Article

Heavy metals, risk indices and its environmental effects: A case study of Ogoniland, Niger Delta region of Nigeria

Ogwugwa Vincent Happy[1], **Ogwugwa Joy**[2], **Idowu Olagoke Kunlere**[3], **Nwadike Blessing Ifeoma**[3], **Falodun O. Israel**[3], **Fagade O. Ezekiel**[3]

[1]Department of Microbiology, University of Lagos, Nigeria

[2]Department of Microbiology, Delta State University, Abraka, Nigeria

[3]Department of Microbiology, University of Ibadan, Nigeria

E-mail: vh.ogwugwa@gmail.com

Received 9 June 2018; Accepted 28 June 2018; Published 1 September 2018

Abstract

Nigeria has the largest petroleum industries in West African region and the second largest in Africa after Algeria. Nigeria has a total of 159 oil fields and 1481 wells in operation, Explorations in the oil industry in Nigeria have resulted in release of hydrocarbons and associated pollutants including heavy metals into the Niger Delta environment from refine and unrefined petroleum products. Extraction, processing, and transport of crude oil dating back to the 1950s have had a devastating impact on Ogoniland, a territory in the Niger Delta region of Nigeria. Unlike hydrocarbons that can be degraded by microorganisms, heavy metals are recalcitrant to biodegradation, hence this research. Samples were collected from five communities in Ogoniland and these samples were analyzed for heavy metal concentration using inductively coupled plasma-mass spectrometry. The mean of the heavy metals detected are Co (0.912 mg/kg), As (1.04 mg/kg) and Ba (42.39 mg/kg). Heavy metal concentration in these sampled sites exceeded the maximum limit set by Standard Organization of Nigeria. From the results Barium had the highest concentration of heavy metal which is due to the use of barium sulphate to increase the density oil during drilling operations. Barium present in the environment is of public health concern and uptake of water-soluble barium may cause a person to experience vomiting, abdominal cramps, diarrhea, difficulties in breathing, increased or decreased blood pressure, numbness around the face and muscle weakness. Therefore, there is need for stringent implementation of regulations guiding oil exploration industries in the release of heavy metals to the environment as in the case of Ogoniland.

Keywords heavy metal; environmental concerns; Ogoniland; pollution; sediment.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Environmental pollution either land, air, water and sediment has been of concern to the society, especially in developing countries witnessing tremendous and rapid industrialization as Nigeria (Chikere et al., 2017).

Nigeria has Africa's largest reserves of oil and gas within its borders and most of these resources exist in the Niger Delta region that comprises of nine states. Oil spills have occurred repeatedly for decades in the Niger Delta and large parts of the land and wetlands are chronically affected by oil spills (Linden and Jonas, 2013). Nigeria has the largest petroleum industries in West African region and the second largest in Africa after Algeria. Nigeria has a total of 159 oil fields and 1481 wells in operation (Ekperusi and Aigbodion, 2015). Explorations in the oil and gas industry in Nigeria has resulted in release of hydrocarbons and associated pollutants including heavy metals into the Niger Delta environment (Obot et al., 2006; UNEP, 2011). Several researchers have found elevated levels of heavy metals in oil and gas facilities (Iwegbue et al., 2006), street dusts (Mnolawa et al., 2011; Wei and Jiang, 2010; Baba et al., 2009; Abdel-Latif and Saleh, 2012; Salmamanzadeh, 2012), agricultural soils (Dinev et al., 2008; Wei and Yang, 2010), solid waste dumps (Ajah et al., 2015) and lake sediments (Li et al., 2013). High concentrations of heavy metals in different parts of the globe have increased the interest for environmentalists and ecotoxicologists in toxicity and environmental degradation (Prajapati, 2012; Al-Farraj et al., 2013; Su et al., 2014; Ackah et al., 2015; Afsaneh et al., 2018). Inhabitants of the ecosystem may be exposed to these elevated heavy metals that have polluted the ecosystem through direct ingestion of contaminated soil, consumption of crops and vegetables grown on the contaminated lands or drinking water that has percolated through such soils (Mclaughlin et al., 2000).

The severe pollution scenario of these elevated heavy metals have resulted in the degradation of the environment especially soil, resulting in a substantial decline in both below and above ground biodiversity, affect public health and disrupt life support system for local people. Environmental and public health concerns is of interest due to their carcinogenic, mutagenic, recalcitrant, and other detrimental effects of heavy metals on living organisms (Erdogmus et al., 2015). Several health hazards have been associated with consumption of high doses of heavy metals (Mahmood and Malik, 2014; Jarup, 2003). These health hazards range from mild illnesses such as ulcers, diarrhea, nausea, abdominal pain, gastrointestinal disorders, respiratory disorders, cough, nervous disorder, psychological disturbances to life threatening diseases such as cancers, cardiovascular diseases, asthma, kidney and liver damage, coma and diabetes (Ajah et al., 2015). A thorough search of the scientific literature revealed only one health study conducted in the Niger Delta region, which reported higher rates of respiratory and skin disorders in Eleme, a local government in Ogoniland compared to a less-industrialized Nigerian community (Ana et al., 2009). Extraction, processing, and transport of crude oil dating back to the 1950s have had a devastating impact on Ogoniland, a territory in the Niger Delta region of Nigeria. Ogoniland, immediately east of Port Harcourt, this area consists of four local government areas (LGAs): Eleme, Tai, Gokana, and Khana with a total population of 830 000 (UNEP, 2011). Ogoniland is heavily polluted with pretroleum hydrocarbon and heavy metals, at the request of the Federal Government of Nigeria, the United Nations Environment Programme (UNEP) carried out a survey of the nature and extent of oil pollution in Ogoniland. The assessment covered contaminated land, ground and surface water, sediments etc. (Linden and Jonas, 2013). The United Nations Development Programme estimates that 6178 oil spills occurred in Ogoniland between 1976 and 2011 (Kponee et al., 2015). Once oil has contaminated wetlands such as marshes and mangroves, it is often very difficult to remove without causing further damage to these environments (NOAA, 1994, 2002; NRC, 2003; Chan and Baba, 2009), the resulted unmitigated pollution of land, air and water exposes the populace to miasma of health hazards (Ajah et al., 2015). Most heavy metals along side with petroleum hydrocarbon are naturally occurring in the earth crust as trace elements are usually found buried deep in the heart of the earth. However, massive exploitation of natural resources has given rise to a build-up of these toxic elements in the human environment. Many of the toxic as well as non-toxic hydrocarbons evaporate and are degraded by microorganisms quite rapidly (NRC, 2003; ITOPF, 2011b) but heavy metals which are xenobiotics are recalcitrant to biodegradation.

From the above background of literature review, the aim of this report was to know the extent of heavy metal contamination in Ogoniland. The specific objective of this research therefore, was to evaluate the extent of heavy metal pollution using pollution indices such as Contamination Factor (CF), Pollution load index (PLI) and Geoaccumulation index (I_{geo}).

2 Material and Methods

2.1 Study areas and sampling

Ogoniland is a region covering some 1,000 km^2 in the south-east of the Niger Delta basin, It has a population of close to 832,000 (UNEP, 2011). The region is divided administratively into four local government areas: Eleme, Gokana, Khana, and Tai (Fig. 1). Five communities in Ogoniland was sampled, At each location, five sub-samples were collected in a plastic bucket and mixed before being transferred to a glass sampling jar (UNEP, 2011). Only the top 10 cm of the sediment core were used for the samples and care was taken to avoid flushing away the surface floc on top of the more solid sediment. The samples were stored frozen until the analyses were performed, heavy metal analyses was carried out as described by (UNEP, 2011), briefly, For the determination of trace metals in sediments, sediments were finely grounded by agate pestle and mortar. Triplicate samples of 0.25g were oven dried (105°C), ashed (450°C) and digested in concentrated HNO_3 (Aristar, VWR) for "pseudo-total" digestion using a microwave (CEM Mars 5) following the adapted USEPA method 3051 (Yafa and Farmer, 2004). Pseudo-total digestion was used since the main interest was in anthropogenic rather than mineral-bound elements. Following digestion the samples were evaporated to near-dryness on a hot plate, added to a 25ml volumetric flask (three washes from beaker were also added) and diluted with dilute nitric acid (2% v/v, VWR, Aristar). This was filtered (Ashless Whatman 45) into a polypropylene centrifuge tube (Fisher) and stored at 4°C prior to analysis with inductively coupled plasma-mass spectrometry (ICP-MS). The following trace elements were detected using ICP-MS analysis: Co, As and Ba.

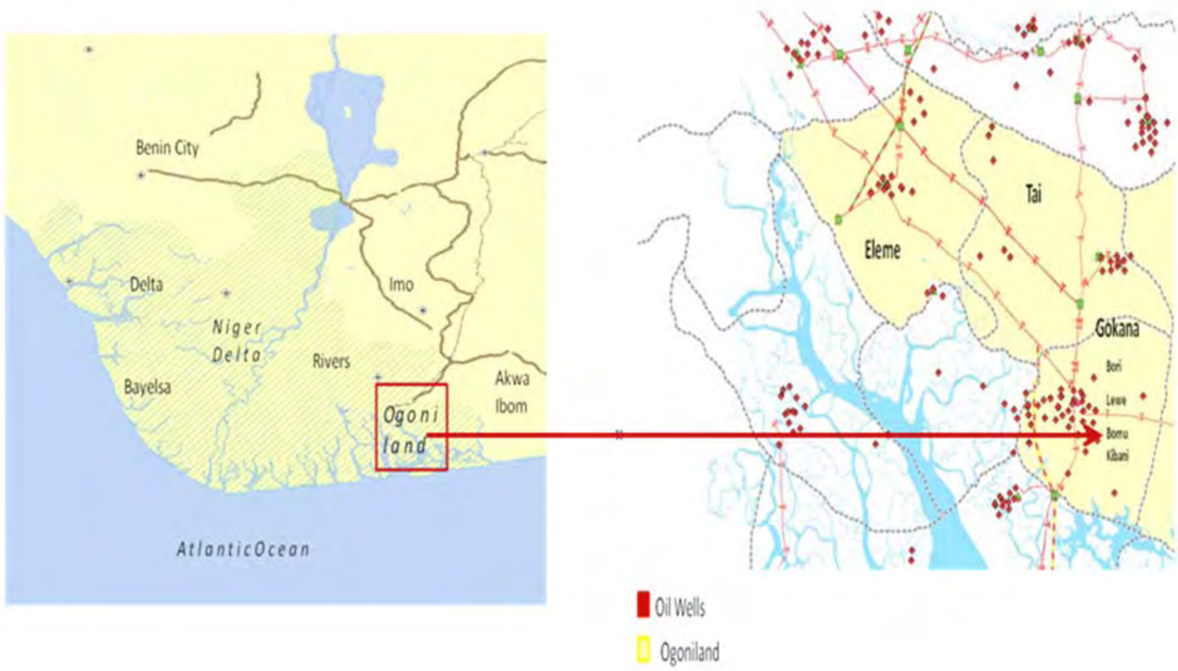

Fig. 1 Map of Ogoniland showing sampling sites.

2.2 Contamination factor

Contamination factor has been widely used to evaluate the degree of contamination by each element in the sediments (Hakanson, 1980; Chakraborty et al., 2014). It is calculated using the equation $C_f^i = C_f/Cn$. Where C_f and C_n are the concentrations of the trace elements in the sediment and geochemical background value of the element respectively.

2.3 Pollution load index (PLI)

The Pollution Load Index (PLI) is used to estimate degree of contamination and pollution in coastal and estuarine sediments (Tomlinson et al., 1980). The classification of the sediments of the study locations is based on PLI values. It has been calculated using the following equation: PLI= $(CF1 \times CF2 \times CF3 \times \ldots\ldots\ldots CFn)^{1/n}$. The Pollution Load Index (PLI) is obtained as Contamination Factors (CF). This CF is the quotient obtained by dividing the concentration of each metals.

2.4 Geoaccumulation index (I_{geo})

The Igeo is measured to quantify the degree of contamination in sediments according to seven enrichment classes (Müller, 1969; Forstner and Stoffers, 1990). It has been calculated using $I_{geo} = \log_2 (Cn / K \times Bn)$. where Cn and Bn are the concentration of the trace elements in the sediment and geochemical background of that element. Classification of the sediments of the study sites is based on the Igeo value (Müller, 1979).

2.5 Statistical analysis

Statistical analyses using Pearson correlation matrix (Zhang, 2018; Zhang and Li, 2015) was done to reveal the relationship between metals. Hierarchical cluster analysis was also done using the five sampling sites for better explanation and to comprehend the sampling stations with respect to analyzed heavy metal concentrations.

3 Results and Discussion

Three major heavy metals were found in five sediment samples collected from five communities in Ogoniland. The concentrations of the heavy metals obtained for the samples generally exceeded maximum allowed limits as shown in (Table 1a). NWIKARA-AGU site had the highest concentration of all metals assayed for. From these results, we can say categorically that NWIKARA-AGU sampling site contained high concentrations of Cobolt (0.59 mg/kg), Arsenic (1.99 mg/kg) and Barium (166 mg/kg) as against the maximum allowed limit approved by Nigerian Industrial Standard (NIS)/Standard Organization Of Nigeria (SON, 2007). These metals are associated with petroleum contamination of which Ogoniland is known to be contaminated with petroleum hydrocarbon. The presence of these metals in aquatic environment ensures a selective pressure such that only tolerant fauna and flora can survive in such environment thereby eliminating sensitive ones. The sediments are in contact with petroleum seepage as these areas are prone to petroleum explorations. Heavy metal pollution in the five communities sampled could be attributed to anthropogenic heavy metals enrichment of the oil-rich industrialized state, as well as oil exploration. There are previous reports of elevation of heavy metals as a result of oil development activities in the Niger Delta (Iwubgue et al., 2006; Howard et al., 2006) and there are evidences of heavy metal bioaccumulation (James et al., 2003; Davies et al., 2006; Obire et al., 2003; Ohimain et al., 2004; Chindah et al., 2004).

Table 1a Heavy metal concentrations and pH at various sites.

Community/LGA	Cobalt (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	pH
AKPAJO, ELEME	0.92	0.3	9.8	5.72
OKULUEBO, ELEME	2.12	1.54	21.9	6.34
KPITE, TAI	0.72	1.07	13	6.2
NWIKARA-AGU	0.59	1.99	166	5.12
GBE, GOKANA	0.21	0.3	1.25	5.26

Table 1b Background knowledge of metals.

Elements	Conc.(mg/kg)
Arsenic (As)	0.01
Barium (Ba)	0.7
Cobolt (Co)	0.15

Barium was the prominent element amongst other elements and NWIKARA-AGU site had the highest concentration of Ba, it ranged from (1.25 mg/kg to 166mg/kg). From best of our knowledge, this is the first time Barium was detected in sediment in Niger Delta region of Nigeria. In exploration oil from the ground, exploration industries use barium sulphate to increase the density of the fluid used in drilling operations. During the drilling process, the cuttings which come up with the drilling fluid are separated and are disposed off in a pit next to the wellhead. These pits were unlined and, on close observation, it is not uncommon to find a range of contaminants in them, including barium. Based on the results, a risk reduction strategy that involves local containment, or excavation and transport should be carried out on the sites.

Table 2 Contamination factor (CF).

Community/LGA	Cobalt (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)
		Contamination factor	
AKPAJO, ELEME	6.12	30	14
OKULUEBO, ELEME	14.13	154	31.29
KPITE, TAI	4.80	107	18.57
NWIKARA-AGU, KHANA	3.93	199	237.1
GBE, GOKANA	1.40	30	1.79

The concentration of sediment contamination was observed by contamination factor (CF) proposed by Hakanson (1980) to express the level of contamination by each metal in sediment. CF<1 refers to low contamination, 1≥CF≥3 means moderate contamination, 3≥CF≥6 means considerable contamination, and CF>6 which means a very high contamination. Table 2 shows the contamination factor of all elements assayed. At site GBE Co and Ba showed moderate contamination CF>1. Co shows considerable contamination (3≥CF≥6) at locations NWIKARA-AGU, KPITE and AKPAJO but showed very high contamination at location OKULUEBO. Asenic and Barium showed very high contamination (CF>6) at locations AKPAJO, OKULUEBO, KPITE and NWIKARA-AGU. These metals are mainly derived from lecheates from petroleum.

Table 3 Pollution Load Index (PLI).

Community/LGA	Cobalt (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	PLI
		Pollution Load Index (PLI)		
AKPAJO, ELEME	6.12	30	14	13.7
OKULUEBO, ELEME	14.13	154	31.29	40.8
KPITE, TAI	4.80	107	18.57	21.2
NWIKARA-AGU, KHANA	3.93	199	237.1	57.0
GBE, GOKANA	1.40	30	1.79	4.2

Pollution Load Index (PLI) proposed is a summative indication for the overall level of heavy metal pollution in sediments has been widely employed to evaluate the contamination status (Tomlinson et al., 1980; Ray et al., 2006; Badr et al., 2009). As per the PLI classification a PLI score of zero indicates “no pollution”, PLI score of 1 indicates “baseline levels of Pollutants” and a PLI score more than 1 indicates “deterioration in the sediment quality” (Tomlinson et al., 1980; Chakraborty et al., 2014). Table 3 shows the pollution load index calculated from the five communities, the five sampling sites fall under deterioration in the sediment quality as PLI is more than 1. Heavy metal contamination of these aquatic ecosystems found in Ogoniland as revealed by this research poses a serious health threat and economic survival of the people of Ogoniland. The occupation of Ogoni people are farming and fishing, fish living in polluted waters contain a considerable amount of toxic metals deposited preferably in fish tissues (Jezierska and Witeska, 2006; El-Moselhy et al., 2014; Velusamy et al., 2014; Leung et al., 2014; Baharom and Ishak, 2015).

To know the level of contamination with respect to heavy metals, the values of heavy metals were used to find geoaccumulation index (I_{geo}). I_{geo} as defined by Muller (1979) as measure of aquatic sediment quantitatively (Ridgway and Shimmield, 2002). According to I_{geo} classification, extent of pollution can be categorized as: very strongly polluted (Igeo > 5), strongly to very strongly polluted (I_{geo}=4–5), strongly polluted (I_{geo}=3–4), moderately to strongly polluted (I_{geo}=2–3), moderately polluted (I_{geo}=1–2), unpolluted to moderately polluted (I_{geo}=0–1) and unpolluted ($I_{geo} < 0$). The results of I_{geo} accumulation index of five different communities in Ogoniland showed that sites OKULUEBO, KPITE and NWIKARA-AGU were very strongly polluted (Igeo > 5) with As. NWIKARA-AGU site is very strongly polluted (Igeo > 5) with Ba. Strongly polluted (I_{geo}=3–4) with Ba was observed at sites AKPAJO, OKULUEBO and KPITE. Sites AKPAJO and GBE were Strongly polluted (I_{geo}=3–4) with As. Site OKULUEBO showed Strongly polluted (I_{geo}=3–4) with Co. AKPAJO, KPITE and NWIKARA-AGU were moderately polluted (I_{geo}=1–2) with Co. Site GBE were unpolluted ($I_{geo} < 0$) with Co and Ba showing a negative trend as shown in Fig. 2. The level of contamination in these locations is as a result of anthropogenic activities (Martin et al., 2011) such as the use of speed boat which could also leave some levels of heavy metals in the water. Our results are in the same range with the work of Martin et al. (2011). Previous research by Ciji and Nandan (2014), reported the presence of extremely high concentration of metals in water and sediments.

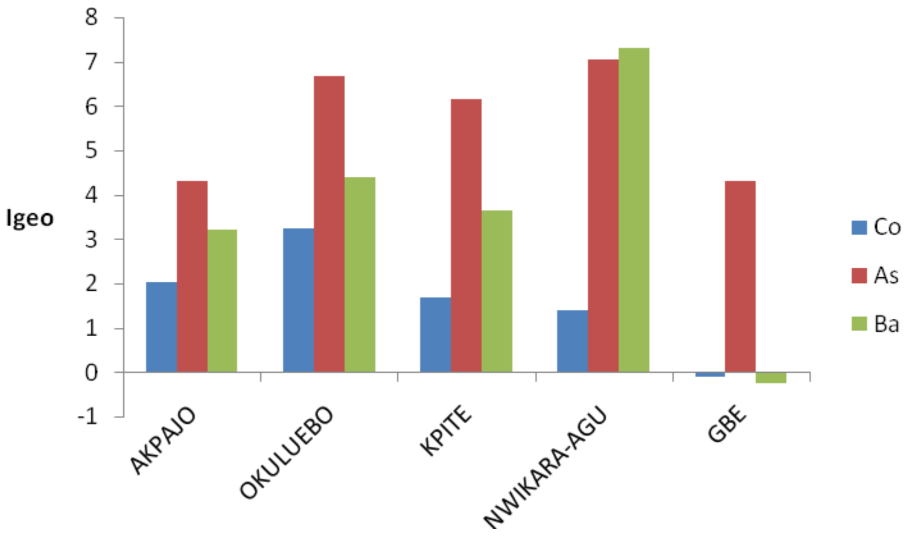

Fig. 2 Igeo pattern of contamination.

Table 4 Pearson correlation matrix for the analyzed metals.

Correlations[a]				
		Co	As	Ba
Co	Pearson Correlation	1		
	Sig. (1-tailed)			
As	Pearson Correlation	.372	1	
	Sig. (1-tailed)	.269		
Ba	Pearson Correlation	-.151	.772	1
	Sig. (1-tailed)	.404	.063	

a: listwise N=5.

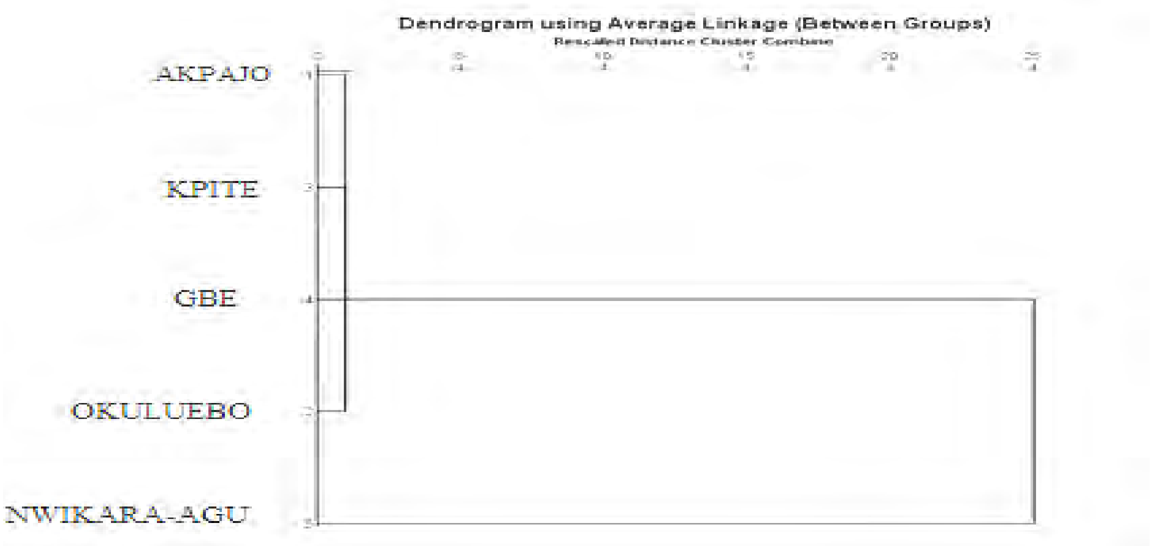

Fig. 3 Dendrogram showing the cluster of sampling locations.

Multivariate statistical analyses using Pearson correlation matrix revealed that positive relationship exist between As and Ba indicating that these metals travel together in a point source, it also means that as one of the metal is increasing in an ecosystem, the other metal is also increasing. Weak relationship exists between Co and As but there was negative correlation between Co and Ba as shown in Table 4. Salas et al. (2017) reported metal to metal correlation. Hierarchical cluster analysis was done using the five sampling sites for better explanation and to comprehend the sampling stations with respect to analyzed heavy metal concentrations. Using agglomeration schedule statistics, dendrogram plot, centroid clustering and Squared Euclidean distance, a dendrogram was obtained Figure 3. Dendrogram showed two cluster analysis with respect to sampling sites. Cluster 1 includes locations AKPAJO, KPITE, GBE and OKULUEBO. It is observed that low to moderate pollution of metals were observed at these sites. Cluster 2 contains NWIKARA-AGU site which is an out cluster, this site in this cluster has been influenced by severe anthropogenic activities coupled with oil exploration in this site showing very high pollution of heavy metals studied. Cluster analysis has helped to better classify the sampling sites, according to the observed metal levels.

4 Conclusion

From this study, we have observed that sediments as an indicator to know the loads of heavy metals present in these aquatic environment proved to be loaded with heavy metals, these metals are xenobiotic that is, are not biodegradable by microorganisms, therefore, there is need for bioremediation of these contaminated environment of which the future work of this group would be focusing on.

Acknowledgement

The authors wish to say a big thank you to UNEP for analyzing the heavy metals used for this research; we would not forget to appreciate Professor Fagade O.E. for his tutelage all through the period of the research.

References

Ackah M, Osei J, Anim AK, et al. 2015. Status of some metals contained in imported nail polish and lipsticks on the Ghanaian market. Proceedings of the International Academy of Ecology and Environmental Sciences, 5(4): 142-147

Afsaneh M, Nabiollah M, Faramarz M, et al. 2018. Assessment of heavy metal contamination in urban dusts and road dusts of Tehran. Proceedings of the International Academy of Ecology and Environmental Sciences, 8(2): 124-138

Al-Farraj AS,Al-Sewailem M, Aly A, et al. 2013. Assessment and heavy metal behaviors of industrial waste water: A case study of Riyadh city, Saudi Arabia. Proceedings of the International Academy of Ecology and Environmental Sciences, 3(3): 266-277

Ana G, Sridhar MK, Bamgboye EA. 2009. Environmental risk factors and health outcomes in selected communities of the Niger delta area, Nigeria. Perspect Public Health, 129(4): 183-191

Abdel-Latif NM, Saleh IA. 2012. Heavy metals contamination in roadside dust along major roads and correlation with urbanization activities in Cairo, Egypt. Journal of American Science, 8(6): 379-389

Ajah KC, Ademiluyi J, Nnaji CC. 2015. Spatiality, seasonality and ecological risks of heavy metals in the vicinity of a degenerate municipal central dumpsite in Enugu, Nigeria. Journal of Environmental Health Science and Engineering, 13: 15

Badr NBE, El-Fiky AA, Mostafa AR, Al-Mur BA. 2009. Metal pollution records in core sediments of some Red Sea coastal areas, Kingdom of Saudi Arabia. Environmental Monitoring and Assessment, 155: 509-526

Baharom, Z.S., Ishak, M.Y., 2015. Determination of heavy metal accumulation in fish species in Galas River, Kelantan and Beranang mining pool, Selangor. Procedia Environmental Sciences, 30: 320-325

Baba AA, Adekola FA, Lawal A. 2009. Trace metals concentration in roadside dust of Ilorin Town. Centrepoint (Science Edition), 16: 57-64

Chakraborty P, Ramteke D, Chakraborty S, Nagender Nath B. 2014. Changes in metal contamination levels in estuarine sediments around India—an assessment. Marine Pollution Bulletin, 78: 15-25

Chan HT, Baba S. 2009. Manual on guidelines for rehabilitation of coastal forests damaged by natural hazards in the Asia-Pacific region. ISME & ITTO, Japan

Chikere CB, Christopher CA, Evan MF. 2017. Shift in microbial group during remediation by enhanced natural attenuation (RENA) of a crude oil-impacted soil: a case study of Ikarama Community, Bayelsa, Nigeria. Biotechnology, 7: 152

Chindah AC, Braide AS, Sibeudu OC. 2004. Distribution of hydrocarbons and heavy metals in sediment and a crustacean (Penaeus notialis) from the Bonny River/New Calabar River Estuary, Niger Delta. African Journal of Environmental Assessment and Management, 9: 1-17

Ciji PP, Nandan SB. 2014. Toxicity of copper and zinc to *Puntius parrah* (Day, 1865). Marine Environmental Research, 93: 38-46

Davies OA, Allison ME, Uyi HS. 2006. Bioaccumulation of heavy metals in water, sediment and periwinkle (Tympanotonus fuscatus var radula) from the Elechi Creek, Niger Delta. African Journal of Biotechnology, 5(10): 968-973

Ekperusi OA, Aigbodion FI. 2015. Bioremediation of petroleum hydrocarbons from crude oilcontaminated soil with the earthworm: *Hyperiodrilus africanus*. Biotechnology, 5: 957-965

Erdogmus SF, Korcan SE, Konuk M, Guven K, Mutlu MB. 2015. Aromatic hydrocarbon utilization ability of *Chromohalobacter sp*. Ekologi, 24: 10-16

El-Moselhy KM, Othman AI, El-Azem HA, El-Metwally MEA. 2014. Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. Egyptian Journal of Basic and Applied Sciences, 1: 97-105

Forstner U, Stoffers P. 1990. editors, Sediment and environmental geochemistry: selected aspects can case histories. 311-338, Springer, Berlin, Heidelberg, New York, USA

Hakanson L. 1980. An ecological risk index for aquatic pollution control, a sedimentological approach. Water Research, 14: 975-1001

Howard IC, Horsfall M, Spiff IA, Teme SC. 2006. Heavy metals levels in surface waters and sediments in an oilfield in the Niger Delta, Nigeria. Global Journal of Pure and Applied Sciences, 12(1): 79-83

ITOPF. 2011b. Fate of marine oil spills. International Tankers Owners Pollution Federation (ITOPF).

Iwegbue CMA, Egbozue FE, Opuene K. 2006. Preliminary assessment of heavy metals levels of soils of an oilfield in the Niger Delta, Nigeria. International Journal of Environmental Science and Technology, 3(2): 167-172

James M, Okolo PO. 2003. Variation of heavy metal concentrations in water and freshwater fish in the Niger Delta waters. A case study of Benin River. Pakistan Journal of Science and Industrial Research, 46(6): 439-442

Jarup L. 2003. Hazards of heavy metal contamination. British Medical Bulltin,68(1): 167-182

Jezierska B, Witeska M. 2006. The metal uptake and accumulation in fish living in polluted waters. In: Soil and Water Pollution Monitoring, Protection and Remediation. NATO Science Series 69 (Twardowska I, Allen HE, Häggblom MM, Stefaniak S, eds). Springer, Dordrecht, Netherlands

Kponee KZ, Andrea C, Iyenemi IK, Donna V, Wendy H. 2015. Petroleum contaminated water and health symptoms: a cross-sectional pilot study in a rural Nigerian community. Environmental Health, 14: 86

Leung HM, Leung AOW, Wang HS, Ma KK, et al. 2014. Assessment of heavy metals/metalloid (As, Pb, Cd, Ni, Zn, Cr, Cu, Mn) concentrations in edible fish species tissue in the Pearl River Delta (PRD), China. Marine Pollution Bulletin, 78: 235-245

Li F, Huang J, Zeng G, Yuan X, Li X, Liang J, et al. 2013. Spatial risk assessment and sources identification of heavy metals in surface sediments from Dongting Lake, Middle China. Journal of Geochemical Exploration, 132: 75-83

Linden O, Jonas P. 2013. Oil Contamination in Ogoniland, Niger Delta. AMBIO, 42(6): 685-701

Mahmood A, Malik RN. 2014. Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arabian Journal of Chemistry, 7: 91-99

Mclaughlin, MJ, Zarcinas BA, Stevens DP, Cook N. 2000. Soil testing for heavymetals. Communications in Soil Science and Plant Analysis, 31(11-14): 1661-1700

Müller G. 1979. Schwermetalle in den Sedimenten des Rheins-Veränderungen seit 1971. Umschau, 79: 778-783

Mnolawa KB, Likuku AS, Gaboutloeloe GK. 2011. Assessment of heavy metals pollution in soils along major roadside areas of Botswana. African Journal of Environmental Science and Technology, 5(3): 186-196

NRC. 2003. Oil in the Sea III: Inputs, Fates, and Effects. National Academy Press, Washington DC, USA

NOAA. 1994. Recovery of mangrove habitats at the Vesta Bella spill site. Hazmat Report. 1-37, National Oceanic and Atmospheric Administration (NOAA), USA

NOAA. 2002. Oil spills in mangroves: Planning and response considerations. Report. 1-72, National Oceanic and Atmospheric Administration (NOAA). http://archive.orr.noaa.gov/book_shelf/34_mangrove_complete.pdf

Prajapati SK. 2012. Biomonitoring and speciation of road dust for heavy metals using *Calotropis procera* and *Delbergia sissoo*. Environmental Skeptics and Critics, 1(4): 61-64

Salas PM, Sujatha CH, Ratheesh Kumar CS, Cheriyan E. 2017. Heavy metal distribution and contamination status in the sedimentary environment of Cochin estuary. Marine Pollution Bulletin, 119: 191-203

Tomlinson, DC, Wilson JG, Harris CR, Jeffery DW. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgol. Marine Research, 33: 566-575

Obire O, Tamuno DC, Wemedo SA. 2003. Physicochemical quality of Elechi Creek in Port Harcourt, Nigeria. Journal of Applied Sciences and Environmental Management, 7(1): 43-49

Ohimain EI, Andriesse W, van Mensvoort MEF. 2004. Environmental impacts of abandoned dredged soils and sediments: available options for their handling, restoration and rehabilitation. Journal of Soils and Sediments, 4(1): 59-65

Obot E, Antonio QB, Braide S, Dore M, Wicks C, Steiner R. 2006. Niger delta natural resource damage assessment and restoration project, phase 1 – scoping report. Federal Ministry of Environment, Abuja, Nigeria Conservation Foundation, Lagos, WWF UK, CEESP- IUCN Commission on Environmental, Economic, and Social Policy

Ray AK, Tripathy SC, Patra S, Sarma VV. 2006. Assessment of Godavari estuarine mangrove ecosystem through trace metal studies. Environment International, 32: 219-223

Ridgway J, Shimmield G. 2002. Estuaries as repositories of historical contamination and their impact on shelf seas. Estuarine, Coastal and Shelf Science, 55: 903-928

Salmamanzadeh M, Saeedi M, Nabibidhendi G. 2012. Heavy metals pollution in street dusts of Tehran and their ecological risk. Journal of Environmental Studies, 38(61): 4-6

Standards Organization of Nigeria. 2007. Nigerian Standard for Drinking Water Quality. NIS 554: 2007. Available at www.unicef.org/nigeria/ng_publications_Nigerian_Standard_for_Drinking_Water_Quality.pdf

Su C, Zhang WJ, Jiang LQ. 2014. A review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques. Environmental Skeptics and Critics, 3(2): 24-38

UNEP. 2011. Environmental Assessment of Ogoniland, United Nations Environment Programme. http://www.unep.org/nigeria. Accessed 12 Oct 2014

Velusamy A, Kumar, PS, Ram A, Chinnadurai S. 2014. Bioaccumulation of heavy metals in commercially important marine fishes from Mumbai Harbor, India. Marine Pollution Bulletin, 81: 218-224

Wei B, Jiang F. 2010. Heavy metals induced ecological risk in the City of Urumqi, NW China. Environmental Monitoring and Assessment, 160: 33-45

Wei B, Yang L. 2010. A review of heavy metal contamination in urban soils, urban road dust and agricultural soils from China. Michrochemical Journal, 94: 99-107

Yafa C, Farmer JG, Graham MC, Bacon JR, et al. 2004. Development of anombrotrophic peat bog (low ash) reference material for the determination of elemental concentrations. Journal of Environmental Monitoring, 6: 493-501

Zhang WJ. 2018. Fundamentals of Network Biology. World Scientific Europe, London, UK

Zhang WJ, Li X. 2015. Linear correlation analysis in finding interactions: Half of predicted interactions are undeterministic and one-third of candidate direct interactions are missed. Selforganizology, 2(3): 39-45