	0.01
	3	0.030±0.01	0.021±0.01	0.014±0.01	0.042±0.01	0.063±0.03	0.078±0.03	0.041±0.01	0.00
	Mean	**0.018±0.01**	**0.012±0.01**	**0.006±0.00**	**0.030±0.01**	**0.048±0.02**	**0.058±0.01**	**0.029±0.01**	

Factors: Site = 3 levels; Month = 6; Site x Month = 18; ND: Not Detected (Values < 0.001)

Table 2: Monthly concentrations **(**µg/kg dry weight) of heavy metals in the tissue of *C. nigrodigitatus* in the Lower Ogun River (mean ± standard deviation)

Organs	Element	January	February	March	April	May	June	Mean	p
Gills	Pb	3.91±1.21	3.84±1.11	3.92±1.01	3.94±1.41	4.12±1.56	4.37±1.34	4.02±1.54	0.619
	Cd	2.89±0.97	1.99±0.73	1.55±0.69	3.25±0.92	3.89±1.01	5.42±1.20	3.17±1.09	0.296
	Zn	14.31±1.87	10.12±1.56	8.88±1.42	20.88±2.54	21.34±2.75	25.17±2.98	16.78±2.11	0.009
	Cu	4.82±1.11	3.94±1.01	2.57±0.88	4.82±1.11	9.68±1.55	12.94±1.99	6.46±1.21	
	Mean	**6.78±1.36**	**5.22±1.19**	**4.23±1.11**	**8.97±1.24**	**10.70±1.61**	**12.92±1.89**	**7.61±1.20**	
Skin	Pb	2.11±0.74	1.87±0.69	1.54±0.65	2.41±0.93	2.86±0.99	3.07±0.97	2.31±0.95	0.214
	Cd	0.98±0.00	0.54±0.00	0.47±0.00	1.10±0.39	1.35±0.58	1.42±0.61	0.98±0.01	0.089
	Zn	3.91±1.01	2.12±0.79	1.46±0.67	4.56±1.09	5.20±1.25	6.95±1.33	4.03±1.07	0.052
	Cu	1.57±0.67	1.17±0.41	0.99±0.00	1.89±0.79	2.94±0.97	4.85±1.10	2.24±0.98	
	Mean	**2.14±0.79**	**1.43±0.62**	**1.11±0.40**	**2.49±0.94**	**3.09±1.00**	**4.07±1.00**	**2.39±0.89**	
Muscles	Pb	2.56±0.88	2.25±0.81	2.12±0.79	2.97±1.00	3.34±1.21	4.10±1.11	2.89±0.09	0.104
	Cd	2.42±0.79	1.90±0.71	1.46±0.67	2.99±1.06	3.21±1.20	3.66±1.35	2.61±0.81	0.009
	Zn	10.82±1.64	9.65±1.49	7.66±1.11	13.91±2.04	15.12±2.65	16.88±2.69	12.34±2.01	0.021
	Cu	2.81±0.96	1.99±0.82	0.85±0.00	3.22±0.91	5.75±1.31	8.61±1.55	3.88±1.10	
	Mean	**4.66±1.098**	**3.95±1.01**	**3.02±0.99**	**5.77±1.25**	**6.85±1.41**	**8.31±1.51**	**5.43±1.13**	

Factors: Element = 4; Month = 6; Element x Month = 24; ND: Not Detected (Values < 0.001)

and antifouling paints which are serious lead pollution sources into most river bodies (Al-Yousuf *et al*. 2000; Topcuoglu *et al.* 2002 and Monday and Nsikak, 2007).

Some documented consequence of the consumption this metals include a delay in the development of embryo and delayed reproduction process; neurological problem, dysfunction of kidney as well as increased mucous formation (Rompala *et al*., 2004; Fafioye *et al*., 2008).

In this study, Zn concentrations ranged from 1.46µg/kg to 6.95µg/kg with an average value of 4.03µg/kg in the skin of *C. nigrodigitatus* samples from Lower Ogun River. This obtained result are higher than Jinadasa and Edirisinghe (2012) who recorded lower concentrations of Zn with a range of ND-0.24µg/g and average concentration of 0.06µg/g in tilapia fish species in Sri Lanka coast. Also, the recorded mean values of Zn in this research are greater compared to values in the report of Adeosun *et al.* (2011) that recorded a mean concentration of 0.038µg/kg in fish species from the same study area. This variation could be as a result of the differences in the magnitude of human activities in place within the study area coupled with the time difference. However, Mwashote (2003) reported a higher level of Zn when compared with the present study with an average concentration of 13.915µg/kg in species of fish from Mombasa of Kenya.

Also, it can be seen that the concentrations of Cu found in skin/flesh of silver catfish in this study were still considered as those of uncontaminated fish (3.88µg/kg). Copper represents an important part of several enzymes that are necessary for hemoglobin synthesis, but can cause harm at high concentrations and lead to serious health risks (Telisman *et al*., 2000). Furthermore, the concentrations of Cu (2.24ug/kg) in the skin of the sampled fish species of the Lower Ogun River were within permissible limits for Cu in fish (30.0mg/kg) as proposed for human consumption by FAO (1983). Copper is present in surface water, ground water and tissues of aquatic organisms due to the increased use of pesticide sprays containing copper compounds for agricultural purposes. It is an important element in human metabolism, but can cause anemia, bone disorders and liver damage at excessive levels depending on the water hardness and pH (Taha, 2004).

The major body organs where accumulation of heavy metals takes place in aquatic organisms are the kidneys and liver; other notable sites are the gills, bone and exoskeleton (Bashir *et al.*, 2013). Although, the tissue (flesh) of fish is the most relevant organ consumed by man, the bone and liver may also be consumed to some extent (Sivaperumal *et al.*, 2007). Several other body organs such as liver, eye and gill also have a tendency to accumulate these metals in high values as reported by Abdel-Moniem, *et al*. (1994), Yilmaz (2003, 2005) and George *et al*. (2013). The greatest concentration of heavy metals was found in the gills (7.606µg/kg), followed by muscle (5.428µg/kg), and the least in the skin (2.390µg/kg). A high value of heavy metals was recorded in the gills of *C. nigrodigitatus* used in this study, contrary to findings in the report of Yilmaz (2003) who found higher concentrations of heavy metals in flesh samples than in other parts of a fish. The reason for high metal concentrations found in the gills of *C. nigrodigitatus* could be as a result of the continuous exposure to the concentrations of heavy metals in the water during gaseous exchange (El-Nemr, 2003).

Figure 2 depicts the fluctuations in the heavy metals concentrations across the sampling months in the sediment samples of the Lower Ogun River. The average concentration of the heavy metals were in the order of Zn>Cu>Pb>Cd with mean values of 19.783ug/kg, 8.280ug/kg, 8.067ug/kg and 4.800ug/kg respectively. This recorded order corroborates with the reports of Kwon and Lee (2001), Topcuoglu *et al.* (2002), Mwashote 2003) Suresh *et al.* (2007) and Adeosun *et al.* (2011)

who reported similar trends of heavy metal concentrations in the sediments of their different study areas. However, the recorded mean values were higher than the report of Ali and Abdel-Satar (2005) who obtained a mean value of 10.34μg/kg and 5.25μg/kg for Zinc and Lead in the sediment samples of EL-Fayoum province of Egypt.

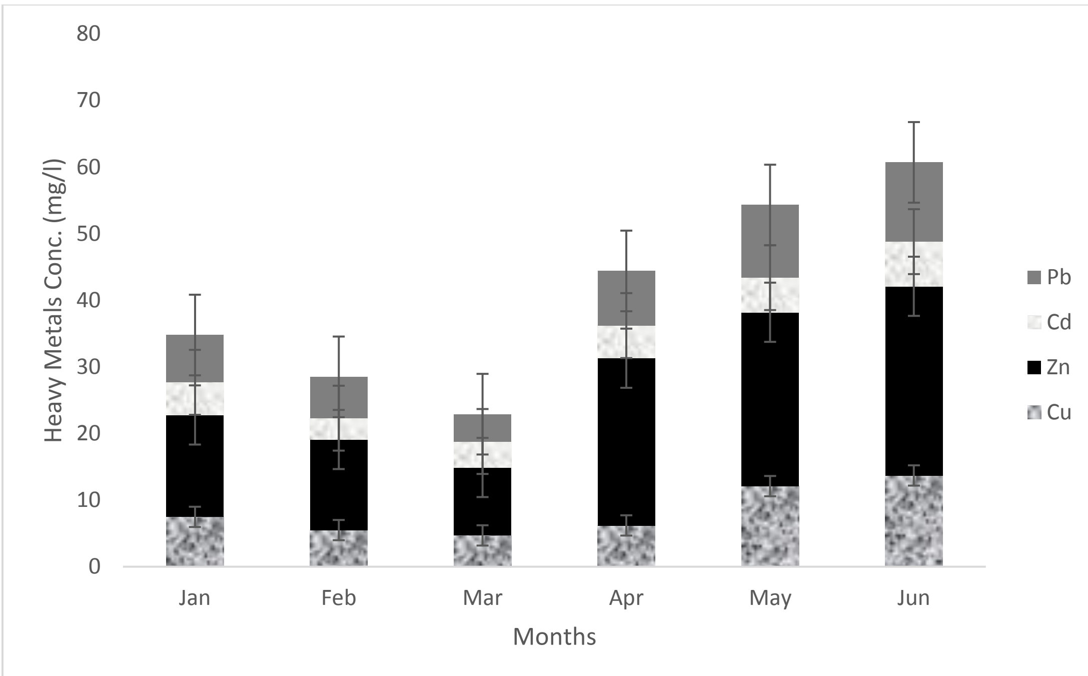

Figure 2: Error bar-chart showing the mean monthly variation in the concentrations of heavy metals in the sediment of Ogun River.

Correlation between Heavy Metals

Correlation analysis principally calculates the association between two or more functionally independent parameters. The value of correlation coefficient ranges between -1 and 1. Values closer to +1 and -1 show a strong positive and negative correlation respectively, while values closer to zero indicate weak correlation (Armah *et al*., 2010). Table 3 shows the result of correlation coefficients between various heavy metals in the skin of the fish samples collected from the Lower Ogun River and surrounding area. Result in Table 3 shows that Cd was not significantly correlated with Zn and Cu. Positive significant correlations were observed between Cd and Pb (0.81), Cu and Zn (0.931) and Pb and Zn (0.73). Moreover, moderate positive correlations were found between Cd and Zn (0.69) and Pb and Cu (0.52). These obtained results may be an indication that the four heavy metals investigated in this study had similar or related topographical sources (El-Serehy *et al*., 2012).

Table 3. Correlation matrix among four heavy metals in fish muscles

Heavy metals	Pb	Cd	Zn	Cu
Pb	1	0.81*	0.73*	0.52
Cd		1	0.69	0.43
Zn			1	0.931*
Cu				1

*: Significant correlations at 95% confidence limit

Conclusion

The study revealed the levels of some heavy metals in the Lower Ogun River, its sediment and fish. The presence of these heavy metals could be ascribed to the level of human and commercial activities that generate wastes including heavy metals which are discharged into the River. The higher concentrations of these metals recorded in this study coincided with the onset of the rainy months. The concentrations of all the analyzed heavy metals were within acceptable limit as stipulated by WHO, thus posing little or no threat to the aquatic organisms. Industrial and public education programs are required on awareness of health risks associated with heavy metal pollution of waters; but a continuous monitoring of heavy metals in fish species from the Lower Ogun River is necessary in fisheries management.

References

Abdel-Moniem M. and Khaled A. Iskander M (1994): A Study on Levels of Some Heavy Metals in El-mex bay, Alexandria, *Egypt*. 155-174.

Ali, M.H.H. and Abdel-Satar, A.M. (2005). Studies of some heavy metals in water, sediment, fish and fish diets in some fish farms in EL-Fayoum Province, Egypt. *Egyptian Journal of Aquatic Res*ources 31(2): 261-273.

Aharamwa, B.C. and Umunnakwe, J.E. (2014). Assessment of water quality and heavy metal levels of fish species in Oguta lake, Imo state Nigeria. *Journal of Natural Sciences Research* 4: 103-111.

Al-Yousuf, M.H., El-Shahawi, M.S. and Al-Ghais, S.M. (2000). Trace metals in liver, skin and muscle of *Lethrinus lentjan* fish species in relation to body length and sex. *Journal of Science Total Environment* 256:87-94.

Adeosun, F.I., Akinyemi, A.A., Idowu, A.A., Taiwo, I.O., Omoike, A. and Ayorinde, B.J.O. (2011). The effects of heavy metals concentration on some commercial fish in Ogun River, Opeji, Ogun State, Nigeria. *African Journal of Environmental Science and Technology* 9(4):365-370.

Akinrotimi, O.A., Onunkwo, D.N., Cliffe, P.T., Anyanwu, P.E. and Orokotan, O.O. (2007). The role of fish in nutrition and livelihoods of families in Niger Delta, Nigeria. *International Journal of Tropical Agriculture and Food Systems* 1(4):344-351.

APHA (1998). Standard methods for the Examination of Water and Wastewater (20th ed). New York: American Public Health, Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WPCF). Pp17-41.

Armah, F.A., Obiri, S., Yawson, D.O., Onumah, E.E. and Yengoh, G.T. (2010). Anthropogenic sources and environmentally relevant concentrations of heavy metals in surface water of a mining district in Ghana: A multivariate statistical approach. *Journal of Environmental Science and Health* 45: 1804-1813. DOI: 10.1080/10934529.2010.513296

Bashir, F.H., Othman, M.S., Mazlan, A.G., Rahim, S.M. and Simon, K.D. (2013). Heavy metals concentration in fishes from the coastal waters of kapar and mersing, Malaysia. *Turkish Journal of Fisheries and Aquatic Science* 13: 375-382.

Bene, C., Macfadyen, G. and Allison, E.H. (2007). Increasing the contribution of small-scale fisheries to poverty alleviation and food security. FAO Fisheries Technical Paper 481. FAO, Rome.

Binning, K. and Baird, D. (2001). Survey of heavy metals in the sediments of the Swartkops River Estuary, Port Elizabeth South Africa. *Water SA* 27(4): 461-466.

Camusso, M., Vigano, L and Baistrini, R. (1995). Bioaccumulation of trace metals in rainbow trout. *Ecotoxicology and Environmental Safety* 31: 133 – 141.

Canli, M. and Atli, G. (2003). The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) Levels and the size of six Mediterranean fish species. *Environmental Pollution* 121: 129-136.

Censi, P., Spoto, S.E., Saiano, F., Sprovieri, M., Mazzola, S., Nardone, G., Di Geronimo, S.I., Punturo, R. and Ottonello, D. (2006). Heavy metals in coastal water system. A case study from the north western Gulf of Thailand. *Chemosphere* 64: 1167 – 1176.

El-Nemr, A. (2003). Concentrations of certain heavy metals in imported frozen fish in Eygpt. *Journal of Aquatic Biology* 7:139-154.

El-Serehy, H., Aboulela. H., Al-Misned. F., Kaiser. M., Al-Rasheid. K. and Ezz El-Din. H. (2012). Heavy metals contamination of a Mediterranean Coastal Ecosystem, Eastern Nile Delta, Egypt. *Turkish Journal of Fisheries and Aquatic Sciences* 12: 751-760.

Fafioye, O.O., Adeogun, A.O. and Omoniyi, I.T. (2008). Lethal limits and respiration in the cichlid fishes, *Tilapia zillii, Sarotherodon galilaeus, S. melanotheron and Orechromis noliticus* exposed to effluent from Chemistry Department Laboratories. *Journal of Applied Science and Environmental Management* 12(1):63-66.

FAO (1983). Manual of Methods in Aquatic Environmental Research, Analyses of metals and organochlorines in fish. FAO Fisheries Technical Paper, Rome. P 212

FAO/WHO (1984). List of maximum levels recommended for contaminants by the joint FAO/WHO Codex Alimentarius Commission, 3:1-8.

Fernandez, L.Z. and Olalla, H.Y. (2000) Toxicity and bioaccumulation of lead and cadmium in marine protozoan communities, *Ecotoxicology and Environmental Safety*, 47(266-276):2000.

George, U., Asuquo, F., Idung, J. and Andem, A. (2013). Bioaccumulation of heavy metals in three fresh water fishes caught from Cross River system. *European Journal of Experimental Biology* 3(3):576-582.

Jahan, K.M., Ahmed, M. and Belton, M. (2009). The impacts of aquaculture on food security: lessons from Bangladesh. *Aquaculture Research* 41(4): 481- 495.

Jinadasa, B.K.K.K. and Edirisinghe, E.M.R.K.B. (2012). Assessment of Heavy Metals (Cadmium, Lead and Total Mercury) in Tilapia sp. in Sri Lanka. *Journal of the National Aquatic Resources Research & Development Agency of Sri Lanka* 43: 1-14.

Kwon, T.T., and Lee, C.W. (2001). Ecological risk assessment of sediment in wastewater discharging area by means of metal speciation. *Microchemical Journal* 70, 255-264.

Macfarlane, G.B. and Burchett, M.D. (2000). Cellular distribution of Cu, Pb and Zn in the Grey Mangroove Avicemmia marina (Forsk). *Vierh Aquatic Botany* 68: 45 – 49.

Monday, U.E. and Nsikak, U.B. (2007): Cadmium, Copper, Lead and Zinc Levels in Bonga Shad (*Ethamalosa fimbriata* and *Tilapia guinensis*) caught from Imo River, Nigeria. *American Journal of Food Technology* 2 (1): 48-54.

Muhammad, H.L., R.A. Shehu, L.S. Bilbis & S.M. Dangoggo (2014).Analyses of selected heavy metals and mineral elements in pollution-prone aquatic environments of North-Western region of Nigeria. *Asian Journal of Biological Sciences* 7(6): 252-261.

Mwashote, B. (2003). Levels of Cadmium and Lead in water, sediments and selected fish species in Mombasa, Kenya. *Western Indian Ocean Journal* 1: 25-34.

Obaroh, I.O., Abubakar, U., Haruna, M.A. and Elinge, M.C. (2015). Evaluation of some heavy metals concentration in River Argungu. *Journal of Fisheries and Aquatic Science* 10(6):581-586.

Obaroh, I.O., Elinge, C.M. and Nwankwo, C. (2012). Assessment of some heavy metals and physico-chemical parameters of Jega river, North-western Nigeria. *International Journal of Natural and Applied Science* 8:78-81.

Ogoyi, D.O., Mwita, C.J., Nguu, E.K., Wasoga, C.O. and Shiundu, P.M. (2009). Effect of heavy metal pollution on microalgae richness and diversity in Lake Victoria. In: Lake Victoria Research Initiative Proceedings. *Pollution of Heavy Metal Cluster*, 2009, pp. 193-210.

Rompala JM, Rutosky FW, Putnam DJ (2004). Concentrations of environmental contaminants from selected waters in Pennsylvania.U.S. Fish Wildl. Serv. Rep., State College, Pennsylvania. P 102.

Sivaperumal P, Sankar TV, Viswanathan PG (2007). Heavy metal concentrations in fish, shellfish and fish product from internal markets of India vis-a-vis international standards. *Food Chemistry* 102:612-618

Stephen, C., Jewett, A. and Sathy Naidu, A. (2000) Assessment of heavy metals in red king crabs following offshore placer gold mining. *Marine Pollution Bulletin* 40: 478-490.

Storelli, M.M., Storelli, A., D'ddaabbo, R., Morano, C., Bruno, R. and Marcotrigiano, G.O. (2005). Trace elements in loggerhead turtles (Caretta caretta) from the Eastern Mediterranean; Overview and evaluation. *Environmental Pollution* 135: 163 – 170

Suresh, G., Sutharsan, P., Ramasamy, V. and Venkatachalapathy, R. (2012). Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam lake sediments, India. *Ecotoxicology, Environment and Safety* 84:117–124.

Taha, A.A. (2004). Pollution sources and related environmental impacts in the new communities, Southeast Nile Delta, Egypt. *Emirate Journal of Engineering Resources* 19(1): 44.

Telisman, S., Cvitkovi, P., Jurasovi, J., Pizent, A., Gavella, M. and Roci, B. (2000). Semen quality and reproductive endocrine function in relation to biomarkers of lead, cadmium, zinc, and copper in men. *Environmental Health Perspective* 108(1): 45-53.

Topcuoglu, S., Kirbasoglu, C. and Güngör, N. (2002). Heavy metals in organisms and sediments from Turkish coast of the Black Sea, 1997–1998. *Environment International* 27(7): 521–526.

WHO (2004). Health Criteria and Other Supporting Information in Guideline for Drinking Water Quality (3rd Eds), World Health Organization, Geneva. pp. 301-388.

Yilmaz, A.B. (2003). Levels of heavy metals (Fe, Cu, Ni, Cr, Pb, and Zn) in tissue of Mugil cephalus and Trachurus mediterraneus from Iskenderun Bay, Turkey. *Environmental Research* 92: 277–281.

Yilmaz, A.B. (2005). Comparison of heavy metal levels of grey mullet (*Mugil cephalus* L.) and sea bream (*Sparus aurata* L.) caught in Iskenderun Bay (Turkey). *Turkish Journal of Veterinary and Animal Science* 29: 257-262.