International Journal of Fisheries and Aquatic Studies 2019; 7(2): 193-199

E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2019; 7(2): 193-199

www.fisheriesjournal.com
Received: 17-01-2019
Accepted: 20-02-2019

Samuel Ukpong Okon
Department of Marine Biology, Akwa Ibom State University, Uyo, Nigeria

Edidiong Okokon Atakpa
Department of Animal & Environmental Biology, University of Uyo, Uyo, Nigeria

ITA Ewa-Oboho
Department of Marine Biology, Akwa Ibom State University, Uyo, Nigeria

Correspondence
Samuel Ukpong Okon
Department of Marine Biology, Akwa Ibom State University, Uyo, Nigeria

Spatial and seasonal characteristics of heavy metals in Ikpa River, Niger Delta - Nigeria

Samuel Ukpong Okon, Edidiong Okokon Atakpa and ITA Ewa-Oboho

Abstract
Spatial and seasonal trend of Lead (Pb), Iron (Fe), Nickel (Ni), Cadmium (Cd), Chromium (Cr), and Copper (Cu) in surface waters of Ikpa River were determined using standard methods. The twelve months survey revealed spatial and seasonal variations. In wet season, average concentrations of heavy metals followed the pattern: Fe > Cd > Ni > Pb > Cu > Cr with concentration values 0.59 mg/L, 0.0105 mg/L, 0.005075 mg/L, 0.002575 mg/L, 0.00225 mg/L, 0.000325 mg/L respectively. In dry season, average concentrations followed the pattern Fe > Cu > Cd > Ni > Cr > Pb with concentration values of 3.01 mg/L, 0.6075 mg/L, 0.0065 mg/L, 0.000575 mg/L, 0.000325 mg/L, 0.000165 mg/L respectively. Heavy metal levels in Ikpa River were within the recommended limits set by World Health Organization (WHO). In dry season however, Cu levels across the stations exceeded the guidelines of Federal Environmental Protection Agency (FEPA). Statistically, there was no significant difference in the seasonal variations of respective heavy metals concentrations, except for Fe which showed significant difference in stations one ($t = 3.635$, $p<0.05$), station two ($t = 3.939$, $p<0.05$) and station three ($t = 4.118$, $p<0.05$). Ikpa River is used farm irrigation and domestic activities hence, the need to protect this river from pollution. The ecological and human-health implication of heavy metal pollution in the river is discussed.

Keywords: niger delta, ikpa river, heavy metals, spatial variations, surface waters

1. Introduction

With recent population growth and industrial development, heavy metal pollution in our aquatic systems has become increasingly critical. Greater proportion of heavy metals in aquatic systems are from municipal sewage, agricultural waste and industrial effluents. As one of the most industrialized regions in Nigeria, economic growth in the Niger Delta has resulted in excessive discharge of heavy metals into major aquatic systems and adjacent coastal waters. Since heavy metals are noted for toxicity and persistency in the natural environments [1-2], ecological and human-health implications of its presence in aquatic systems cannot be ignored. It constitutes a serious threat to human health and the ecosystem thereby necessitating adequate monitoring. The Niger Delta is an oil producing area with major oil facilities and industrial activities. Incessant crude-oil spill, gas flaring, and dumping of petroleum wastes associated with heavy metals raises much concerns. Heavy metal pollution is detrimental to the health of the environment [3].

When dissolved in ionic forms, heavy metals are notable for their toxicity. The toxicity, persistency, and bioaccumulation properties of these metals could lead to serious environmental loss [4]. Frequent decline in genetic diversity of organism was observed in heavy metals polluted Southeast Korean waters [5]. Significant reduction of species richness was reported in heavy metals contaminated waters [6]. In human, heavy metals could affect the arterial systems of the kidneys and also cause abnormal conditions in the gastrointestinal tract and nervous system [7]. During feeding activities, aquatic organisms incorporate heavy metals into their tissues and pass it into the food chain [8]. Understanding the potential ecological risk of heavy metals is critical for the management of these metals in aquatic systems.

Ikpa River is one of the important rivers flowing into the Cross River creek before finally emptying into the Atlantic Ocean. Anthropogenic activities such as industrial discharge, farming, sand mining and dredging, have greatly influenced the water quality of the river. Aquatic macrophytes in Ikpa River were studied with recommendations that chemical fertilizer be discontinued in the floodplain [9].

Spatial variations in physico-chemical variables and nutrients along Ikpa River were assessed with conclusions that high nutrient levels affect the water quality of the river [10]. It has been confirmed that the topsoil of Ikpa River adjoining floodplain is heavily contaminated with heavy metals resulting from fertilizers application [11]. Toxic chemicals, heavy metals and suspended solids have been recorded in surface runoff draining into Ikpa River [12]. Despite few available studies on Ikpa River, comprehensive heavy metal assessment in the river has not been reported. The present study aims at assessing the spatial and seasonal variations of Pb, Fe, Ni, Cd, Cr, and Cu, along the river course. This study is significant for adequate management of the river.

2. Materials and Methods

2.1 The Study Area

Ikpa River is one of the major rivers in the Niger Delta region of Nigeria (Figure 1). With a total length of about 53.5 km between its source and the point of discharge, it is characterised by a small perennial rainforest and drains a catchment area of 516.5km^2. Nigeria has a tropical climatic condition with two weather seasons. Wet season is between April and September while dry season is from October to March. The southern coast is characterised by mangrove forests and swamps, with hot humid temperatures along the Niger Delta. In the river, transparency varies between 12.5 cm to 100 cm, and the substrate is made up of fine sand, mud/sand, and organic debris. The river has current a velocity ranging between 3.5 – 6.9 cm/s.

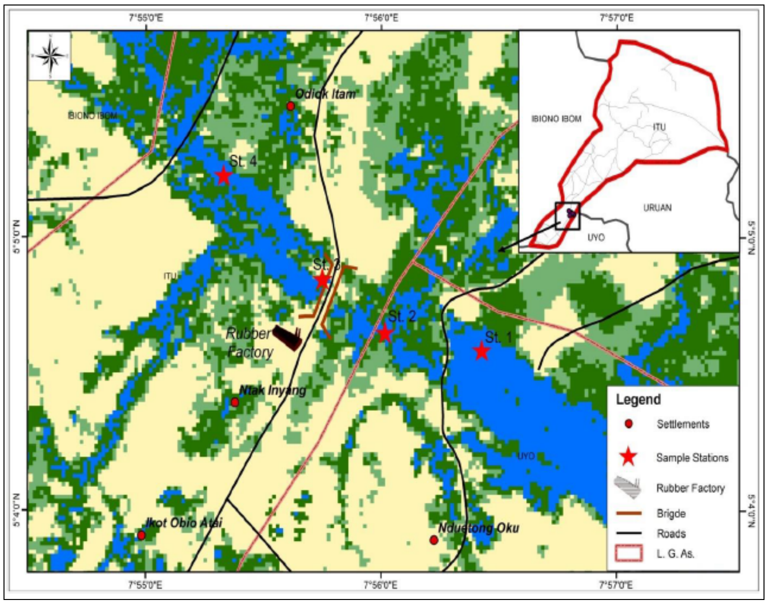

Fig 1: Map of Ikpa River showing sampling stations.

Ikpa River has a rich composition of various floral and faunal communities which are subjected to alteration by a wide range of industrial and agricultural activities going on in the area. A large oil palm processing mill is sited along the River where the wastewaters from the mill is discharged into the river course. There are rubber processing industries which channels wastewaters into the river as well. Bordered by a rich fertile soil, the adjoining land is used for crop production.

2.2 Sampling Stations

Four sampling stations were established along the river course. Station one (Latitude 5.09° 62′ 8.53″ N and Longitude 7.89° 89′ 69.861″ E) was located upstream. Bordered by thick riparian vegetation, human activities such as fishing and farming is prevalent around this station. It is the point where artisanal fishers commence and retire from their daily fishing activities. Station two (Latitude 5.09° 42′ 90.551″ N and Longitude 7.91° 61′ 13.701″ E) had palm plantation. Here, palm wine tapping is the major occupation of the coastal dwellers. With the rich fertile soil within this station, vegetables such as waterleaf, fluted pumpkin are cultivated for commercial purposes. Station three (Latitude 5.09° 42′ 45.212″ N, and Longitude 7.92° 86′ 83.498″ E) is characterised by sparsely distributed vegetation. It is an area influenced by anthropogenic perturbations such as effluent deposition, sewage disposal, dredging, and laundry activities. It is also the discharge point of rubber company effluents. Station four (Latitude 5.06° 81′ 42.114″ N and Longitude 7.94° 74′ 59.825″ E) was located downstream and surrounded by riparian forest characterized by vegetation such as *Elaeis guineensis* and *Bambusa vulgaris*,

2.3 Sampling and Laboratory Analysis

During the twelve months field campaign, water samples were collected monthly considering six months for wet season (April – September) and six months for dry season (October – March). At each station, 1 liter of water was collected at 50 cm depth into a pre-washed sample bottle and acidified with nitric acid. This was to ensure that heavy metals did not adsorb to the container during transportation and storage. In the laboratory, heavy metals concentrations were determined following the standard procedures of APHA [13]. Statistical Package for Social Sciences (SPSS) version 20.0 was employed to compute mean, and standard error in the data. Also, two-way analysis of variance (ANOVA) was employed to separate significant differences in mean values computed for stations while paired sample t-test was used to compare seasons. Matlab computer software was used to produce bar graphs representing spatial and seasonal variations.

3. Results
3.1 Spatial Variability
Spatial variations in mean concentrations of six heavy metals recorded during the study is shown in Table 1. In station one, the mean concentrations followed the pattern Fe > Cu > Cd > Pb = Ni = Cr with values 1.455 mg/L, 0.3415 mg/L, 0.005 mg/L, 0.0001 mg/L, 0.0001 mg/L, 0.0001 mg/L respectively. In station two, the mean concentrations followed the pattern Fe > Cu > Cd > Pb > Ni = Cr with values 1.80 mg/L, 0.4455 mg/L, 0.0095mg/L, 0.00025 mg/L, 0.0001 mg/L, 0.0001 mg/L respectively. In station three, the mean concentrations followed the pattern Fe > Cu > Cd > Pb = Ni = Cr with values 1.89 mg/L, 0.4265 mg/L, 0.0145mg/L, 0.0001 mg/L, 0.0001 mg/L, 0.0001 mg/L respectively. In station four, the mean concentrations followed the pattern Fe > Ni > Pb > Cu > Cd > Cr with values 2.055 mg/L, 0.011 mg/L, 0.008mg/L, 0.006 mg/L, 0.005 mg/L, 0.001 mg/L respectively.

Table 1: Spatial Variations (mean ± S.E) in Heavy Metals concentrations in Ikpa River

Heavy Metals (mg/L)	Station 1	Station 2	Station 3	Station 4
Lead (Pb)	0.0001±0.00	0.00025±0.001	0.0001±0.011	0.008±0.001
Iron (Fe)	1.455±0.50	1.80±0.61	1.89±0.64	2.055±0.18
Nickel (Ni)	0.0001±0.00	0.0001±0.00	0.0001±0.00	0.011±0.006
Cadmium (Cd)	0.005±0.002	0.0095±0.003	0.0145±0.003	0.005±0.001
Chromium (Cr)	0.0001±0.00	0.0001±0.00	0.0001±0.00	0.001±0.00
Copper (Cu)	0.3415±0.23	0.4455±0.30	0.4265±0.29	0.006±0.002

± S.E = Standard Error

Highest Pb value was recorded in station four with mean value of 0.008±0.001 mg/L while station one recorded the lowest concentration of Pb (0.0001±0.00 mg/L). Fe concentrations in the river increased from station one (1.455 ± 0.50 mg/l) to station four (2.055±0.18 mg/l). Ni concentrations in the river was higher in station four with the mean value of 0.011±0.006 mg/l while the remaining stations recorded same low values of 0.0001±0.00 mg/L respectively. Highest Cd value was recorded in station three with the mean value of 0.0145±0.003 mg/L while station one and station four had the lowest value of 0.005±0.002 mg/L and 0.005 ± 0.001 mg/L respectively. Cr value was higher in station four (0.001 ± 0.00 mg/L), while the remaining stations recorded the least value of 0.0001 ± 0.00 mg/L respectively. Station two had the highest value of Cu (0.4455 ± 0.30 mg/l) while station four had the lowest Cu concentration of 0.008 ± 0.002 mg/L. Statistically, there was no significant difference in respective metal concentrations across the four stations and all the metals were within the recommended limit of WHO [14]. Figure 2 revealed that high concentration area of heavy metals were mainly at the downstream reaches of the Ikpa River which could be attributed to the disequilibrium of industrial, agricultural and municipal waste discharge prevalent in the area.

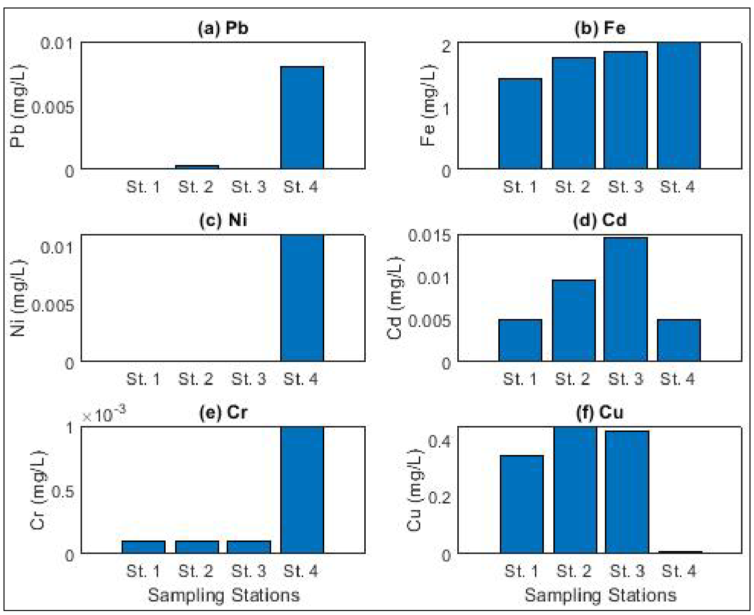

Fig 2: Spatial Variation of Heavy Metal Concentration in Ikpa River

3.2 Seasonal Variability
Seasonal variations in average concentrations of the six heavy recorded during the study is shown in Ikpa River in Table 2. In wet season, average concentrations followed the pattern Fe > Cd > Ni > Pb > Cu > Cr with values 0.59 mg/L, 0.0105 mg/L, 0.005075 mg/L, 0.002575 mg/L, 0.00225 mg/L, 0.000325 mg/L respectively. In dry season, average concentrations followed the pattern Fe > Cu > Cd > Pb > Ni > Cr with values 3.01 mg/L, 0.6075 mg/L, 0.0065 mg/L, 0.00165 mg/L, 0.000575 mg/L, 0.000325 mg/L respectively. Table 2 reveals that the concentration values of Pb, Ni, and Cd in the wet season were higher than that of the dry season while Fe and Cu content were higher in dry season than in wet season. Cr content remained the same in both seasons. Statistically, only Fe showed significant seasonal variation ($p<0.05$) in concentrations.

Table 2: Average Seasonal Variations (mean ± S.E) in concentrations across four stations

Heavy Metals (Mg/L)	Wet Season	Dry Season	FEPA 2003	WHO 2017
Lead (Pb)	0.002575±0.00	0.00165 ± 0.00	0.01	0.01
Iron (Fe)	0.59 ± 0.10 *	3.01 ± 0.59 *	0.2	-
Nickel (Ni)	0.005075 ± 0.00	0.000575 ± 0.00	0.02	0.07
Cadmium (Cd)	0.0105 ± 0.00	0.0065 ± 0.00	0.03	0.003
Chromium (Cr)	0.000325 ± 0.00	0.000325 ± 0.00	-	0.05
Copper (Cu)	0.00225 ± 0.00	0.6075 ± 0.39	0.05	2.0

± S.E = Standard Error, * = significant at $p<0.05$

Table 3-6 shows seasonal variations in heavy metals concentrations from station one to station four respectively. Table 3 shows that Fe, Cd and Cu were higher in dry season while Pb, Ni and Cr remained the same in both seasons. Table 4 revealed that Pb, Fe, and Cu were higher in dry season, Cd was higher in wet season while Ni and Cr remained the same in both seasons. Table 5 revealed that Fe and Cu were higher in dry season while Cd was higher in wet season. However, Pb, Ni and Cr remained the same in the same in both seasons. Table 6 showed that Fe and Cu were higher in dry season while Pb, Ni and Cd content were higher in wet season and Cr remained the same in the same in both seasons. Statistically, Fe showed seasonal difference in stations one (t = 3.635, $p<0.05$), station two (t = 3.939, $p<0.05$) and station three (t = 4.118, $p<0.05$).

Table 3: Seasonal Variations (mean ± S.E) in Heavy Metals concentrations (Station One)

Heavy Metals (Mg/L)	Wet Season	Dry Season	FEPA 2003	WHO 2017
Lead (Pb)	0.0001±0.00	0.0001±0.00	0.01	0.01
Iron (Fe)	0.19±0.02*	2.72±0.70*	0.2	-
Nickel (Ni)	0.0001±0.00	0.0001±0.00	0.02	0.07
Cadmium (Cd)	0.003±.001	0.007±0.004	0.03	0.003
Chromium (Cr)	0.0001±0.00	0.0001±0.00	-	0.05
Copper (Cu)	0.003±.001	0.68±0.43	0.05	2.0

± S.E = Standard Error, * = significant at $p<0.05$

Table 4: Seasonal Variations (mean ± S.E) in Heavy Metals concentrations (Station Two)

Heavy Metals (Mg/L)	Wet Season	Dry Season	FEPA 2003	WHO 2017
Lead (Pb)	0.0001±0.00	0.0004±0.00	0.01	0.01
Iron (Fe)	0.20±0.02*	3.40±0.81*	0.2	-
Nickel (Ni)	0.0001±0.00	0.0001±0.00	0.02	0.07
Cadmium (Cd)	0.01±0.00	0.009±0.00	0.03	0.003
Chromium (Cr)	0.0001±0.00	0.0001±0.00	-	0.05
Copper (Cu)	0.001±0.00	0.89±0.57	0.05	2.0

± S.E = Standard Error, * = significant at $p<0.05$

Table 5: Seasonal Variations (mean ± S.E) in Heavy Metals concentrations (Station Three)

Heavy Metals (Mg/L)	Wet Season	Dry Season	FEPA 2003	WHO 2017
Lead (Pb)	0.0001±0.00	0.0001±0.00	Yes	0.01
Iron (Fe)	0.21±0.02*	3.57±0.82*	0.2	-
Nickel (Ni)	0.0001±0.00	0.0001±0.00	0.02	0.07
Cadmium (Cd)	0.02±0.00	0.009±0.00	0.03	0.003
Chromium (Cr)	0.0001±0.00	0.0001±0.00	-	0.05
Copper (Cu)	0.003±0.00	0.85±0.56	0.05	2.0

± S.E = Standard Error, * = significant at $p<0.05$

Table 6: Seasonal Variations (mean ± S.E) in Heavy Metals concentrations (Station Four)

Heavy Metals (Mg/L)	Wet Season	Dry Season	FEPA 2003	WHO 2017
Lead (Pb)	0.01±0.00	0.006±0.00	0.01	0.01
Iron (Fe)	1.76±0.35*	2.35±0.01*	0.2	-
Nickel (Ni)	0.02±0.01	0.002±0.00	0.02	0.07
Cadmium (Cd)	0.009±0.00	0.001±0.00	0.03	0.003
Chromium (Cr)	0.001±0.00	0.001±0.00	-	0.05
Copper (Cu)	0.002±0.00	0.01±0.00	0.05	2.0

± S.E = Standard Error, * = significant at $p<0.05$

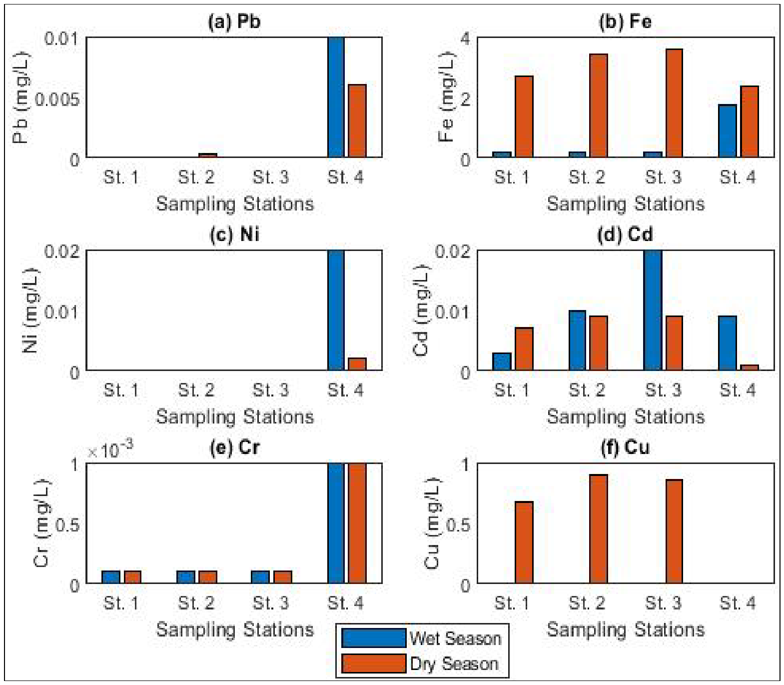

Fig 3: Seasonal variation of the heavy metals across stations

4. Discussion

Water samples were analysed to assess heavy metal concentrations in Ikpa River. Results revealed that heavy metal pollution increased spatially from station one to station four. This result reflects the level of anthropogenic activities taking place in respective stations. Station three was influenced by serious anthropogenic perturbations such as effluent deposition, sewage disposal, dredging, and laundry activities. It is also the discharge point of rubber company effluents. Due to river flow direction, station four also recorded significant concentrations of some metals. High levels of heavy metals in station three and four give credence to the fact that the water quality of the river is deteriorating. This agrees with earlier report that high metal contaminants in Nigerian waters results from increased human population and proliferation of industries [15].

During the field survey, it was observed that the adjoining land is used for agricultural activities. Topsoil of the farmland is likely contaminated with heavy metals as a result of fertilizer application to improve the soil fertility. This supplies high quantity of heavy metal concentration from the farmland to the river during irrigation or rainstorm. Earlier report revealed that surface run-off draining into Ikpa River contains heavy metals and other toxic chemicals resulting from poorly disposed wastes on the hinterlands [12]. This explains why some metals had greater concentration in rainy season than in dry season. Heavy metals such as Cd, Pb, and Ni were also recorded in this river and these metals are known for extreme toxicity even at trace levels [3].

Although mean concentration of Pb was within the WHO [14] recommended limits, average Pb content was higher in rainy season than dry season. Pb concentrations in the river could be attributed to runoff from hinterland. Significant amount of Pb originating from traffic emissions, municipal and industrial wastes are usually transported into urban rivers through surface run-off. Unfortunately, Pb suppresses the supply of metabolic products that acts as electron accepters [16]. Despite the fact that Fe lacks WHO [14] guideline value, its concentration values in the present study were significantly higher than what is permitted by federal environmental protection agency (FEPA) in Nigeria. Higher values of Fe in the study could be attributed to leaching from erosion site as well as deposition from surface runoff [17]. Although Fe is present in natural fresh waters, high concentrations is undesirable. Ni was also recorded with concentrations within the WHO [14] permissible limit. This metal is widespread in areas of industrial activity following its role in manufacturing processes. Ni is however regarded as an essential element to plants but its usefulness to man is yet to be established [18]. Accumulation of Ni in humans could lead to lung fibrosis, cardiovascular, kidney diseases [19] and certain Ni compounds are assumed to be carcinogenic.

Wet season concentrations of Cd in station one was at the threshold of the permissible limit while the remaining three stations exceeded the WHO [14] permissible limit. Apart from domestic sources, Cd and its compounds have also been linked to vehicle tyres. Uncontrollable burning of vehicle tyres contributes to Cd levels in the environment. High levels of Cd recorded in wet season could be attributed to discharge of domestic effluents, sewage discharge and urban runoff. Implication of Cd toxicity include alteration of biomolecules, modulation of DNA repairs and genotoxic consequences. Genome stability is influenced through inhibition of DNA repair and generation of free radical-induced damage. At the cellular stage, Cd is known to induce oxidative stress by reducing endogenous antioxidants. Mitochondrial damage, induction of apoptosis and interference with intracellular calcium signaling has also been attributed to Cd [20].

Cr concentrations in all sampling stations were within the WHO permissible limit. Possible sources of Cr in the river include abandoned metals from dredging activities and engine boat repairs. It may also be unconnected with inputs from anthropogenic sources such as waste water derived from adjoining companies. Emissions from vehicle in the hinterland could also be a possible source [21]. High Cu levels in all stations during dry season could be attributed to surface runoff resulting from farm irrigation in the hinterland as well as the dumping of waste in the stations. Dredging and harbour activities along the shoreline could also be a possible source. Cu concentrations in water has been reported to pose a great ecological risk to aquatic species [22]. Ikpa River has great specie biodiversity and heavy metals presence could likely affect both the species diversity and the ecosystem.

As one of the most important rivers in the Niger Delta, most of the commercial important fish species in Nigeria are present in the River. However, with several anthropogenic perturbations taking places within and around the river, heavy metals toxicity and accumulative tendency could modify the species diversity of aquatic organisms as well as the ecosystem. Cd and Pb also recorded in the present study are known to have no identified important role in the body of aquatic organisms but these metals have characteristic high toxicity even at low concentrations [23]. Heavy metals accumulation in marine organisms depends on the feeding behavior, physiological characteristic of the organisms as well as the biological function of heavy metals [24]. This infers that the extent of heavy metal accumulation in aquatic organisms likely depends on the species and its feeding habits.

Fish is a rich source of proteins with nutritional and therapeutic benefits [25]. Vital minerals, vitamins and long-chain polyunsaturated omega-3 fatty acids are also obtained from fish consumption [26]. Since Ikpa River is one of the main sources of fishes in the Niger Delta Region of Nigeria, it is risky for concentrations of these heavy metals in the river to exceed WHO and FEPA recommended limit. However, due to rapid industrial and agricultural development together with high population growth in the hinterland, heavy metals pollution is inevitable in the river and it constitutes a significant environmental hazard to shell and fin-fishes. In Nigeria, most of the riverine communities use river waters for domestic activities. At the peak of the dry season, Ikpa River becomes a source of water for household activities thereby exposing the riverine communities to health hazards. Vegetable gardens at the river bank are usually irrigated with the water from the river thereby posing a high risk of food poisoning if heavy metals in the river increases beyond the permissible limit.

5. Conclusion

Monitoring the aquatic environment serves the urgent need of protecting aquatic resources and reducing health risk in human. This study assessed the spatial and seasonal concentrations of heavy metals in Ikpa River with the aim of providing information for monitoring and management strategies. Apart from species abundance and biodiversity, water from the river is used for irrigation and other domestic activities. It is necessary to protect this river from pollution thereby reducing environmental risks. We therefore recommend regular monitoring of the river. Further investigations on the biological effects of heavy metals in the river would probably provide the much needed information on the taxonomy of the available aquatic species. Pollution control and management policies should be formulated and implemented accordingly.

6. References

1. Dimari GA, Abdulkarim FI, Akan JC, Garba ST. Metal concentrations in Tissues of *Tilapia galier, Clarias lazera,* and Osteoglossidae caught from Alau Dam, Maiduguri, Borno State, Nigeria. American Journal of Environmental Sciences. 2008; 4(4):473-379.
2. Sun Z, Mou X, Tong C, Wang C, Xie Z, Song H *et al*. Spatial variations and bioaccumulation of heavy metals in intertidal zone of the Yellow River estuary, China, Catena. 2015; 126:43-52.
3. Akintujoye JF, Anumudu CI, Awobode HO. Assessment of heavy metal residues in water, fish tissue and human blood from Ubeji, Warri, Delta State, Nigeria. Journal of Applied Science and Environmental Management. 2013; 17(2):291-297.
4. Ikem A, Egiebor NO, Nyavor K. Trace Elements in Water, Fish and Sediment from Tuskegee Lake, Southeastern USA. Water, Air & Soil Pollution. 2003; 149:51-75.
5. Kim SJ, Rodriguez-Lanetty M, Suh JH, Song JI. Emergent effects of heavy metal pollution at a population level: *Littorina brevicula* a study case. Marine Pollution Bulletin. 2003; 46(1):74-80.
6. Johnston EL, Roberts DA. Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. Environmental Pollution. 2009; 157(6):1745-1752.
7. Chen Q, Lu Z, Yan D, Wang Q, Xin S. Source analysis and health risk of heavy metals in the different seasons from Taizihe River, China. Acta Ecological Sinica. In Press, 2019.
8. Li S, Zhang Q. Spatial characterization of dissolved trace elements and heavy metals in the upper Han River (China) using multivariate statistical techniques. Journal of Hazardous Materials. 2010; 176:579-588.
9. Ekpo IE, Onuoha GC, Chude LA. Diversity and Variability of Aquatic Macrophytes in Ikpa River, Ikot Ebom (Akwa Ibom State) Nigeria. Nigerian Journal of Agriculture, Food and Environment. 2011; 7(2):1-9.
10. Ekpo IE, Chude LA, Onuoha GC, Udoh JP. Studies on the physico-chemical characteristics and nutrients of a tropical rainforest river in southeast Nigeria. International Journal of the Bioflux Society. 2012; 5(3):142-162.
11. Dennis EI, Essien RA, Udoh UH. Heavy Metal Runoff Dynamics from Farmland around IKPA River Basin, Nigeria, Current World Environment. 2013; 8(2):241-250.
12. Ukpong EC. Impact of Surface Run-Off on Ikpa River in Akwa Ibom State. International Journal of Research in Earth & Environmental Sciences. 2015; 2(9):7-15.
13. APHA. Standard Methods for the examination of Water and Waste Water. 21st Edition., New York: American Public Health Association, 2005, 1498pp.
14. WHO. Guidelines for Drinking-water Quality. World Health Organization, Geneva, Switzerland. 4th Edition, 2017, 631pp.
15. Ugwu LLC, Mgbenka BO, Ugwuaka KA. Effect of Industrial Effluents and Municipal Wastes on Aspects of Water Quality of Ogba River, Benin City, Nigeria. Journal of Aquatic Sciences. 2008; 23(1):1-12.
16. Nunez-Delgado B, Morrison L, Gulson L. Threshold of concern: a technique for evaluating environmental impact and amenity values. Journal of forestry. 2002, 84-86.
17. Song J, Xiaogana Y, Junlon Z, Yongging L, Yan Z, Taifan Z. Assessing the Variability of Heavy Metal Concentrations in Liquid Solid Two Phase and Related Environmental Risks in the Weine River of Shaanxi Province, China. International Journal of Environmental Resources and Public Health. 2015; 12(7):8243-8262.
18. Chen J, Teo KC. Determination of cobalt and nickel in

water samples by flame atomic absorption spectrometry after cloud point extraction. Analytica Chimica Acta. 2001; 434:325-330.
19. Salnikow K, Denkhaus E. Nickel essentiality, toxicity and carcinogenicity, Critical Review in Oncology/Hematology. 2002; 42(1):35-56.
20. Anetor JI. Rising environmental cadmium levels in developing countries: Threat to genome stability and health. Journal of Environmental and Analytical Toxicology. 2012; 2:4.
21. Ahmed TAI, Ekbal TW, Mariana SA. Heavy metals Assessment in water, sediments and some organs of *Oreochromis niloticus* under the Impact of sewage water. Journal of Heavy metal Toxicity and Diseases. 2016; 24(5):61-6.
22. Fu Z, Wu F, Chen L, Xu B, Feng C, Bai Y *et al.* Copper and zinc, but not other priority toxic metals, pose risks to native aquatic species in a large urban lake in Eastern China. Environmental Pollution. 2016; 219:1069-1076.
23. Ogar E, Nnammonu LA, Wuana RA, Etim EE. Bioaccumulation of Trace Heavy Metals in Freshwater *Clarias gariepinus* of North Central Nigeria. International Journal of Modern Chemistry. 2013; 4(1):38-49.
24. Sfakianakis DG, Renieri E, Kentouri M, Tsatsakis AM. Effect of heavy metals on fish larvae deformities: Environmental Research Reviews. 2015; 137:246-255.
25. Rajeshkumar S, Li X. Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicology Reports. 2018; 5:288-295.
26. Kris-Etherton P, Harris W, Appel L. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease, Circulation. 2002; 106:2747-27.