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Preliminary Assessment of Trace Metals in Sediments of the Ebonyi River, Abakaliki Metallogenic Province, Nigeria

Olufemi Victor Omonona[1*], Somtochukwu Goodness Azombe[1]

Department of Geology/Geophysics, Alex Ekwueme Federal University, Ndufu Alike, Nigeria

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Abstract

Ebonyi River, Nigeria, acts as a sink for the trace metal-laden wastewater discharged from the mining zone into the river. This study evaluated the enrichment characteristics and ecological risks of trace metals in the fluviatile sediments of the Ebonyi River. Fifteen sediment samples were collected: five samples were collected at the upstream (US) and midstream (MS), and four samples were collected from the downstream (DS). The MS coincides with the mining zone. A control sample was collected from a lake that was not connected to the river. Different pollution indices, including the geoaccumulation index (Igeo), enrichment factor (EF), and pollution load index (PLI), were used to assess the degree of contamination of these trace metals in the sediments. The associated ecological risk was assessed using the potential ecological hazard index (EI). The results showed that the average values of the concentrations of the trace metals varied spatially (US, MS, and DS). The Igeo results revealed that the sediment samples were practically unpolluted by Cu, Ni, V, and Ba (Igeo <0) across the three zones but were strongly polluted by Pb and Zn in the midstream. The calculated EI showed the upstream and downstream samples have low ecological risks, while the midstream samples have ecological risks that range from low to considerable.

Keywords: *Contamination, Geochemical pollution indices, Pb-Zn mining, Sediments, Nigeria.*

1. Introduction

River sediment contamination by trace metals usually poses a serious threat to ecological and human health because of its persistence and accumulation in the food chain. Trace metal contamination of sediment is a great global concern because of its wide range of sources, high toxicological effects, non-biodegradable properties, mobility, and accumulative behaviors. Trace metals in sediment come from lithogenic and anthropogenic sources. Anthropogenic contributions from industrialization, mining, and agricultural activities produce large amounts of trace metals. Mining of lead (Pb) and zinc (Zn) ores in the Enyigba metallogenic provinces, Nigeria, dates back to 1925 but was halted during the Nigerian Civil War of 1966–1970 (Obiora et al., 2016). However, local mining continued intermittently after the civil war until about 2009, when massive mining activities resumed fully in the area (Omonona et al., 2022). Galena (PbS), Sphalerite (ZnS), and Chalcopyrite (CuFeS2) are the major ore minerals that are exploited in the area. Acid mine drainage and untreated ore mineral processing wastewater are usually discharged into the nearby streams that follow the Ebonyi River. The Ebonyi River is the only perennial river in the area, and it serves as a source of irrigation water for dry-season farming when food crops are grown. Contamination of river sediments by trace metals from mining activities can have lethal effects on the ecosystem and the environment in general. Potential toxic trace metals (PTMs) associated with the mining of galena, sphalerite, and chalcopyrite include Pb, Zn, As, Cd, Cu, Mn, Sb, Bi, and Se. The accumulation of PTMs in river sediment, when absorbed above stipulated guideline concentration values by plants and animals, can decimate an extensive population of species.

2. Materials and Methods

2.1. Physiography and Geology of the Study Area

The area of the present study is located in the Upper Cross River basin, bounded by 6^0 0′ and 6^0 40′ N, 8^0 0′ and 8^0 20′ E (Figure 1). The River Ebonyi takes its origin from the Benue hills and flows through the Ebonyi lowlands into the Cross River in the southeast coastal region. The study area belongs to the Guinea Savannah Belt, which is characterized by two seasons: the wet season, which lasts from April to October, and the dry season, which spans from November to March. A vast portion of the northern section of the study area is cultivated for growing rice because of the swampy nature of the soil. Several government-owned rice farms are located in this region. At the beginning of each year's farming season, herbicides are usually employed to clear the grasses, and pesticides are used for pest control. Agricultural activities dominate the human anthropogenic activities of the northern portion of the area, while the major human anthropogenic activities of the central area are mining activities. Geomorphological features in the area include the Abakaliki anticlinorium, lush plain lands, and a few scattered hills. Geologically, the area is underlain by the shale rock of the Albian Abakaliki formation and the siltstone of the Eze-Aku formation. The shale is impervious, and this encourages surface runoff after precipitation. Several Pb and Zn ore mining companies are located within the study area; however, they are all concentrated around the lower reaches of the Ebonyi River.

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* Corresponding author e-mail: victor.omonona@funai.edu.ng

2.2 Sample Collection and Laboratory Analysis

A total of fifteen sediments were collected across the entire length of the Ebonyi River (Figure 1) using the Grab Burrow device and preserved in distilled water and nitric acid-pre-washed polythene bags. The sediment samples were then sent in cool boxes to the Bureau Veritas Laboratory, Canada, for heating, digestion, and analysis processes. Using repeated dilutions, mono-element standard solutions were used to produce a set of composite calibration standard solutions for all metals. All multi-element standards were created in matrix solutions, which comprised alkaline fusion and microwave digestion solutions. Diluting a 100 mg L1 multi-element commercial standard with the suitable matrix solution yielded a 1 mg L1 multi-element quality control standard. A linear calibration was created using up to seven multi-element standards. The first reference material was an external reference material, OxC109, provided by Rock Labs, Auckland, New Zealand, and the second reference material was an internal reference material, DS 10, provided by Bureau Veritas Commodities, Canada, which was used to verify the repeatability and accuracy of the entire analytical procedure. Inductively coupled plasma optical emission spectroscopy (ICP-OES, Optima 8000; Perkin Elmer) was used to analyze the samples. Soil and sediment samples were oven-dried to a constant weight at 60 °C, and fractions larger than 2 mm were collected using nylon sieves. The 2 mm fraction was then pulverized and sieved to ensure a particle size of no more than 100 m; this was done to reduce variability caused by grain size composition. Finally, samples were kept in the refrigerator at 4 °C until they were analyzed. To determine heavy metal contents, sediment samples were digested using microwave-assisted aqua regia digestion (AD). This was chosen so that the microwave apparatus could be utilized with the least quantity of acids.

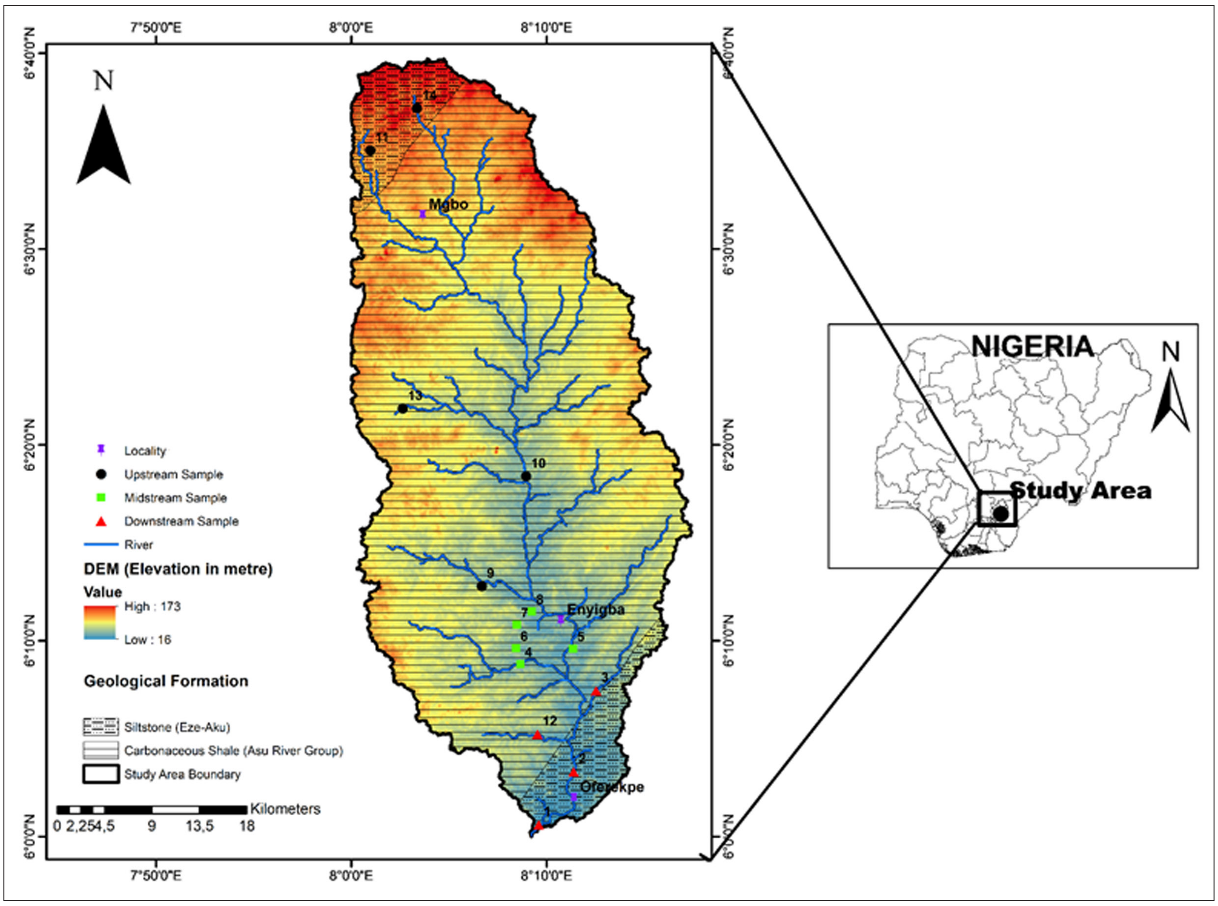

Figure 1. Geological map of the study area with the drainage and topographical (relief) elements.

2.3 Pollution Evaluation Methods

The evaluation of pollution was carried out using the geoaccumulation index (Igeo), enrichment factor (EF), pollution load index (PLI), and potential ecological risk index (RI). In this study, the upper continental crust concentration of trace metals as given by Taylor and McLennan (1885, 1995) was used as the trace metal background concentration for the estimation of the various pollution indices. Al and Fe were used as the reference metals and hence were excluded from the calculation of the pollution indices. In addition, Mn was not used in the estimation of the pollution indices because there was no background concentration set for Mn in the trace metal background concentration estimates provided by Taylor and McLennan (1998, 1995). For the estimation of RI, only Pb, Cd, Ni, As, Zn, Cr, and Cu were used in the calculation because they were the only trace metals with a toxicity response factor.

The Igeo is a single metal method that gives the degree of metal accumulation above background concentration values; enrichment factor (EF) is often used to evaluate anthropogenic contributions of trace metals to soil and sediments. Pollution load index (PLI) is a multiple element pollution index that provides a cumulative pollution status resulting from the synergistic effects of different elements on the environment. Finally, potential ecological risk index (RI), a multi-metal index that gives the synergistic ecological risks associated with trace metals pollutions are used. Igeo, EF, PLI and RI were determined using the mathematical equations expressed in equations 1, 2, 3, and 4 respectively (Müller, 1969):

$$I_{geo} = log_2(\frac{C}{1.5Bn}) \quad (1)$$

where C is the measured concentration of each trace metal, and Bn is the geochemical background concentration value of each trace metal. (Loska et al., 2003):

$$EF = \frac{(\frac{C_i}{C_{ref}})sample}{(\frac{S_i}{S_{ref}})background} \quad (2)$$

where C_i is the concentration of the measured trace metal, C_{ref} is the concentration of the reference trace metal used for the normalization process, S_i and S_{ref} are the background concentration value of the measured metal and the background concentration value of the reference metal respectively. EF classification is given as: lithogenic or geogenic origin (EF<1.5) and anthropogenic origin (EF) (Adeyemi et al., 2019). Al was used as the reference element because it best fits the required criteria for a reference metal. Every metal that has low variation in occurrence and is in trace concentration in the environment is suitable to be used as a reference metal.

$$PLI = [Cf_1 \times Cf_2 \times Cf_3 \times \ldots \times Cf_n]^{1/n} \quad (3)$$

where Cf_1 represents the contamination factor $(\frac{C_i}{S_i})$ of each individual trace metal and n indicates the number of trace metal used in the process (Tomllinson et al., 1980).

When PLI value is less than one, the sediment pollution is at baseline and when PLI is greater than one, it indicates sediment pollution from anthropogenic and lithogenic sources (Hakanson, 1980):

$$RI = \sum_{i=1}^{n} E_f^i \quad (4)$$

where $E_f^i = C_f^i \times T_f^i$

where E_f^i represents the potential ecological risk factor of each trace metal, is the contamination factor for each trace metal, indicates the toxicity response coefficient of each trace metal (Pb=5, Cd=30, Ni=5, As=10, Zn =1, Cr=2, Cu=5) (Tian et al., 2020). The degree of ecological risk of sediment pollution is given as: low ecological risk (ERI<110); moderate risk (110 considerable risk (200 <400); severe risk (ERI) (Tian et al., 2020).

3. Results and Discussion

3.1 Trace Metal Concentrations Characteristics

The results of the laboratory analysis are presented in Table 1 as summary statistics. It was found that the average concentrations of As, Co, Fe, Al, and Mn are highest upstream (Mgbo). The mean concentrations of Cd, Ba, Sr, Al, Cu, Pb, and Zn are highest at the midstream (Enyigba), and the average concentrations of Cr, Ni, and V are highest at the downstream (Oferekpe); see Table 1. The concentrations of Bi and Sb in all the sediment samples analyzed were below the instrument detection limit of 3.0mg/kg (Table 1). The results (Table 1) also revealed that the average concentrations of Sr, Cr, Ni, Co, Mn, Pb, and Zn in sediment from the upstream zone are higher than the concentrations in the control sample. For the midstream zone, the average concentrations of Ba, Sr, Mn, Cu, Pb, and Zn are higher than the concentrations of the control sample, and for the downstream zone, the mean concentrations of Sr, Cr, Ni, V, and Zn are higher than the concentrations of the control sample, indicating some degree of contamination. It was also observed that there is a wide range of Pb and Zn concentrations in the midstream area. The wide range can be attributed to the size and number of mining pits within a given cluster and thereby the amount of wastewater discharged. Stream flow rate could have contributed to this observed range value of Pb and Zn; a fast-moving stream could lower the number of adsorbed metals. The two localities with very high Pb and Zn concentrations are located close to the mining area, where wastewater is discharged into slow-moving streams.

The sources of As, Co, and Mn concentrations in the sediment of the area may be attributed to agricultural activities, mainly the application of chemical fertilizers and the use of pesticides and herbicides. Mechanized agriculture is predominant in the upstream section, where crops such as rice, cassava, and vegetables are grown. The high concentrations of Pb and Zn around the Midstream area could be attributed to the mining of galena and sphalerite around the zone.

3.2 Trace Metal Pollution Characterization

The results of the geoaccumulation indices of Cd, Sr, V, Cr, Ba, Cu, Pb, Zn, Ni, Co, and As are presented in Figure 2. From Figure 2, it was observed that at the upstream area, the Igeo values of Sr, V, Cr, Ba, Cu, and Ni are below zero, indicating that there is practically no pollution of the sediment by these six trace metals. At the same upstream area, Cd, Pb, Zn, Co, and As have Igeo values that range from -1.0 to 4.7. Based on the classification scheme (Table 2), the pollution by these five metals varied between “unpolluted” and “strongly to extremely polluted.” The Igeo values lower than zero indicate “unpolluted.” For these four trace metals, Cd, Ba, Cu, and As, their Igeo values range from 0.2 to 7.8 (Figure 2). The pollution status of these four trace metals falls within the “moderately polluted” to extremely polluted” class (Table 2).

Finally, in the downstream area, a different scenario was observed. Only three metals, namely Sr, V, and Ba, have Igeo values less than zero, indicating there is no pollution by these three trace metals. The Igeo values of Cd, Cr, Cu, Pb, Zn, Ni, Co, and As, on the other hand, varied between -1.2 (“unpolluted”) and 1.2 (“moderately polluted”). Figure 2 revealed that only Cd, Pb, Zn, Co, and As of the all trace metals used for the estimation of Igeo have values greater than zero at the three zones (upstream, midstream, and downstream), thus, indicating that these trace metals have concentrations above the natural background concentrations in the entire study area. The Igeo values for Pb and Zn at the upstream and midstream are higher than one but lower than one at the downstream (Figure 2). This result indicates that only the upstream and midstream sediments are strongly contaminated by these metals. The highest Igeo values for Pb (5.1) and Zn (2.7) are found in the midstream sediments, indicating extreme and moderate contamination by these two metals, thus, reflecting the impact of mining activities in the zone. The Igeo value of Cd downstream is lower than one, indicating no contamination by the trace metal, but greater than 4.0 for the upstream and midstream sediments, which indicate strong contamination by Cd.

Table 1. Univariate statistics of the trace metals concentrations.

	Cd (mg/kg)	Sr (mg/kg)	V (mg/kg)	Cr (mg/kg)	Ba (mg/kg)	Al (%)	Fe (%)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Ni (mg/kg)	Co (mg/kg)	Mn (mg/kg)	As (mg/kg)	Bi (mg/kg)	Sb (mg/kg)
IDL UPS (n=5)	0.5	2.0	1.0	1.0	1.0	0.01	0.01	1.0	3.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0
Min	0.5	11	27	38	83	0.9	4.5	11	18	75	11	15	945	2	bdl	bdl
Max	3.3	43	93	144	118	2.9	14.5	36	308	757	55	38	1795	6	bdl	bdl
Mean	1.1	**22**	**47.8**	**67.8**	97.2	**1.8**	7	20	**97.6**	**235**	**29.6**	**27.6**	**1404**	3.4	bdl	bdl
Median	0.5	21	38	46	96	1.8	5.5	14	53	117	24	28	1527	2	bdl	bdl
SD		11.2	23.5	39.2	11.9	0.7	3.8	9.6	106.2	261.3	16.1	7.3	313	1.7	bdl	bdl
MDS (n=5)															bdl	bdl
Min	0.5	11	17	24	78	0.8	2.6	12	34	52	15	11	346	2	bdl	bdl
Max	27.6	543	85	107	2380	2.3	14.1	40	2197	1114	34	25	1378	4	bdl	bdl
Mean	**7.2**	**124**	40.4	51.2	**565**	1.6	6.6	**22.8**	**904**	**689**	22	19.2	**951**	2.6	bdl	bdl
Median	2.7	18	28	40	82	1.5	4.9	23	370	822	20	21	1080	2	bdl	bdl
SD	10.21	209	24.0	29.2	908	0.4	4.1	9.9	831.6	366	7.2	5.3	352	0.8	bdl	bdl
DNS (n=4)															bdl	bdl
Min	0.5	4	3	3	26	0.1	0.2	1	3	5	2	1	28	2	bdl	bdl
Max	0.5	30	154	252	117	4.0	14.4	52	49	138	124	32	908	3	bdl	bdl
Mean	0.5	**18**	**52**	**78.5**	73.7	**1.8**	5.9	**21**	28.7	**78**	**43**	16.5	603	2.5	bdl	bdl
Median	0.5	19	25.5	29.5	76	1.5	4.6	15.5	31.5	84.5	23	16.5	738	2.5	bdl	bdl
SD	0	9.8	59.6	100.8	32.4	1.4	5.2	19.2	16.5	50.1	48.1	10.9	339	0.5	bdl	bdl
															bdl	bdl
Control (n=1)	0.5	7	47	66	175	1.3	8.1	20	41	63	27	26	829	4	bdl	bdl

IDL: instrument detection limit; bdl: below detection limit; UPS: Upstream; MDS: Midstream; DNS: Downstream; Min: Minimum; Max: Maximum; SD: Standard deviation; trace metal concentrations above control values are written in bold.

Table 2. Range of values for soil classification using pollution indices.

Index value	Class	References
Geoaccumulation index		
Igeo < 0	Unpolluted	Men et al., 2018
0<Igeo>1	Unpolluted to moderately polluted	Khademi et al., 2019
1<Igeo>2	Moderately polluted	Monged et al., 2020
2<Igeo>3	Moderately to strongly polluted	Adimalla et al., 2020
3<Igeo>4	Strongly polluted	Egbueri et al., 2020
4<Igeo>5	Strongly to extremely polluted	Egbueri et al., 2020
Igeo>5	Extremely polluted	Egbueri et al., 2020
Enrichment factor		
EF < 2	Deficiency to minimal enrichment	Relic et al., 2019
2 < EF<5	Moderate enrichment	Jiang et al., 2020
5 <EF >20	Significant enrichment	Monged et al., 2020
20 < EF > 40	Very high enrichment	Adimalla et al/. 2020
EF > 40	Extremely high enrichment	Radomirovic et al., 2020
Pollution load index		
PLI < 1	Unpolluted	Relic et al., 2019
1<PLI<2	Moderately polluted	Jiang et al., 2020
2<PLI >10	Strongly polluted	Egbueri et al., 2020
PLI >10	Extremely polluted	Monged et al., 2020
Risk index		
RI < 150	Low ecological risk	Men et al., 2018
150<RI>300	Moderate ecological risk	Gan et al., 2019
300<RI>600	Significant ecological risk	Hakanson, 1980
600<RI > 5000	Very high ecological risk	Men et al., 2018
RI>5000	Extremely high ecological risk	

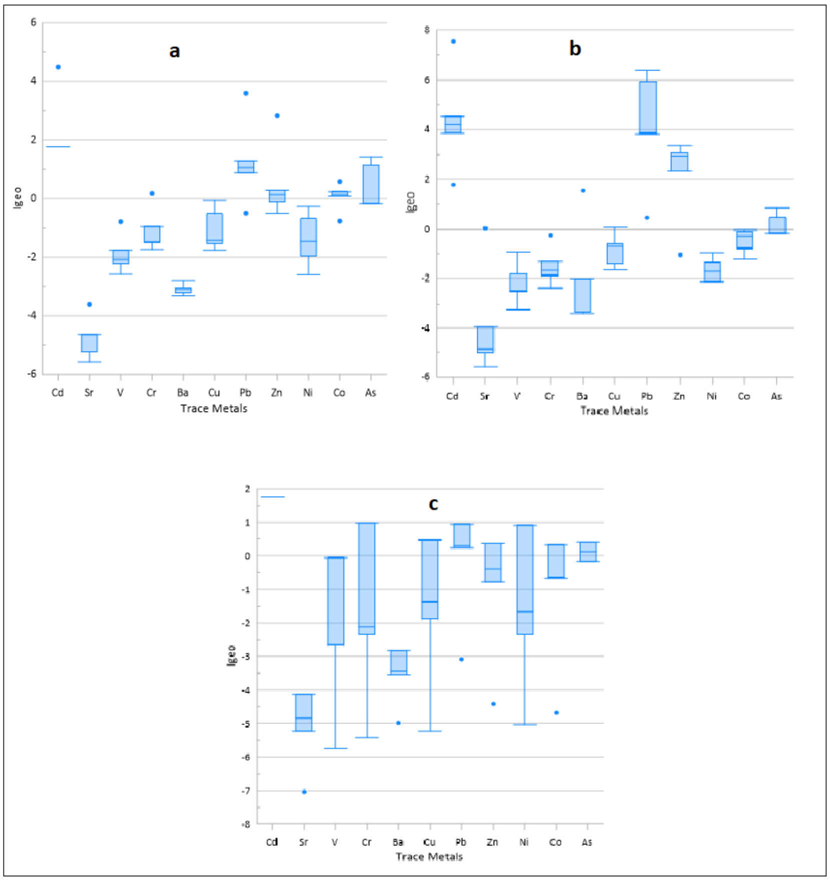

Figure 2. Geoaccumulation index across the three zones (a-upstream; b-midstream; c-downstream).

The mean values of EF for the different trace metals are presented in Table 3. From the table, it was revealed that only Cd, Pb, Zn, and As have EF values greater than 1.5. Trace metals with EF values greater than 1.5 indicate the effect of human influences on their sources (anthropogenic contributions), while trace metals with EF values lower than 1.5 indicate geogenic sources (Hu et al., 2013; Islam et al., 2020; Ezewudo et al., 2021). The order of sediment enrichment by trace metals across the zones is midstream>downstream>upstream (Table 3). Most of the trace metals are thought to be released mainly by mining activities at midstream and transported downstream. The results of the pollution load index (Figure 3) revealed that the PLI ranged from 0.09 to 2.08. Figure 3 shows that the least measured PLIs are around the Mgbo area in the north and close to the Oferekpe area in the south. PLI is highest around the mining zone in the Enyigba area. Normally, areas around the downstream (Oferekpe) in the south should exhibit the highest degree of pollution, but in this case, it is not so. The low PLI occurrence in the downstream zone may be attributed to the very rich clay materials that underlie the entire region. The Abakaliki formation, which underlies a very large percentage of the study area (Figure 1), is very rich in shale, a porous but impermeable rock that has a high adsorption capacity, thereby reducing the amounts of trace metals transported from the source to the sink. Another factor is the size of the Cross River downstream, into which all the other streams drain or empty their water. The volume of water and the size of the Cross River are incomparable to the tributaries that supply the water to the main Cross River. For the midstream zone, the high PLI of the area is largely contributed by Pb and Zn contaminants that result from the galena and sphalerite ore mining in the zone, and for the upstream zone, the sediment contamination is thought to emanate mainly from Cd and As concentrations resulting from agricultural activities.

Table 3. Results of enrichment factor (EF).

Sample ID	Cd	Sr	V	Cr	Ba	Cu	Pb	Zn	Ni	Co	As
UPS											
9	**2.6**	0.03	0.2	0.2	0.09	0.2	**1.6**	0.5	0.2	0.9	0.6
10	**13.6**	0.02	0.1	0.1	0.06	0.5	**7.3**	**4.3**	0.3	0.6	0.5
11	**4.2**	0.03	0.2	0.4	0.12	0.3	**2.2**	1.1	0.3	1.3	1.1
13	**1.7**	0.04	0.2	0.5	0.07	0.3	1.2	0.5	0.4	0.7	1.3
14	**5.2**	0.03	0.5	0.8	0.18	0.5	1.0	1.8	0.2	0.9	**3.4**
MDS											
4	**201**	0.06	0.2	0.2	0.10	0.6	**14.8**	**11.2**	0.3	0.8	0.9
5	**3.1**	0.03	0.3	0.3	0.09	0.2	**1.2**	0.4	0.2	0.9	1.2
6	**17.3**	0.02	0.4	0.6	0.18	0.8	**46.1**	**3.8**	0.2	0.7	1.3
7	**11.5**	0.6	0.1	0.1	1.82	0.2	**9.1**	**5.3**	0.3	0.3	0.5
8	**23.8**	0.03	0.2	0.3	0.16	1.1	**143**	**12.8**	0.3	0.7	1.4
DNS											
1	**26.3**	0.05	0.1	0.1	0.24	0.2	0.9	0.3	0.2	0.3	**6.8**
2	**4.5**	0.03	0.2	0.2	0.13	0.3	**1.7**	0.7	0.3	0.8	1.1
3	**2.5**	0.04	0.1	0.2	0.10	0.4	0.8	0.7	0.3	0.5	1.0
12	1.2	0.01	0.3	0.7	0.03	0.5	0.7	0.4	0.6	0.4	0.4
CONTROL	**3.7**	0.01	0.3	0.5	0.23	0.6	**1.7**	0.6	0.4	1.1	**1.9**

* EF values greater than 1.5 are written in bold; UPS-upstream; MDS-midstream; DNS-downstream

Potential ecological risk indices (ERI) of the study area ranged from 167 to 8589, with a mean value of 1094. The RI classification showed that all the sediments in the study area show moderate to very high ecological risk (Table 2). The highest ecological risk at the present time was found around the Enyigba area (midstream), where mining activities are ongoing (Figure 4). The mean contribution of each of the trace metals to the overall RI follows the following order: Cd (86.98%)>Pb (9.79%)>As (1.89%)>Zn (0.45%)>Cu (0.41%)>Ni (0.33%)>Cr (0.15%). This study reveals that Cd is the trace metal that poses the highest ecological risk out of the trace metals examined. Similar results have been reported for studies carried out in Nigeria (Egbueri et al., 2020; Attah et al., 2022) and other parts of the world (Khudhur et al., 2018; Gan et al., 2019; Yaseen and Al-Hawari 2019; Radmanovic et al., 2020; Tarawneh et al., 2021).

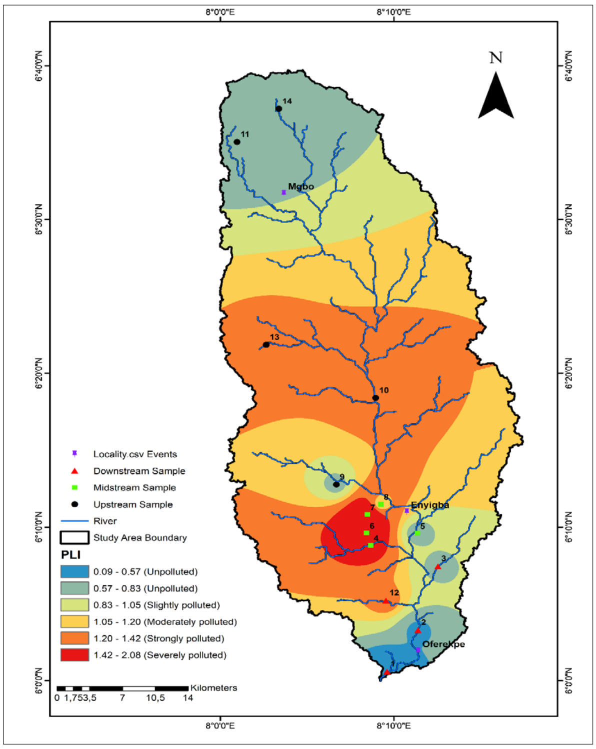

Figure 3. A map of pollution load index (PLI) depicting the spatial variation across the study area.

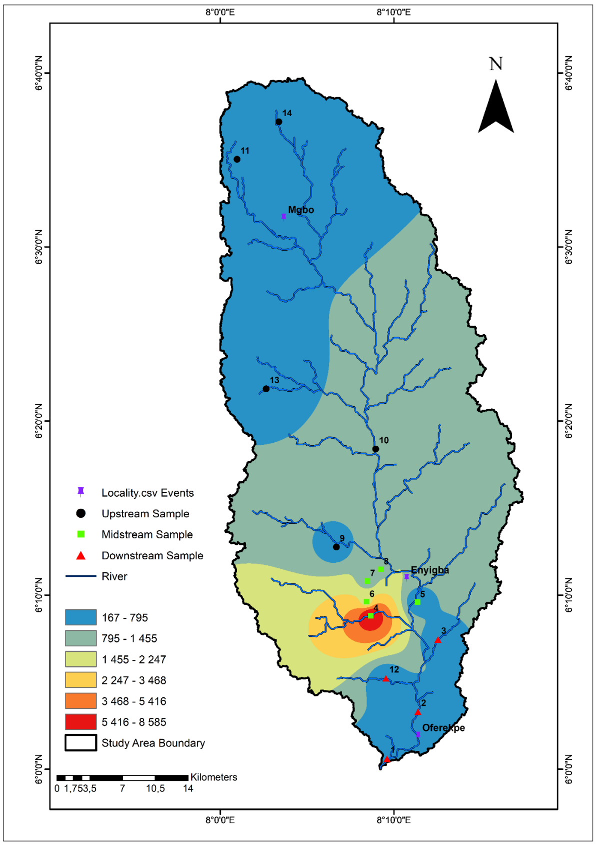

Figure 4. Spatial distribution map of ecological risk index (ERI) for the study area.

3.3 Comparison of the Pollution Indices

The pollution indices used in this study can be grouped into two categories: pollution indices (Igeo and EF) that deal with the individual trace metal accumulation in the earth material (sediment) and enrichment in the environment and pollution indices that deal with the pollution status of the individual sediment samples. Table 4 shows the percentage of pollution classes for the individual trace metals. The table shows that both Igeo and EF distinctively classify the trace metals into different degrees of accumulation and enrichment. It is revealed in Table 4 that there is no conflicting or antagonizing description between the two indices. For example, 7% of Cd classified as "extremely polluted" were also classified as "extremely high ecological risk" by Igeo and EF, respectively. Likewise, Pb has been classified as "extremely polluted" and "extremely high ecological risk" by Igeo and EF, respectively. In addition, all the V concentrations are classified as unpolluted and 100% as "deficiency to minimal enrichment" by Igeo and EF, respectively.

PLI and RI were also perfectly related. All the samples described by PLI as unpolluted are also described by RI as having low to moderate ecological risks. Samples described as moderately polluted by PLI are described as having a moderately high ecological risk. As shown in Table 5, 7% of the samples described as strongly polluted by Igeo were also described by RI as having an extreme ecological risk.

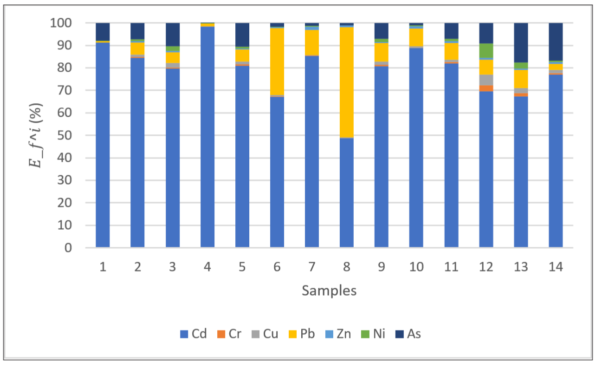

Figure 5. A graphical plot of values showing the contributions of individual trace metals to ecological risk indices.

Table 4. Pollution category distribution of individual trace metals expressed in percentages.

Class	Cd	Sr	V	Cr	Ba	Cu	Pb	Zn	Ni	Co	As
Igeo											
<0	0	93	100	86	93	86	14	36	93	64	57
0-1	0	7	0	14	7	14	37	29	7	36	29
1-2	65	0	0	0	0	0	14	0	0	0	14
2-3	0	0	0	0	0	0	0	21	0	0	0
3-4	7	0	0	0	0	0	21	14	0	0	0
4-5	21	0	0	0	0	0	0	0	0	0	0
>5	7	0	0	0	0	0	14	0	0	0	0
EF											
<2	14	100	100	100	100	100	58	65	100	100	86
2-5	36	0	0	0	0	0	7	14	0	0	7
5-20	29	0	0	0	0	0	21	21	0	0	7
20-40	14	0	0	0	0	0	0	0	0	0	0
>40	7	0	0	0	0	0	14	0	0	0	0

Table 5. Pollution category distribution of sediment samples expressed in percentages.

Class	Unpolluted	Moderately polluted	Strongly polluted
PLI	50	43	7
Class	Moderate ecological risk	Very high ecological risk	Extreme ecological risk
RI	64	29	7

4. Conclusion

The study is centered on the assessment of trace metals in river and stream sediments using pollution indices. The concentrations of the different trace metals examined in sediments around the Enyigba-Abakaliki area varied from one locality to another. The sediment trace metal enrichment factors were in the order of: Fe>Al>Mn>Pb>Zn>Ba>Cr>Sr> V>Ni>Cu>Co>Cd>As.

The results of the Igeo from the study area showed that the soil sample contamination level varied from unpolluted to extremely polluted, with soil samples from the midstream showing the highest trace metal contamination. From the results of the enrichment factor, it can be seen that Cd, Pb, Zn, and As, among the trace metals studied, have their sources mainly from anthropogenic activities. Trace metals that show the predominance of lithogenic sources over anthropogenic activities include Sr, Cu, Ni, Co, V, Cr, and Ba.

The pollution load index revealed that the soil samples are characterized by an unpolluted to severely polluted status. Severely polluted soil samples were those influenced by the effects of human activities. Risks to the environment arising from trace metal contamination evaluated through the ecological risk index showed that no soil sample fell below low ecological risk. The soil samples all varied from moderate ecological risk to extremely high ecological risk.

In general, this study has revealed that the soils around the mining sites have been seriously polluted by heavy metals. Over time, if nothing is done to ameliorate the effects of mine wastewater discharge into the nearby streams, the entire surface water drainage system, groundwater resources, and river sediments will be unfit for use by anyone. The findings of this work will be useful for land management boards and all environmental agencies.

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