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Application of pollution indices in estimating the toxicity of heavy metals in sediments of Okoro River in Eastern Obolo, Southeastern Nigeria

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Abstract

The sediments of Okoro River were studied to assess the contamination status of the heavy metals present. Particle induced X-ray emission (PIXE) technique employed revealed the present of Ti, Cr, Mn, Fe, Cu, Zn, Rb, Sr, Zr, and Pb. The results revealed that the concentrations ranged from 1942.2-6299.3 mg/kg for Ti, 55.5 - 171.7 mg/kg for Cr, 71.7 to 374.2 mg/kg for Mn, 6881.5 - 66477.0 mg/kg for Fe, 5.9 - 37.6 mg/kg for Cu, 8.6 - 84.5 mg/kg for Zn, 0.0 - 226.4 mg/kg for Rb, 0.0 - 107.0 mg/kg for Sr, 59.7 - 1333.2 for Zr and 0.0 -51.7 mg/kg for Pb. Pollution indices such as enrichment factor (EF), geoaccumulation index (Igeo), contamination factor (CF) and pollution load index (PLI) were employed to assess the levels of pollution of the sediments of the River. The results revealed that the sediments were polluted with the present of these heavy metals detected as confirmed from the mean value of PLI greater than 1 (i.e. mean value of PLI = 1.13). This pollution is as a result of external influences on the River. The concentrations were also subjected to multivariate statistical analysis such as Pearson correlation coefficient and cluster analysis, which revealed only positive coefficient of some heavy metals and that, signified artificial similar sources of the heavy metals to the aquatic bodies in the river.

***Keywords*:** sediments; heavy metals; enrichment factor (EF); geo-accumulation index (Igeo); contamination factor (CF); pollution load index (PLI)

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1.0 Introduction

Studies on environmental pollution have gained increasing attention both internationally and nationally especially in this era of high technological knowhow. Management of pollution on samples and their respective sources of intrusion have been a serious task due to lack of technological knowhow in a developing countries like Nigeria. According to Obiajunwa et al., (2002), international and national agencies are setting up standards and regulations to minimize the man-made contributions to environmental pollution especially in coastal bodies. However, in developing countries such as Nigeria where industrialization is being encouraged, and with the establishment of many cottage industries, strict regulations for environmental and personnel protection are not rigorously enforced. Barakat et al., (2012) reported that out of the various kinds of pollution, the high contamination of aquatic systems with toxic heavy metals is of major concern since these elements are not biodegradable and their elevated uptake by crops may also affect food quality and safety.

In the late 80's and early 90's, Okoro River was one of the sources of livelihood for the dwellers through which aquatic foods were constantly harvested and has been the medium of wastes disposition from when the people recited along that coast till date. Continuous introduction of wastes materials into coastal bodies from agricultural produce, industrial activities such as oil spill and other anthropogenic activities constantly disrupt sediments settling and increased the concentration of heavy metals in sediments. Potentially harmful heavy metals are effectively accumulated in the sediments and in certain conditions; they can be readily released into water in an unpredictable way. On the other hand, concentrations of elements in sediments can serve as an indicator of water quality (Yawo and Akpan, 2021).

Sediments serve as home for contaminants. According to Akpan and Thompson (2013), sediments can emanate from the erosion of bedrocks and soil or from the decomposition of plants and animals. Sediments are mixture of several components of mineral species as well as organic debris, represented as ultimate sink for heavy metals discharged into the environment (Abbas et al., 2009; Bettinentti et al., 2012; Salah et al., 2012).Water current of coastal bodies such as seas and rivers affects the deposition of contaminants in sediments, thus there are variations of heavy metals at different points of the sediments. Toxic substances drained from domestic, industrial establishments and other sources to coastal bodies are deposited in sediments and formed part of the major sources of environmental pollution especially to the aquatic life. Petroleum exploration and development, like many other mining activities and chemical industries, generate large amount of gaseous, liquid and solid hazardous wastes that impact on our environment (Obiajunwa et al., 2002) especially on aquatic function.

In the urban environment, the emission from motor vehicles and biomass burning, lead from battery reprocessing and paint pigment production are all transported as fine particles (Begum et al., 2006), which eventually drain to the coastal bodies by some processes and are accumulated in those coastal sediments, thereby increasing the concentrations of the heavy metals present in them. In rural areas, coastal bodies are considered as means through which wastes are disposed, thereby increasing concentration level of heavy metals in aquatic functions. According to Barakat et al., (2012), most rivers in the world flowing through the populated areas are highly vulnerable to heavy metal pollution due to urbanization and industrialization. Chemical leaching of bedrocks, water drainage basins and runoff from banks are the primary sources of heavy metals (Raju et al., 2012; Salah et al., 2012). According to Chakravarty and Patgiri (2009), mining operations, disposal of industrial wastes and applications of biocides for pest are other anthropogenic sources. Heavy metals are serious pollutants because of their toxicity, persistence and non-degradability in the environment (Rieumont et al., 2005; Idris et al., 2007; Brunner et al., 2008; Morin et al., 2008). Polluted sediments, in turn, can act as sources of heavy metals, imparting them into the water and debasing water quality (Zhong et al., 2006; Atkinson et al., 2007). Heavy metals are of high ecological significance since they are not removed from water as a result of self purification, but accumulate in reservoirs and enter the food chain (Loska and Wiechula, 2003). Heavy metals are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains (Forstner and wittman, 1983; Demirbas et al., 2005). Heavy metals may enter into aquatic ecosystems from anthropogenic sources, such as industrial wastewater discharges, sewage wastewater, fossil fuel combustion and atmospheric deposition (Linnik and Zubenko, 2000; Campbell, 2001; Lwanga et al., 2003; El Diwani and El Rafie, 2008; Idrees, 2009; Mhandi et al., 2010;Sekabira et al., 2010).

All metals are toxic above some threshold bioavailable level. Silver (Ag), Mercury (Hg), Copper (Cu), Cadmium (Cd) and Lead (Pb) are particularly toxic (Kontas, 2008). Among the metals especially known to have toxic effect in environmental studies are arsenic, cadmium, lead, mercury and Thallium (Addo et al., 2012). Adeniyi (2011) noted that cadmium and lead are stable and persistent environmental pollutants, and are known to exhibit extreme toxicity even at low levels under certain conditions. Interests in metals like copper and zinc which are required for metabolic activity in organisms lie in the narrow 'window' between their essentiality and toxicity (Skidmore, 1964; Spear, 1981; Fatoki and Mathabatha, 2010; Adeniyi et al., 2011). Lead is potentially hazardous to most forms of life and is considered toxic and relatively accessible to aquatic organisms (USEPA, 1986a). Low lead concentrations affect fish by carrying the formation of coagulated mucous over gills and subsequently over the entire body and thus cause the death of the fish due to suffocation (DWAF, 1996b). The high concentrations of heavy metals always get to human being through environmental parameters of which coastal sediments form part of it.

The distribution of heavy metals in sediments can provide evidence of the anthropogenic impact on aquatic and other ecosystem, and therefore aid in assessing the risk associated with human induced change (Bentum et al. 2011). Recently, many researchers have conducted extensive surveys of heavy metal contamination in sediments (Harikumar and Jisha, 2010; Mmolawa et al., 2011; Wang et al., 2011; Salah et al., 2012) but there have not been any study of sediments of Okoro River. The purpose of this study was to determine the distribution and level of contamination of sediments of Okoro River in Eastern Obolo, Southeastern Nigeria by some heavy metals such as Ti, Cr, Mn, Fe, Cu, Zn, Rb, Sr, Zr and Pb from 6 stations of the river and the extent of enrichment using pollution indices such as enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF) and pollution load index (PLI) with the view of providing information on the level of pollution.

2.0 Materials and Methods

2.1 Study Area

Okoro River is a river along one of the major creek in Eastern Obolo which separates Okoroete from Okorombokho and Okoroiti communities whereby the name Okoro River is derived as shown in figure 1. It flows through the Southern Eastern Obolo to Atlantic Ocean and Andoni in River State and also gets through Ibeno River in Ibeno L.G.A., Akwa Ibom State, Nigeria. Okoro River sediment has always been perturbed by fishing activities, though there have not been much catch of fishes and other aquatic bodies in recent time due to some factors. It serves as river bank from which waters from farms, mechanic shops, welding shops, etc. drain into. Dumping of wastes products into this River has been the common practice of the dwellers. Latrines are sited along this River, which serves as convenience for most dwellers. All these anthropogenic activities could raise the concentration level of heavy metals in the sediments of this river. Mangroves trees are present at some point of Okoro River, which could pose negative effect on this River too due to their leaves that always fall into this river.

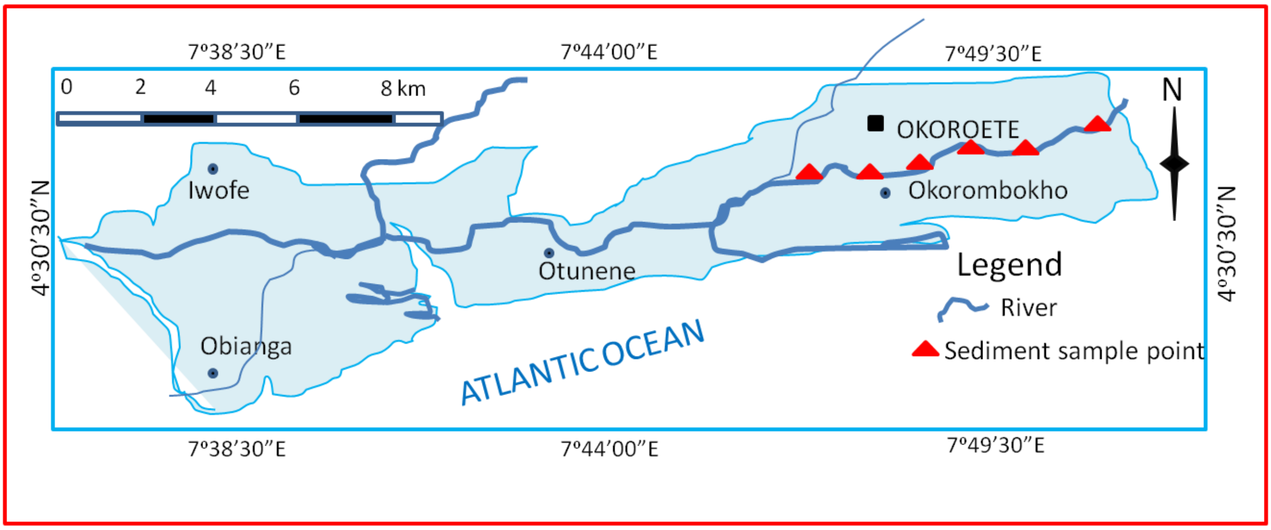

Fig. 7: Map of study area showing the samples location in Okoro River in Eastern Obolo

2.2 Samples Collection and Analysis

Sediment samples were collected at six sampling stations in Okoro River, Eastern Obolo, Southeastern Nigeria, which covers Latitude 04°31'00" to 04°32'15" north and Longitude 007°43'27" to 007°44'57" (Figure 1) east using Van Veen grab. At every sampling site, triangular grid system of sampling collection recommended by IAEA 4-33, (2003), and Herut and Sandler, (2006) were employed in which sediments taken at each grid were combined to form the composite sediments. This formed the sample for the respective sampling sites. Global Positioning System (GPS) was employed to note the location of every site and the average was taken and recorded for the composite site sampling. The composite sediments obtained at six (6) sampling sites were taken to Centre for Energy Research and Development (CERD), Obafemi Awolowo University (OAU), Ile Ife where they were dried and then subjected to pre-analytical treatment such as removal of debris, homogenization and pelletization after which they were subjected to Particle Induced Emission (PIXE) technique. The concentration of heavy metals obtained were assessed for the contamination status of the heavy metals using the pollution indices such as the enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF) and the entire toxicity status due to the heavy metals for the respective sampling site was determined using pollution load index (PLI). Their relationships were determined using multivariate statistical analysis such as Pearson’s correlation coefficient (PCC) and cluster analysis (CA).

2.3 **Assessment of pollution impact on ecosystem**

Several methods have been employed to quantify the degree of enrichment of heavy metals in coastal sediment. Various authors (Müller, 1969; Hakanson, 1980; Salomons and Förstner 1984) have proposed pollution impact scales (or ranges) to convert the calculated numerical results into broad descriptive bands of pollution ranging from low to high intensity (Abrahim and Parker, 2007). Four pollution indices such as enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF), and pollution load index (PLI) were employed to assess the contamination impact of the heavy metals present on the ecosystem of the study area.

Enrichment factor (EF) was employed to assess the degree of contamination and to understand the distribution of elements of anthropogenic origin from sites by individual elements in sediments (Ren et al., 2015). It is the proportion of the concentrations of heavy metals and the normalizing element in sediments to that in the background sources. Fe was chosen as the normalizing element to determine the EF values since in wetlands it is mainly supplied from sediments and is one of the most widely used reference elements:

$$EF = (C_n/Fe)sample/(C_n/Fe)background \quad (1)$$

where $(C_n/Fe)sample$ is the ratio of the concentrations of heavy metal to that of Fe respectively in sediments sample, $(C_n/Fe)background$ is the concentrations of heavy metal to that of Fe in the background sources. Its application follows that proposed by Mmolawa et al., 2011; Salah et al., 2012 as presented in Table 1.

The geo-accumulation index (Igeo) was originally introduced by Müller (1969) to determine and define metal contamination in sediments. The geo-accumulation index (Igeo) is defined by the following equation:

$$Igeo = Log_2(C_n/1.5B_n) \quad (2)$$

where C_n is the measured concentration of the examined metal (n) in the sediment and B_n is the geochemical background concentration of the metal (n). The factor 1.5 is the background matrix correction factor due to lithological variability. The background values of the metals here are the same as those recorded in the enrichment factor calculation. Similar to metal enrichment factor, geoaccumulation index can be used as a reference to estimate the extent of metal pollution (Zhang et al., 2009; Soliman et al., 2015) with its description presented in Table 2.

The contamination factor (CF) is the ratio obtained by dividing the concentration of each heavy metal (M_n) in the sediments by baseline of background values (M_b). Thus, CF is given by the equation:

$$CF = \frac{M_n}{M_b} \quad (3)$$

as proposed by Hakanson, 1980, Salah et al. (2012) and its description is in Table 3.

Pollution load index (PLI) has been determined as the nth root of the product of the nCF for the entire sampling sites and is given in equation 4:

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots \times CFn)} \quad (4)$$

where CF is the contamination factor, n is the total number of the heavy metals determined. This empirical index provides a simple, comparative means for assessing the level of heavy metal pollution. When PLI >1, it means that a pollution exists; otherwise, if PLI<1, there is no metal pollution (Tomlinson et al., 1980; Soliman et al. 2015).

2.4. Multivariate statistical analysis

Multivariate analysis (i.e. Pearson Correlation Coefficient; PCC and Cluster analysis; CA) has been proved to be an effective tool for providing suggestive information regarding heavy metal sources and pathways (Hu et al., 2013, Soliman et al., 2015). They have been employed in this work.

Table 1: Enrichment factor (EF) categories (Mmolawa et al., 2011; Salah et al., 2012)

Enrichment factor (EF)	Enrichment factor (EF) categories
$EF < 2$	Deficiency to minimal enrichment
$2 \leq EF < 5$	Moderate enrichment
$5 \leq EF < 20$	Significant enrichment
$20 \leq EF < 40$	Very high enrichment
$EF \geq 40$	Extremely high enrichment

Table 2: Muller's classification for index of geo-accumulation (Igeo**) (** Müller (1969)

I_{geo} Values	I_{geo} Class	Designation of sediment quality
≤ 0	0	Uncontaminated
$0 - 1$	1	Uncontaminated to moderately contaminated
$1 - 2$	2	Moderately contaminated
$2 - 3$	3	Moderately to strongly contaminated
$3 - 4$	4	Strongly contaminated
$4 - 5$	5	Strongly to extremely contaminated
> 5	6	Extremely contaminated

Table 3: Contamination factor (CF) and level of contamination (Hakanson, 1980, Salah et al., 2012)

Contamination factor (CF)	Level of contamination
$CF < 1$	Low contaminationn
$1 \leq CF < 3$	Moderate contamination
$3 \leq CF < 6$	Considerable contamination
$CF > 6$	Very high contamination

3.0 Results and Discussion

The concentrations (mg/kg) of heavy metals in surface sediments of Okoro River in Eastern Obolo are reported in Table 4. The mean value of heavy metals concentrations in the study area follows a descending order as Fe>Ti>Zr>Mn>Cr>Rb>Sr>Zn>Pb>Cu. The mean concentration values of Ti, Mn, Zn, and Sr in Okoro River sediments were lower than the TEC (threshold effect concentration which is the measured value) and PEC (probable effect concentration which is the certified value) values, thus pose no toxicity threats on that ecosystem. The mean concentration values of Cr , Rb, Cu and Fe are lower than PEC values but higher than their respective TEC values (Table 5), which could pose pollution threats on the environment if not properly checked. The mean concentration values of Zr and Pb are higher than their respective TEC and PEC values described in Table 5. There could be contamination threat of Zr and Pb on that ecosystem. The spatial variations of TEC and PEC values as used in this study are shown in Fig. 2. The mean concentration values of Fe of this study is higher than that reported of Europhate River, Iraq (Salah et al., 2012), Balok River, Pahang, Malaysia (Abdullah et al., 2015) and Qinghai, Yellow River, China (Ren et al., 2015) but lower than the value of Fe reported of Chilika Lake, Odisha, India (Banerjee et al., 2017) as compared with other Rivers in other parts of the world (Table 6). Thus, the Okoro River bed rock is richly of feldspar minerals than some part of the Rivers in other part of the world compared. The mean concentration value of Cu in Okoro sediments is smaller than that reported in other Rivers in some part of the world as presented in Table 6.

The EF values for heavy metal in Okoro sediments are shown in Table 7. The EF values for heavy metals in Okoro sediments at site 1 (OKR1) follows the descending order as Zr>Cr>Rb>Ti>Cu>Fe>Mn>Zn while Sr and Pb were not present there. The EF values for heavy metals in Okoro sediments at site 2 (OKR2) follows the descending order as Cu>Zr>Fe>Pb>Zn>Sr=Cr>Ti>Mn while Rb was not present. The EF values for heavy metals in Okoro sediments at site 3 (OKR3) follows the descending trend as; Pb>Zr>Fe>Cr>Cu>Ti>Mn>Zn>Sr and Rb was not present. The EF values for heavy metals in Okoro sediments at site 4 (OKR4) follows the d escending order as; Rb>Fe>Pb>Mn>Zn>Ti>Cu>Zr>Cr>Sr. The EF values for heavy metals in Okoro sediments at site 5 (OKR5) follows the descending trend as Rb>Pb>Zr>Fe>Cu>Ti>Sr>Mn>Zn>Cr. The EF values for heavy metals in Okoro sediments at site 6 (OKR6) follows the descending order as Cr>Rb>Cu>Fe>Mn>Zn>Zr while Sr and Pb were not present. Using the interpretation employed by Salah et al., (2012) and Mmolawa et al., (2011) as in Table 1, OKR1 is significantly enriched with Zr, moderately enriched with Cr while other heavy metals are at deficiency to minimal enrichment, OKR2 is deficient to minimal enrichment of all the heavy metals detected, OKR3 is moderately enriched with Pb while other heavy metals are at deficiency to minimal enrichment stage, OKR4 is moderately enriched with Rb and other heavy metals are at deficiency to minimal enrichment stage, OKR5 is moderately enriched with Rb and Pb and other heavy metals are at the state of deficiency to minimal enrichment, OKR6 is moderately enriched with Cr but other heavy metals are at deficiency to minimal enrichment state. The spatial variation of EF values of the determined heavy metals is shown in Fig. 4. The mean EF values of heavy metals in Okoro sediments follow the descending sequential order Rb>Cr>Zr>Pb>Cu>Fe>Ti>Mn>Zn>Sr with which Cr, Zr, Pb, Cu, Fe, Ti, Mn, Zn and Sr showed deficiency to minimal enrichment while Rb was at the point of moderate enrichment in Okoro River.

On the average of the geo-accumulation index (Igeo) (Table 8), the heavy metals showed the levels of their contamination in the descendi ng order as; Pb>Rb>Cr>Zr>Fe>Cu>Ti>Sr>Mn>Zn. Using the interpretation developed by Müller (1969) as shown in Table 3, the geoaccumulation index of the heavy metals are in class 0 and class 1 such that Pb, Rb, Cr, Zr, Fe, Cu, Ti and

Sr fall in class 1; thus designated uncontaminated to moderately contaminated of the sediments while Mn and Zn fall in class 0; thus they are uncontaminated of the sediments. The spatial variation of the Igeo values of the heavy metals for the respective site of Okoro River is shown in Fig. 5. On the basis of the average values of CF, heavy metals contamination follows the descending order as; Rb>Pb>Zr>Fe>Cr>Cu>Ti>Zn>Mn>Sr (summarized in Table 9). CF values were interpreted as suggested by Hakanson, (1980) and employed by Salah et al., (2012) as summarized in Table 3.

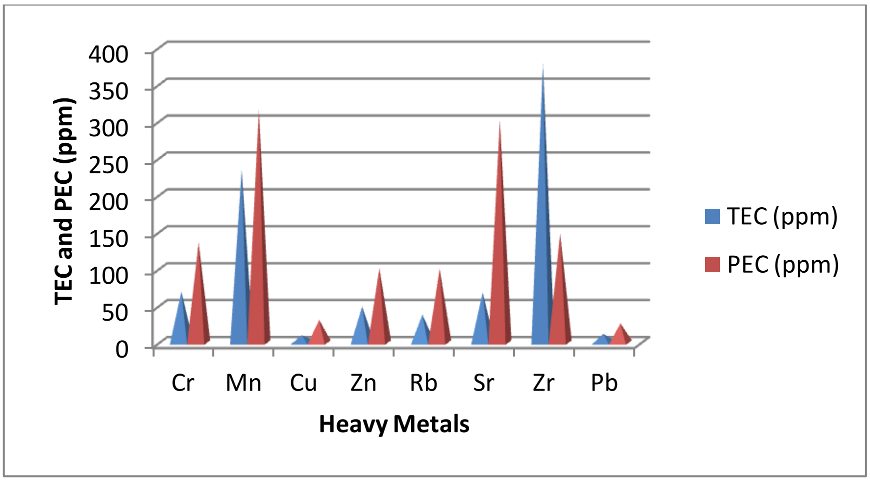

Fig.2: Spatial variation of TEC (mg/kg) and PEC (mg/kg) of some heavy metals in sediments of Okoro River in Eastern Obolo, Southeastern Nigeria

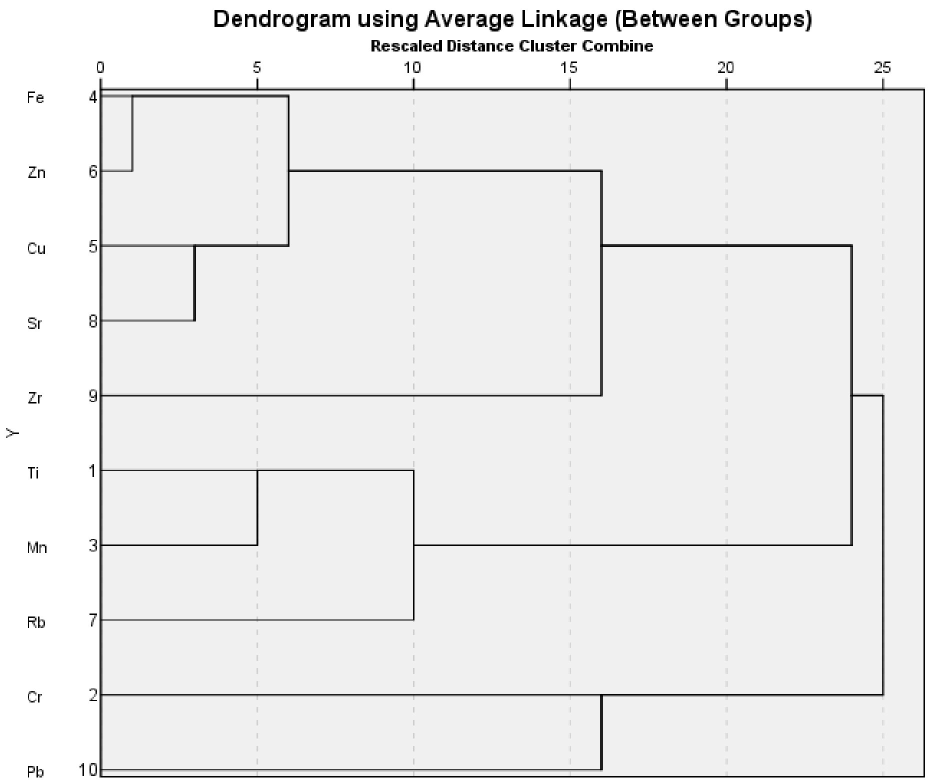

Fig. 3: Hierarchical dendrogram of heavy metals of sediments in Okoro River in Eastern Obolo, Southeastern Nigeria

Table 4: Concentration of Heavy Metals in Sediments of Okoro River in Eastern Obolo, Southeastern Nigeria

Heavy Metals	OkR1 (mg/kg)	OkR2 (mg/kg)	OkR3 (mg/kg)	OkR4 (mg/kg)	OkR5 (mg/kg)	OkR6 (mg/kg)	*Mean* (*mg/kg*
Ti	4385.10 ± 36.83	4176.90 ± 37.17	4410.60 ± 37.93	6299.30 ± 43.47	5216.00 ± 41.21	1942.20 ± 24.86	4405.02
Cr	96.70 ± 7.59	111.10 ± 9.67	90.90 ± 10.68	55.50 ± 8.27	171.70 ± 12.23	109.10 ± 7.69	105.83
Mn	109.90 ± 14.91	123.30 ± 20.54	161.00 ± 18.40	374.20 ± 20.73	156.60 ± 18.15	71.70 ± 12.68	166.12
Fe	9770.10 ± 54.71	66477.00 ± 139.60	33457.80 ± 100.37	50352.60 ± 120.85	24496.50 ± 85.74	6881.50 ± 44.73	31905.92
Cu	6.30 ± 1.89	37.60 ± 4.53	12.30 ± 2.86	12.70 ± 2.87	11.80 ± 2.52	5.90 ± 2.08	14.43
Zn	8.60 ± 5.23	84.50 ± 12.63	27.80 ± 7.53	76.90 ± 9.66	29.00 ± 6.39	10.40 ± 7.46	39.53
Rb	48.30 ± 24.29	*ND*	*ND*	191.30 ± 36.84	226.40 ± 65.18	25.70 ± 9.92	81.95
Sr	*ND*	107.00 ± 32.55	34.20 ± 17.60	35.80 ± 31.91	73.80 ±31.92	*ND*	14.80
Zr	1220.80 ± 110.73	1333.20 ± 15.32	642.50 ± 67.53	406.00 ± 70.36	606.80 ± 66.63	59.70 ± 9.92	711.50
Pb	*ND*	21.39 ± 6.50	49.70 ± 16.62	19.20 ± 5.60	51.70 ± 17.66	*ND*	23.65

- ND implies not detected
- OkR indicates Okoro River

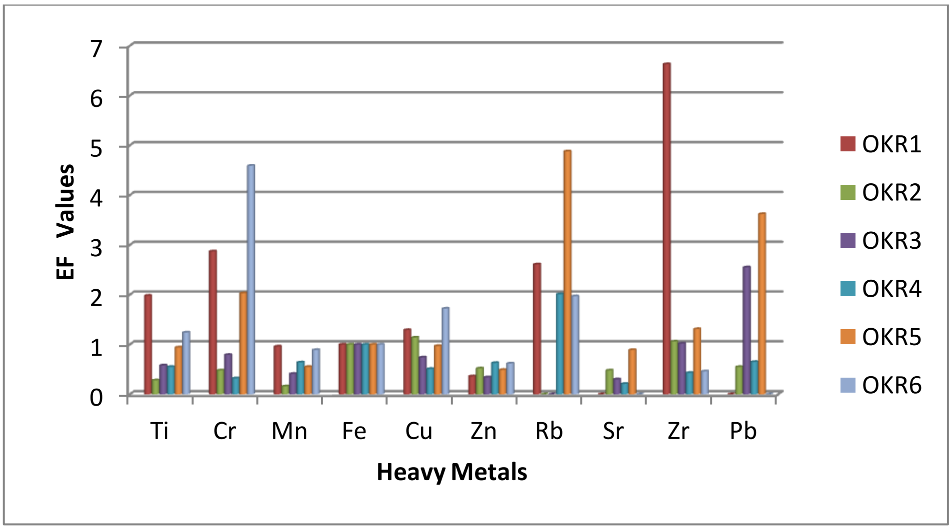

Fig. 4: Spatial variation of enrichment factor (EF) of heavy metals in sediments of Okoro River in Eastern Obolo, Southeastern Nigeria.

Table 5: Comparison of measured concentrations of some heavy metals in sediments sample background source with the certified data in the standard reference materials (IAEA 2003) sediment sample

Heavy Metals	Measured Standard (Control)Values (TEC)(mg/kg)	Certified Values (PEC)(mg/kg)
Ti	4560.00 ± 34.66	–
Cr	69.30 ± 12.90	136.00
Mn	234.50 ± 14.63	316.00
Fe	20080.20 ± 74.30	40800.00
Cu	10.00 ± 2.50	30.80
Zn	48.90 ± 8.23	101.00
Rb	38.00 ± 10.47	99.90
Sr	68.00 ± 23.88	302.00
Zr	378.60 ± 62.39	148.00
Pb	11.70 ± 6.81	26.00

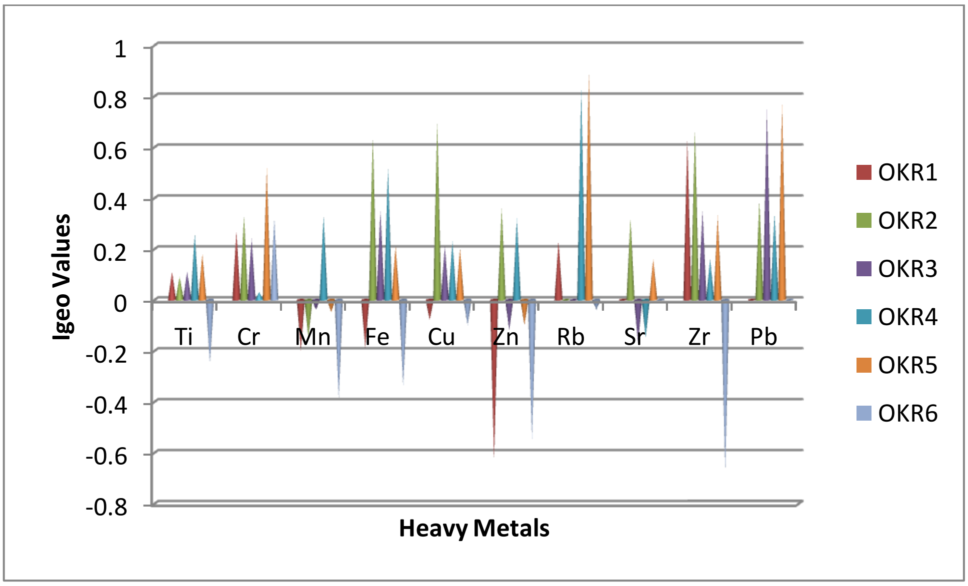

Fig. 5: Spatial variation of geo-accumulation Index (Igeo) of heavy metals in Okoro River Sediments in Eastern Obolo, Southeastern Nigeria

The mean Igeo values of Ti, Zn, Mn and Sr are less than zero which shows low contamination and suggests that the sediment has not been polluted overall by these heavy metals. The mean Igeo values of Cu, Cr, Fe and Zr are between one and two suggesting moderate contamination while that of Rb and Pb are between three and four, which suggests that the sediments have been considerably polluted with these heavy metals.. The spatial variation of CF of the heavy metals in sediments of Okoro River is shown in Fig. 6.

The pollution load index (PLI) ranged from 0.42 to 1.77. According to the mean PLI value (1.13), the Okoro River was polluted. The spatial variation of PLI of the heavy metals for the respective sites of the sediments of Okoro River studied is shown in Fig. 7.

In order to establish relationships among the metals and determine the common source of heavy metals in Okoro River, a correlation matrix was calculated for heavy metals in the sediments. According to the values of Pearson correlation coefficients (Table 10), only a significant positive correlation exists among the metals studied. In this study, Fe was significantly correlated with Cu, and Zn. It indicated strong association of these metals in the sediments where they might be sharing common sources (Saleem et al., 2013). The significantly positive correlation of Cu and Sr (r=0.869, p<0.05) suggests that these metals were redistributed in the sediments by the same physico-chemical processes or had a similar source (Bai et al., 2011). Mn is positively significant to Ti, that is Mn and Ti (r =0.817, p<0.05).

Cluster analysis was performed on the data to understand the similarities among the heavy metals. Fig. 2 shows a dendrogram using average linkage. The cluster results indicate four clusters: (1) Fe-Zn-Cu-Sr (2) Zr (3) Ti-Mn-Rb, (4) Cr-Pb in terms of similarities. This indicates that Fe, Zn, Cu and Sr originated from the same sources. Cluster 2 further shows that Zr has no association with these elements. Cluster 3 shows that Ti, Mn and Rb are from the same sources. Cluster 4 reveals that Cr and Pb got to the sediments from similar sources. This is consistent with the results from the Pearson's correlation coefficient described above.

Table 6: Comparing the mean concentrations of heavy metals in Okoro River, Eastern Obolo, Southeastern Nigeria with that of other Rivers in some part of the World

Locations	Mean concentrations (mg/kg) of Heavy metals										References
	Ti	*Cr*	*Mn*	*Fe*	*Cu*	*Zn*	*Rb*	*Sr*	*Zr*	*Pb*	
Okoro River	4405.02	105.83	166.12	31905.92	14.43	39.53	81.95	41.80	711.50	23.65	
Euphrate River, Irag	–	58.40	228.18	2249.47	18.91	48.00	–	–	–	22.56	Salah et al., (2012)
Chilika Lake Odisha, India	–	77.60	626.18	45727.32	30.94	77.02	–	–	–	17.73	Banerjee et al., (2017)
Balok River, Pahang, Malaysia	–	42.93	155.61	2734.69	24.31	159.40	–	–	–	29.31	Abdullah et al., (2005)
Qinghai Yellow River, China	–	122.21	669.84	30424.57	24.03	96.23	–	–	–	9.73	Ren et al., (2015)

Table 7: Values of enrichment factor (EF) of heavy metals in Okoro River sediments

Station (OKR)	Ti	Cr	Mn	Fe	Cu	Zn	Rb	Sr	Zr	Pb
1	1.98	2.87	0.96	1.00	1.29	0.36	2.61	-	6.63	-
2	0.28	0.48	0.16	1.00	1.14	0.52	-	0.48	1.06	0.55
3	0.58	0.79	0.41	1.00	0.74	0.34	-	0.30	1.02	2.55
4	0.55	0.32	0.64	1.00	0.51	0.63	2.01	0.21	0.43	0.65
5	0.94	2.03	0.55	1.00	0.97	0.49	4.88	0.89	1.31	3.62
6	1.24	4.59	0.89	1.00	1.72	0.62	1.97	-	0.46	-
Mean	0.93	1.85	0.60	1.00	1.06	0.49	2.87	0.47	1.82	1.59

Table 8: Values of geo-accumulation index (Igeo) of heavy metals in Okoro River sediments

Stations (OKR)	Ti	Cr	Mn	Fe	Cu	Zn	Rb	Sr	Zr	Pb
1	0.11	0.27	-0.20	-0.19	-0.08	-0.63	0.23	-	0.63	-
2	0.09	0.33	-0.15	0.64	0.70	0.36	-	0.32	0.67	0.39
3	0.11	0.24	-0.04	0.35	0.21	-0.12	-	-0.17	0.35	0.75
4	0.26	0.03	0.33	0.52	0.23	0.32	0.83	-0.15	0.16	0.34
5	0.18	0.52	-0.05	0.21	0.20	-0.10	0.90	0.16	0.33	0.77
6	-0.25	0.32	-0.39	-0.34	-0.10	-0.55	-0.04	-	-0.68	-
Mean	0.08	0.29	-0.08	0.20	0.19	-0.12	0.48	0.04	0.24	0.56

Table 9: Values of Contamination factor (CF) and pollution lead index (PLI) of heavy metals in Okoro River sediments

Station (OKR)	Ti	Cr	Mn	Fe	Cu	Zn	Rb	Sr	Zr	Pb	PLI
1	0.96	1.40	0.47	0.49	0.63	0.18	1.27	-	3.22	-	0.78
2	0.92	1.60	0.53	3.31	3.76	1.73	-	1.57	3.52	1.82	1.77
3	0.97	1.31	0.69	1.67	1.23	0.57	-	0.50	1.70	4.25	1.16
4	1.38	0.80	1.60	2.51	1.27	1.57	5.03	0.53	1.07	1.64	1.45
5	1.14	2.48	0.67	1.22	1.18	0.59	5.96	0.09	1.60	4.42	1.20
6	0.43	1.57	0.31	0.34	0.59	0.21	0.68	-	0.16	-	0.42
Mean	0.97	1.53	0.71	1.59	1.44	0.81	3.24	0.67	1.88	3.03	1.13

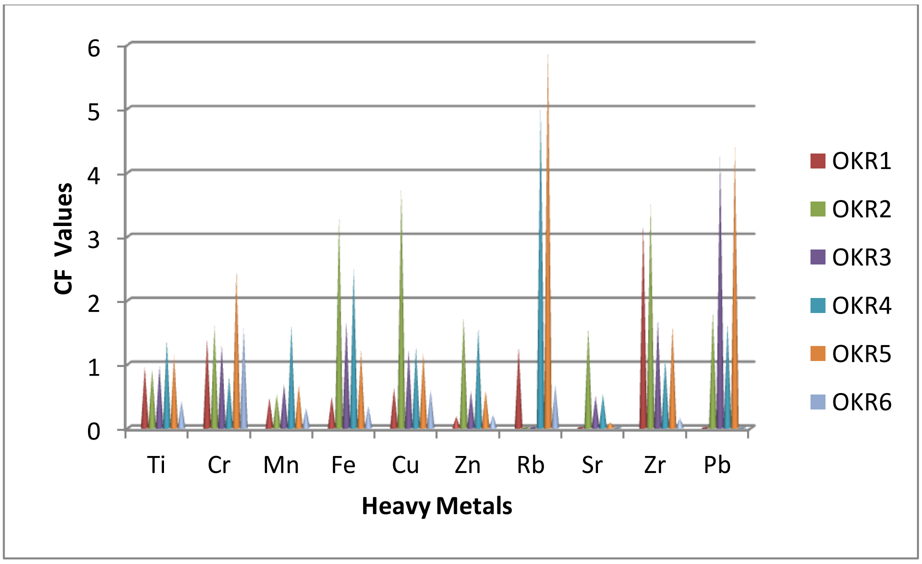

Fig. 6: Spatial variation of contamination factor (CF) of heavy metals in sediments of Okoro. River in Eastern Obolo, Southeastern Nigeria

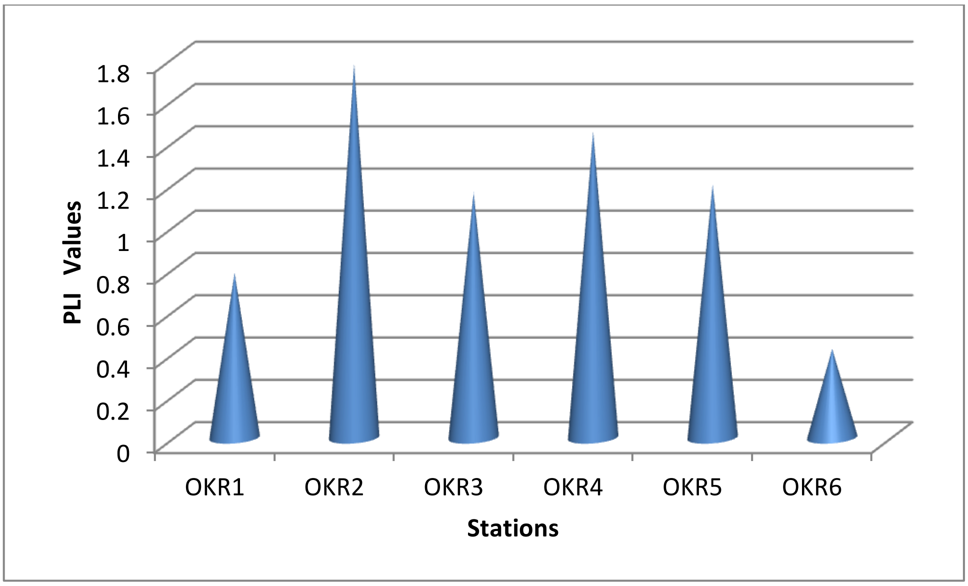

Fig. 7: Spatial variation of Pollution load index (PLI) of heavy metals in sediments of Okoro River, Southeastern Nigeria

Table 10: Pearson Correlation coefficient of heavy metals of sediments of Okoro River in Eastern Obolo, Southeastern Nigeria

Correlations

	Ti	Cr	Mn	Fe	Cu	Zn	Rb	Sr	Zr	Pb
Ti	1									
Cr	-.187	1								
Mn	.817*	-.543	1	.						
Fe	.496	-.257	.484	1						
Cu	.124	.051	-.009	.862*	1					
Zn	.522	-.314	.593	.965**	.787	1				
Rb	.666	.258	.604	.012	-.261	.152	1			
Sr	.341	.389	.088	.789	.869*	.714	.142	1		
Zr	.226	.065	-.215	.381	.588	.270	-.304	.445	1	
Pb	.448	.417	.191	.295	.162	.145	.326	.530	-.026	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.0 Conclusion

This work provides the comprehensive assessment of the contamination levels of the heavy metals present in the sediments of Okoro River in Eastern Obolo, Southeastern Nigeria.
The employment of the pollution indices such as the enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF) revealed from the mean values that the River is significantly polluted with certain heavy metals such as Rb and Pb and are moderately enriched with heavy metals such as Cu, Cr, and Cu. The mean value of

Pollution load index also revealed that the sediments of Okoro River were polluted with the heavy metals determined in total. This is due to the anthropogenic influences on the river. The multivariate statistical analyses applied revealed only positive correlation of some heavy metals such Mn and Ti, Cu and Fe, Rb and Fe which affirm the fact that these heavy metals were introduced into that River from similar anthropogenic processes.

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