THE HEAVY METALS AND BENTHIC MACROINVERTEBRATES DIVERSITY AND ABUNDANCE OF OYUN RIVER SEDIMENTS, ILORIN, KWARA STATE, NIGERIA

ADEYEMI-ALE OLUTOMI ADEOLA AND TIJANI TIJANI OPEYEMI
Department of Zoology, Faculty of Life Sciences, University of Ilorin, Ilorin, Kwara State, Nigeria.

ISSN: 2141 – 3290
www.wojast.org

ABSTRACT
Anthropogenic activities in and around water bodies disrupt their physico-chemical and biological conditions such as sediment qualities and diversity of benthic macroinvertebrates. The purpose of this study was to assess the pH and heavy metal (Mn, Zn, Fe, Cu, Pb, Ni, Cr, Co and Al) contents of the sediments and the occurrence of benthic macroinvertebrates of Oyun river, Ilorin East local government area, Ilorin, Kwara state, Nigeria. Three sampling locations (upstream, midstream and downstream), 500 m apart were selected along the river based on the flow of water current. The kick method (using sweep net) was used to collect sediments and benthos once every two weeks from February to May, 2016. One-way ANOVA was used to assess the variations among the values and the sampling stations, and the macroinvertebrates were identified using standard identification guidelines. The pH of the sediments was alkalinic with mean values 8.39±0.30, 8.14±0.34 and 7.95±0.57 at the upstream, midstream and downstream respectively. All the heavy metals exceeded threshold limits and highest at the downstream. A total of 5 macroinvertebrate species belonging to 2 classes (Insecta 68.97% and Gastropoda 31.03%) were identified. The most abundant species was *Chironomus plomusus* while the least abundant was *Laccophilus congener* accounting for 36 (41.38%) and 1 (1.15%) respectively. The low abundance of benthic macroinvertebrate species coupled with the non-occurrence of EPT indexed taxa and the higher abundance of the pollution-tolerant taxa (*Chironomus plomusus*) could reflect the level of pollution stress of this Oyun River system. Therefore, strict pollution management of this river is recommended.

INTRODUCTION
Water is a very important resource because it is needed for existence of life on earth and in the daily activities of man (Adeyemi-Ale *et al.*, 2014). The two main sources of water are surface water (which include lakes, streams, rivers, etc) and groundwater (which include boreholes, wells, springs, etc). Water covers about 75% of the earth's surface. Thus, we find immense quality of water constituting the hydrosphere, referred to as the water earth's surface (Adjarho *et al.,* 2013). Water is essential to every living organism and inadequate quantity and quality of water have serious influence on sustainable development (Taiwo *et al.,* 2012). Water does not only serve as habitats for its living organisms but also as a medium of gaseous exchange and nutrient (Taiwo *et al.,* 2012).

The management and mobilization of water based on different needs is seen to be an important central point of many federal, state, local and private agencies (Nelson and Lieberman, 2002). The task of balancing those compelling demands of water are sometimes difficult for management agencies because they lack the information needed to make sound decisions, especially for fishes and wildlife. These operational changes may result in modification in the downstream lotic community such as aquatic invertebrate (Vinson, 2001). Water sources such as rivers, stream, well etcetera are the proximate source of water to the people in developing African countries especially in the sub Saharan Africa and the water bodies are likely to cause diseases as they are said to be polluted with domestic, industrial and agricultural wastes (Ojekunle, 2000 and Ayeni *et al.,* 2009). The main sources of water pollution may include agricultural run-off, accidental oil spillage, municipal wastes, industrial wastes, and waste products of free-range animals or migratory or wandering birds.

Sediments can be used to assess the anthropogenic impacts of an aquatic ecosystem since they reflect both the quality of the aquatic system and also the insoluble contaminants in the surface waters (Ogbuagu and Samuel, 2014). Macroinvertebrates include different species of organisms that have no backbone such as various groups of worms (flatworms, eelworms, segmented roundworms), mollusks (snails and bivalves), crustaceans (shrimps, crayfish and other shrimp-like groups), mites and all insects (Winterbourn *et al.*, 1981). Benthic macroinvertebrates are organisms found residing on or inside the bottom sediment of water bodies (Barnes and Hughes, 1999; Adu *et al.*, 2016).

They are often used as bioindicators of pollution, and they play a very vital role in the aquatic food chain as they serve as source of food for larger aquatic organisms and in turn make algae and bacteria which occupy a lower position on the food chain as their own source of food (Olomukoro *et al.,* 2013). They do not serve as food for fish alone but also help in the biodegradation of large amount of nutrients (Neetuh and Ramesh, 2014). Compared to chemical and microbiological data which tend to fluctuate in a very short period of time, macrobenthic invertebrates are better bio-indicators that give very correct information on changing aquatic conditions (Ravera, 1998, 2000; Ikomi *et al.,* 2005) and useful information can be provided about the ecological integrity of a system (Mekdes and Getachew (2020).
The various anthropogenic activities in and around Oyun river may have adverse effects on the sediment quality and the ecology of its indigenous species. The information on the

pH and heavy metal contents of the sediments and macroinvertebrates of this river is scarce. Therefore, this study assessed the pH, heavy metal contents of the sediments of Oyun river and also the abundance and diversity of the benthic macro invertebrates to assess its health status and exposure to pressures due to pollution stress.

MATERIALS AND METHODS

Description of the study area

Oyun River (Figure 1) located in Oyun, Ilorin East local government area, Ilorin, Kwara state, Nigeria lies on latitude 08º7'60" North of the Equator and longitude 04º19'00" East of Greenwich Meridian. It supplies water for domestic use to the people around it. Subsistence fishing, farming, water draining for domestic use and excavation of bottom sediment are the major activities carried out in and around the river. It serves as a recipient of refuse, faecal materials, sewage, agricultural runoff, automobile wastes from the washing of automobiles.

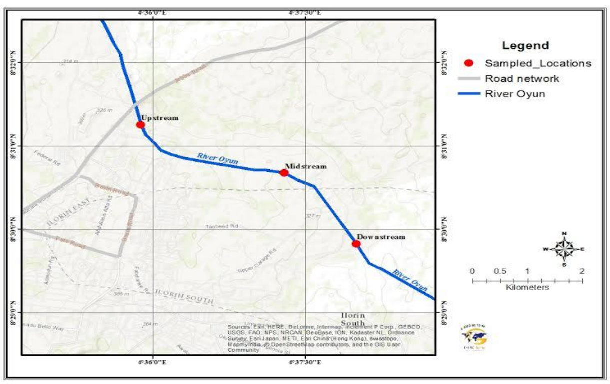

Figure 1: Map of Oyun river showing sampling stations

Collection of sediment and benthic macroinvertebrates' samples

Sediment and benthic macroinvertebrates' samples were collected every two weeks from February to May 2016 between 7:00 am to 9:00 am. The kick method with the use of sweep net was used to collect both samples at the upstream, midstream and downstream of the river. The sampled points were 500 m apart from each other. Organisms trapped in the net were picked and dropped in well labelled sample bottles and preserved in 90% ethanol. Both sediments and macroinvertebrates were taken to the laboratory.

Measurement of sediment variables

At the laboratory, the sediments were air-dried at room temperature of 27^{0}C until they reach a constant weight. After this, they were pulverized separately with porcelain mortar and pestle, and then sieved through 2 mm sieve.

pH was measured by mixing 20 g of the processed sediment with 20 ml of distilled water (ratio 1:1) and allowed to stay for 30 minutes with occasional stirring, then an electronic pH meter (Oakton waterproof instruments phlestr10) was dipped.

Heavy metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb) were determined using the Alpha Atomic Absorption Spectrophotometer after the aqua-regia (3:1 hydrochloric/ nitric acid) digestion (Chen and Ma, 2001).

Identification of benthic macroinvertebrates

The preserved benthic macroinvertebrates were identified in the laboratory following the keys provided by Macan (1959), Quigley (1977), Gerber and Gabriel (2002) and Voshell (2002).

DATA ANALYSIS

pH and heavy metals analysis

The values of pH and heavy metals were subjected to one-way analysis of variance (ANOVA) to check for variations among the values and the sampling stations. SPSS statistical software version 20 and Microsoft Excel Spreadsheet were used for data analysis and graph.

Biological parameters

Biological parameters were used to analyse benthic macroinvertebrates data. These are:
Shannon Weiner's diversity (Equation 1) to measure the fauna diversity:

$$\mathbf{Hs} = \sum\{(\mathbf{Pi}) \times \ln(\mathbf{Pi})\} \qquad 1$$

Where Hs = diversity index
Pi = proportion of total sample represented by species
ln = natural logarithm
i = division of number of individuals of species i by the total number of samples
Shannon's Evenness measures (Equation 2) to measure relative density:

$$E = \frac{Hs}{\ln(S)} \qquad 2$$

Where Hs = Shannon Wiener's index
s = number of species' richness
Sorensen's coefficient (Equation 3) to measure the quotient of similarity:

$$CCS = \frac{2C}{S_1 + S_2} \qquad 3$$

RESULTS

Concentrations of pH and heavy metals

The mean and standard error values of the pH and heavy metals of the sediment samples are shown in Table 1. The pH of the sediment showed that they were alkalinic. The highest pH value (8.39±0.30) was recorded at the upstream while the lowest (7.95±0.57) was at the downstream. There was no significant difference (P<0.05) in the pH values of the three sampling stations. There are no pH limits set for threshold effect level (TEL) and effects range low (ERL) (Macdonald *et al.*, 2000), sediment quality advisory value

(SQAV) (Swartz, 1999) and interim sediment quality guideline (ISQG) (ANZECC, 1997).

There were very high levels of Mn, Zn and Fe at all the three stations of Oyun River. The concentrations of the heavy metals reflected the order: Mn > Zn > Fe > Cu > Pb > Ni > Cr > Co > Al (upstream) and Mn > Zn > Fe > Cu > Ni > Pb > Cr > Co > Al (both midstream and downstream). All the metal values recorded at the sampling stations were highest at the downstream. There were no significant differences of metal values of the three sampling stations. However, Co at the upstream (265.63±46.61) and midstream (332.00±39.86) were significantly different from each other at $P<0.05$. There were no set limits of TEL, ERL, SQAV and ISQG for Al, Mn, Fe, Co. However, the concentrations of Cr, Ni, Cu, Zn and Pb showed that they were extremely higher than the sediment quality guidelines.

Diversity of Benthic Macroinvertebrates

Throughout the sampling period, a total of 87 individual benthic macroinvertebrates were encountered which spread across 5 orders, 5 families, 5 genera and 5 species. Four (68.97%) of them belong to the phylum Arthropoda, class insecta (*Aeshna cyanea* (20), *Laccophilus congener* (1), *Chironomus plomusus* (36) and *Calopteryx virgo* (3)) while one (31.03%) belongs to the phylum Mollusca (27), class gastropoda, (*Melanoides tuberculata*) (Table 2; Figure 2). *Chironomus plomusus* of the order Diptera was the most abundant (41.38%) while *Laccophilus congener* (1.15%) was the least abundant. Throughout the sampling days in the month of May, no organism was found.

Table 1: Mean and standard error of the physicochemical parameters of Oyun river sediment

	Upstream	Midstream	Downstream	TEL	ERL	SQAV	ISQG
pH	8.39±0.30[a]	8.14±0.34[a]	7.95±0.57[a]	-	-	-	-
Al	153.38±55.98[a]	226.25±108.84[a]	227.75±92.62[a]	-	-	-	-
Cr	400.88±64.45[a]	406.88±87.94[a]	417.38±90.71[a]	37.3	80	36	80
Mn	4750.00±1350.65[a]	4857.50±1418.05[a]	4952.50±1508.84[a]	-	-	-	-
Fe	1995.00±564.17[a]	2267.50±503.81[a]	2301.25±444.31[a]	-	-	-	-
Co	265.63±46.61[a]	305.38±26.98[ab]	332.00±39.86[b]	-	-	-	-
Ni	482.50±150.96[a]	565.50±177.76[a]	678.25±227.14a	18	30	20	21
Cu	793.75±525.36[a]	798.00±494.32[a]	902.75±572.65[a]	35.7	70	28	65
Zn	3198.75±729.25[a]	3232.50±681.36[a]	3427.50±538.56a	123	120	98	200
Pb	547.63±146.22[a]	562.36±92.27[a]	612.13±49.57[a]	35	30	37	50

The Shannon Weiner's diversity values for the upstream, downstream and midstream were 0.89, 0.80 and 0.48 respectively and Shannon's evenness values were 0.81, 0.72 and 0.43 respectively (Table 3).

The sampling stations were very similar in terms of benthic macroinvertebrate. The Sorensen's coefficient is 1 because not more than 3 species of organisms were found at each station. In terms of species' richness, *Chironomus plomusus* was the highest because it had the highest number (30) of individuals.

DISCUSSION

The results recorded from this study indicated that there were varying degrees of contamination of the Oyun River through anthropogenic activities. The alkalinic nature of the sediment might be due to the production of ammonia which is as a result of decomposition of the organic sediment (Adeogun and Fafioye, 2011). Similar basic pH at this river was also reported by Okoro and Jimoh (2016). The alkalinic nature of the stream may be a hindrance to the occurrence of fauna at this study site.

Table 2: Benthic macroinvertebrates diversity, distribution and abundance at Oyun river sediment, Ilorin, Kwara state

Benthic Macroinvertebrates	Upstream	Midstream	Downstream	Total	Percentage Abundance
Arthropoda (Insecta)					
Aeshna cyanea (Muller, 1764) Order: Odonata Family: Aeshnidae	7	9	4	20	22.99
Laccophilus congener (Regimbart, 1889) Order: Coleoptera Family: Dytiscidae	1	-	-	1	1.15
Chironomus plomusus (Linnaeus, 1758) Order: Diptera Family: Chironomidae	6	-	30	36	41.38
Calopteryx virgo (Linnaeus, 1758) Order: Odonata Family: Calopterygidae	-	3	-	3	3.45
Mollusca (Gastropoda)					
Melanoides tuberculata (Muller, 1774) Order: Sorbeoconcha Family: Thiaridae	-	26	1	27	31.03
TOTAL	14	38	35	87	

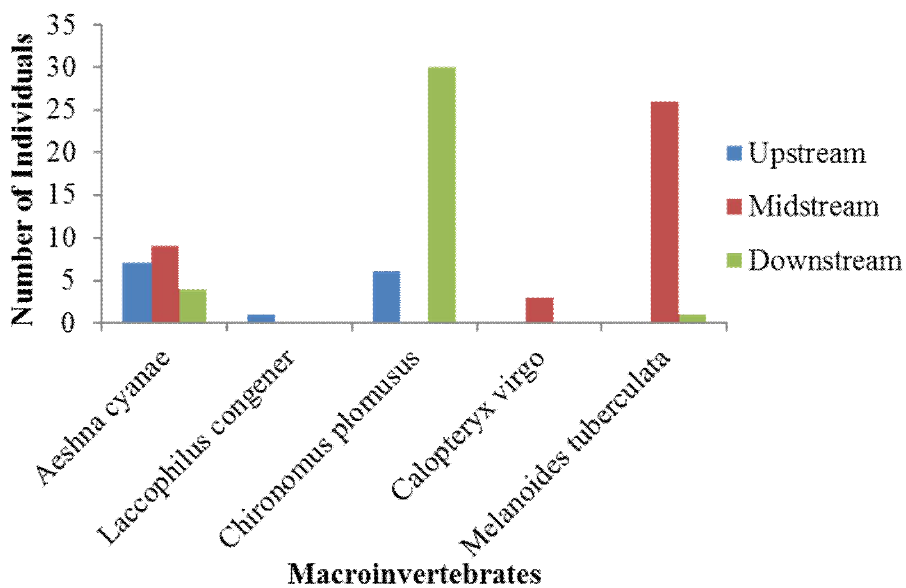

Figure 2: Population of benthic macroinvertebrates at the Oyun stream

Table 3: Diversity indices of benthic macroinvertebrates

Sites	Shannon Weiner	Shannon's Evenness	Sorenson's Coefficient
Upstream	0.89	0.81	1
Midstream	0.80	0.72	1
Downstream	0.48	0.43	1

There are no sediment quality guidelines available in Nigeria. However, there are standards that are universally acceptable. Not all quality guidelines for the analysed heavy metals limits are available. All the ones available (Cr, Ni, Cu, Zn and Pb) exceeded the threshold effect level (TEL) and effects range low (ERL) (Macdonald *et al.*, 2000), sediment quality advisory value (SQAV) (Swartz, 1999) and interim sediment quality guideline (ISQG) (ANZECC, 1997). This shows very high rate of contamination of the Oyun River and adverse effects on the aquatic fauna present in the water body. Metals in the sediment could be as a result of physical and chemical processes (Yan *et al.*, 2018)

The health status of Oyun river system might have been revealed by the diversity indices values which are strong bio-indicator of ecosystem health (Gaskill, 2014). The low diversity of the study sites might be due to the high concentration of lead which inhibit growth of organisms and also cause water and mineral imbalances (Mishra *et al*., 2006). Copper and zinc also have strong negative on taxonomic richness as reported by Armitage (1980) and Malmqvist and Hoffsten (1999). Soils of Kwara State have naturally highest concentration of iron (Ogunwale and Adesoye, 1994). Anthropogenic activities (such as washing of automobiles) and natural factors that emit Pb might be the reason for the high concentration of Pb (Okoro and Jimoh, 2016).

The source of lead could be from the automobile wastes that are being washed into the stream due to the use of leaded gasoline in the automobiles. Okoro and Jimoh (2016) also observed high concentration of Pb in the sediment obtained from Oyun River. The presence of the pollution tolerant species (*Melanoides tuberculata* and *Chironomus plomusus*) may be tagged to the effect of domestic waste discharge and organic pollution (Atobatele *et al*., 2005 and Adjarho *et al*., 2013). Dipterans are generally tolerant to higher levels of pollutants in streams (Haney *et al*., 2013). This accounts for the presence of *Chironomus spp.* The presence of *Chironomus spp.* shows pollution stress of the stations, especially, the downstream which receives a lot of faecal materials. The presence of the haemoglobin (a pigment that transports and stores dissolved oxygen (Tyokumbur *et al*., 2002) helps these insects to adapt and thrive in polluted aquatic environment (Esenowo *et al*.,2018)

The abundance of mollusc might be attributed to the alkalinity nature of the sediment (Olomukoro and Azubuike, 2009). However, it was also noticed that most of the species encountered were during the dry season and at the beginning of rainy season due to little or complete absence of flow of water. In contrast, there were no organisms found when the rainfall increased in May. This implies that not only temperature and pH have great effect on organisms but also water current, as it may lead to a disorder in food chain, reproduction cycle and impose physiological stress on tolerant species (Adakole and Annune, 2003).

Furthermore, excavation is another factor that could have possibly led to low species diversity, as it might have led to the displacement of most organisms in the upstream and downstream. Initially, the depth of the study site was not deep as the surface water was almost dry and the depth increased towards the end of the last sampling (May). In other words, excavation led to increase in depth, which in turn might lead to depletion of oxygen (even though depth and dissolved oxygen level of the water were not measured).

CONCLUSION

The sediment quality and low benthic macroinvertebrates diversity and abundance of Oyun River showed the poor quality of the river system. The non-occurrence of EPT indexed taxa and the higher abundance of the pollution-tolerant taxa (*Chironomus plomusus*) serve as biological measures reflecting that the river could be under the stress of organic pollution from anthropogenic sources such as refuse, sewage and faecal materials from both human and animals. Therefore, there is need for strict pollution management and consistent and continuous monitoring of this river system.

REFERENCES

Adakole, J.A. and Anunne, P.A. (2003). Benthic macro invertebrates as indicators of environmental quality of an urban stream, Zarie, Northern. *Nigeria Journal of Aquatic Science*. 18(2): 85-92.

Adeyemi-Ale, O.A., Aladesida, A.A. and Esenowo, I.K. (2014). The effect of detergent effluent on the physico-chemical characteristics and plankton diversity of Osere Stream, Ilorin, Kwara State, Nigeria. *Journal of Applied Science and Environmental Management* 18(1): 99-103.

Adeogun, O.A. and Fafioye, O.O. (2011). Impacts of effluents on water quality and benthic macroinvertebrate fauna in Awba stream and reservoir. *Journal of Applied Science and Environmental Management* 15(1): 105 - 113.

Adjarho, U.B. Esenowo, I.K. and Ugwumba, A.A.A. (2013). Physicochemical Parameters and Macroinvertebrate Fauna in Ona River, Oluyole Estate, Ibadan. *Research Journal of Environmental and Earth science* 5(11): 671-676.

Adu, B.W., Kemabonta, K.A., and Giwa, O.E. (2016). Study of water quality characteristics and benthicmacroinvertebrate assemblages of Aahoo stream, Akure, South Western, Nigeria. *Nigerian Journal of Scientific Research* 15(3): 499-504.

ANZECC (Australian and New Zealand Environment and Conservation Council) (1997). ANZECC interim sediment quality guidelines. Report for the Environmental Research Institute of the Supervising Scientist. Sydney, Australia.

Armitage, P.D. (1980). The effects of mine drainage and organic enrichment in benthos in the River Nent system, Northern Pennines. *Hydrobiologia* 74: 119–128.

Atobatele, O.E., Morenikeji, O.A. and Ugwumba, O.A. (2005). Spatial variation in physical and chemical parameters of benthic macroinvertebrate fauna of River Ogunpa, Ibadan. *The Zoologist* 3: 58-67.

Ayeni A.O., Soneye A.S.O. and Balogun I.I. (2009). State of water supply sources and sanitation in Nigeria: Implication for Muslims in Ikare-Akoko township. *The Arab World Geographer/ Le Geographe du Monde Arabe*. 12(2): 95-104.

Barnes, R.S.K. and Hughes, R.N. (1999). An Introduction to Marine Ecology, 3rd Ed. Wiley Blackwell Scientific Publications, UK.

Chen, M. and Ma, L.Q. (2001). Comparison of 3 aqua regia digestion methods of 20 Florida soils. *Soil Science Society of American Journal* 65: 491– 499.

Esenowo, I.K., Adeyemi-Ale, O.A., Akpan, A.U., Umoh, I.I. (2018). The physico-chemistry and benthic macro invertebrate diversity and abundance of Nwaniba River, Akwa Ibom State, Nigeria. *Zanco Journal of Pure and Applied Sciences* 30(4): 58-64.

Gaskill, J. A. (2014). Examining the effects of pH and macrophyte diversity on benthic macroinvertebrate assemblages in Adirondack Lakes. *Honors Theses*. 35.

Gerber, A. and Gabriel, M.J.M. (2002). *Aquatic Invertebrates of South African rivers field guide*. Resource Water Quality Services, Department of Water Affairs and Forestry. Pretoria, South Africa.

Hambler, C., and Canney, S. M. (2013). Conservation. Cambridge, UK: Cambridge University Press.

Haney, J.F. *et al*. (2013). An image-based key to stream insects. UNH centre for freshwater Biology.cfb.unh.edu>html>indices>EPT.

Ikomi, R.B., Arimoro, F.O. and Odihirin, O.K. (2005). Composition, distribution and abundance of macro invertebrates of the upper reaches of River Ethiope, Delta State, Nigeria. *The Zoologist* 3: 68-81.

Macan, T.T. (1959). A guide to freshwater invertebrate animals. Longman, England.

MacDonald, D.D., Ingersoll, C.G. and Berger, T.A. (2000) Development and evaluation of consensus-based sediment quality guidelines for fresh-water ecosystems. *Archives of Environmental Contamination and Toxicology* 39:20–31.

Malmqvist, B. and Hoffsten, P. (1999). Influence of drainage from old mine deposits on benthic macroinvertebrate communities in central Swedish streams. *Water Resources* 33: 2415-2423.

Mekdes H. and Getachew B. (2020). Physico-chemical and biological evaluation of Blue Nile River at Lake Tana, Ethiopia, in relation to discharge of tannery effluent. *Ethiopian Journal of Science and Technology* 13(3): 185-195.

Mishra, S., Srivastava, S., Tripathi, R.D., Kumar, R., Seth, C.S. and Gupta, D.K. (2006). Lead detoxification by coontail (*Ceratophylum demersum* L.) involves indication of phytochelatins and antioxidant system in response to its accumulation *Chemosphere* 65(6): 1027–1039.

National Bureau of Statistics (NBS), 2012. *Water supply statistics*, (www.nigerianstat.gov.ng).

Neetuh, S. and Ramesh, C.S. (2014). Some important attributes which regulate the life of macroinvertebrates. *International Journal of Recent Scientific Research* 5(2): 357-361.

Nelson, S.M. and Lieberman. D.M. (2002). The influence of flow and other environmental factors on benthic invertebrates in the Sacramento River, U.S.A. *Hydrobiologia* 489: 117–129.

Ogbuagu, D.H. and Samuel, C.B. (2014). Accumulation and recovery capacity of heavy metals in sand mine ponds of the Otamiri River in Owerri, Nigeria. *Rev. Ambient. Água – An Interdisciplinary Journal of Applied Science* 9(1): 46-54.

Ogunwale, J.A. and Adesoye, A. (1994). Studies on the soil of Kwara state. *Centrepoint* 4: 27-36.

Ojekunle I.A (2000). Transport and urban environmental quality in Nigeria in contemporary to AD 2000. Frankard Publishers, Lagos.

Okoro, H.K. and Jimoh, H.A. (2016). Speciation and determination of priority metals in sediments of Oyun river, Ilorin, Kwara, Nigeria. *Bulletin of Chemical Society of Ethiopia* 30(2): 199-208.

Olomukoro, J. O. and Azubuike, C. N. (2009). Heavy metals and macroinvertebrate communities in bottom sediment of Ekpan Creek, Warri, Nigeria. *Jordan Journal of Biological Sciences* 2(1): 1-8.

Olomukoro, J.O., Osamuyiamen I.M. and Dirisu, A. (2013). Ecological survey of invertebrates of selected ponds in Agbede flood plain, Southern Nigeria. *Journal of Biology, Agriculture and Healthcare* 3(10): 23-29.

Quigley, M. (1977). Invertebrates of streams and rivers: A key to identification. Edward Arnold Publications. UK.

Ravera, O. (1998). Utility and limits of biological and chemical monitoring of the aquatic environment. Annali di Chimica 88: 909–913.

Ravera, O. (2000). Ecological monitoring for water body management. In Proceedings of monitoring Tailor made III. International Workshop on Information for Sustainable Water Management, pp: 157-167, Nunspeet, The Netherlands.

Swartz, R.C. (1999). Consensus sediment quality guidelines for PAH mixtures. *Environmental Toxicology and Chem*istry 18:780–787.

Taiwo, A.M. Olujimi, O.O. Bamgbose, O. and Arowolo T.A. (2012). Surface water quality monitoring inNigeria: Situational analysis and future management strategy. In Water Quality Monitoring and Assessment. In Tech. https://doi.org/10.5772/33720.

Tyokumbur, E.T., Okorie E.T. and Ugwumba, O.A. (2002). Limnological assessment of the effects of effluents on macro invertebrate fauna in Awba stream and Reservoir, Ibadan, Nigeria. *The Zoologist* 1(2): 59-62.

Winterbourn, M.J., Rounick, J.S., Cowie, B (1981). Are New Zealand stream ecosystems really different? *New Zealand Journal of Marine and Freshwater Research* 15: 321- 328.

Vinson, M.R. (2001). Long-term dynamics of an invertebrate assemblage downstream from a large dam. *Ecological Applications* 11(3): 711-730.

Voshell, J. R. (2002). A guide to common freshwater invertebrates of North America. Granville, OH: The McDonald and Woodward Publishing Company.

Yan, X., Liu M., Zhong J., Guo, J. and Wu W. (2018). How human activities affect heavy metal contamination of soil and sediment in a long-term reclaimed area of the Liaohe River Delta, North China. Sustainability 10, 338; doi:10.3390/su10020338.