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Potentially Toxic Metals Enrichment in Soils of Ishiagu Mining Community, Southeastern Nigeria

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Abstract:- This Study was carried out to evaluate potentially toxic metals enrichment, pollution and potential ecological risk in the soils of Ishiagu. The concentrations of Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn), Aluminum (Al) and Iron (Fe) in soil samples from the area were analyzed by Bureau Veritas Laboratory, Vancouver, Canada, using inductively-coupled plasma optic emission spectrometry (ICP-OES). Descriptive statistics, enrichment factor, pollution load and potential ecological risk indices were employed to analyze the data in order to understand the characteristics of potentially toxic metals in the study area. The potentially toxic metals statistic show the mean values (mg/kg^{-1}) of Pb, Zn, Mn, Fe, Al, Cd, Cr, Ni, Co, and Cu to be 205.7, 162, 527, 35892, 11374, 1.3, 21.6, 15, 14.6 and 11.1 respectively. The soil enrichment varied considerably between mining and non-mining areas with mining area being extremely enriched with Pb, Zn and Cd, significantly enriched with Co, Cu, Ni and Fe and highly enriched with Mn. Non- mining areas are minimally enriched with all investigated metals. The soils around the mines are polluted with Pb and Cd, where both metals also pose very high ecological risks.

Keywords:- *Metal, Soil, Enrichment Factor, Pollution Load Index, Potential Ecological Risk, Ishiagu.*

I. INTRODUCTION

Mining provides metals critical in today's technology and human sustenance. It is a major economic activity in many societies, especially in Africa. However, in spite of its benefits, it has negative impact on the environment. One of the key impacts of mining is the contamination of the environment with potentially toxic metals, which has serious human health implications.

Contaminated soils can pose risks to the wider environment such as increased uptake of potentially toxic metals by plants and migration into ground and surface waters [16]. Risks to human health may occur, either via the food chain through consumption of heavy metal contaminated food, or through dermal contact with or ingestion of contaminated soil [7].The exposure of humans to heavy metals can cause serious health challenges such as the incidence in Toyama district, Japan, where local rice farmers suffered a severe cadmium toxicity disease known as Itae-itae from the consumption of rice grown on Cadmium contaminated soil in early 1960s [8]. In the 1950s, in Minamata, Japan, the consumption of methylmercury contaminated fish caused a variety of health problems collectively termed 'Minamata disease' among the fishing population [12]. In 2010, there was an incident of Pb poisoning, resulting from artisanal Gold mining that killed about 163 people(mainly children) in Zamfara State, Nigeria[1]

Ishiagu is an important mining district in southeastern Nigeria with Pb-Zn ore mining dating back to the early 1960s [10]. The ore, which is mined by opencast method, generates huge mine waste dumped around the mines that can serve as source of trace metals into nearby soils. The mines are also usually flooded, requiring the pumping of ore-containing mine water into the surrounding soil from time to time. In addition to mining, Ishiagu is an agrarian community and occupies an important place in the food supply chain within the southeast region due to the availability of cultivatable large expanse of land. It is important that this natural resource be protected as pollution of soil with potentially toxic metals has severe environmental and human health consequences. However, for this to be achieved, knowledge of the soil pollution status is important. It is in this regard, that this study was conducted to establish the status of soils in this area with respect to potentially toxic metals.

II. MATERIALS AND METHOD

A. Study Area

The study area lies within latitude N5º 52ᴵ 0ᴵᴵ to N5º 60ᴵ 0ᴵᴵ and longitude E7º 29ᴵ 30ᴵᴵ to E7º 36¹0ᴵᴵ (Fig. 1). The geology of the area is predominantly shale of Albian age with minor occurrences of sandstone, siltstone and limestone generally referred to as the Asu River Group [3]. The shale is dark grey and finely laminated while the sandstone units are fine to medium grained. The Albian rocks form anticlines and synclines that are transected by several northwest and north- trending faults and fractures [9]. There is also the occurrence of igneous rocks, which are mainly intrusive rocks in this group [3]. Lead and Zinc minerals in Ishiagu occur mainly in shale of the Asu-River Group and the mineral deposit consists principally of lead and zinc in the ratio of approximately 2:1. Other constituents include pyrite, siderite, chalcopyrite, marcasite, bornite, and quartz [9].

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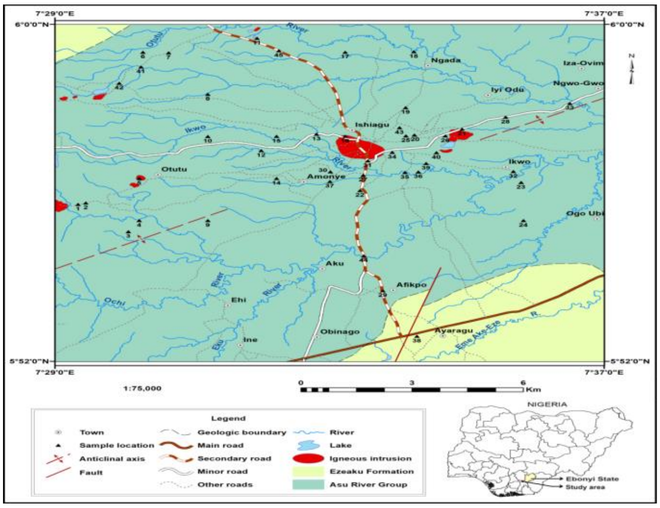

Fig 1. Geological Map of Ishiagu

B. *Field Sampling*

The sampling sites were chosen, based on knowledge of the existence of activities such as mining, and quarrying. Soils were sampled at 0-20cm depths with individual samples of approximately 2 kg collected, mixed and stored in well labeled plastic containers at room temperature. Each sample location was recorded with a GPS at the point of collection. A total of 45 samples were collected which were subsequently dried at room temperature before sending it to Bureau Veritas Laboratory, Vancouver, Canada for analysis. The samples were digested with aqua regia and the concentrations of potentially toxic metals in the samples determined by ICP-OES.

C. *Data Analysis*

➢ *Descriptive Statistics*

The concentration data was analyzed statistically to obtain characteristics such as minimum, maximum, arithmetic mean, median, standard deviation, coefficient of variation and skewness.

➢ *Enrichment Factor (EF)*

In addition to descriptive statistical analysis, enrichment factor was calculated to determine the level of anthropogenic influence on the natural concentration of potentially toxic metals in the soil. The enrichment factor was calculated with respect to a reference element which is characterized by low occurrence variability [11]. The unpolluted earth crust concentration [15] of the reference element is often used in the calculation of enrichment factor. In this study, the choice of the most stable element in EF calculation was based on the element with the least coefficient of variation (CV) because the smaller the CV, the more stable the element [11]. Aluminum (Al) was used as the reference metal because it has the smallest coefficient of variation.

The enrichment factor (EF) was calculated according to [13] as:

$$EF = \frac{\left(\frac{Cx}{Cref}\right) sample}{(Cx/Cref) backgroud} \qquad (1)$$

Where *C*x represents the concentration of the metals determined in this study and *C*ref the average concentration of Al in the earth crust. Table 1 shows the various categories of EF.

Table 1. Classification of Enrichment Factor

EF	Category of Enrichment
< 2	deficiency to minimal enrichment
2 - 5	moderate enrichment
5 - 20	significant enrichment
20 - 40	very high enrichment
>40	extreme enrichment

Source: [14].

According to [6], EF values ranging between 0.5 and 2 can be considered in the range of natural variability, whereas values greater than 2 indicate enrichment corresponding mainly to anthropogenic inputs.

➢ *Pollution Load Index (PLI)*

Pollution load Index was calculated to determine the pollution status of the soils. The PLI assesses the mutual contamination effects of the metals and gives a generalized assessment on the level of soil contamination. PLI is calculated as the nth root of the number of multiplied contamination factors as shown in equation 2.

$$PLI = (CF_1 \times CF_2 \times CF_3 \ldots\ldots \times CF_N)^{1/N} \qquad (2)$$

CF= contamination factor which represents the individual impact of each potential toxic metal on the soils and N = number of metals. The index of pollution is classified as in Table 2.

Table 2. Pollution index classification

PLI	Pollution level
≤ 1	Low
$1 < PLI \leq 3$	Medium
$PLI > 3$	High

Source: [2]

➢ *Ecological Risk (Er) and Potential Ecological Risk Index (RI)*

This is used to indicate soil or sediment pollution according to the properties and environmental behaviour of the metal. This method considers comprehensively, the synergistic effect of multiple elements toxicity level, pollution degree, and environmental sensitivity to potential toxic metal. The ecological risk factor (Er) was assessed according to [5] as:

$$Er = TrxCF \qquad (3)$$

Where Er is the ecological risk for each metal, Tr represents the toxic response for the given metal which according to [5],are: Pb = 5, Zn = 1, Mn = 1, Cr=2, Ni=5, Co=5, Cu=5 and Cd = 30 . CF is the contamination factor for each metal.

The Potential Ecological Risk Index (RI) was calculated from the ecological risk (Er) as the sum of all risk factors for all the metals in soils as in equation 4 and classified as shown in Table 3.

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

Table 3. Potential Ecological Risk Index Classification

RI values	**Description**
: ≤ 150	Low ecological risk of potential
150 < *RI* ≤ 300	Moderate ecological risk potential
300< *RI* ≤600	Considerable ecological risk potential
RI > 600	Very high ecological risk potential

Source: [5]

III. RESULTS

The range in concentration of potentially toxic metals in mgkg^{-1} are: Pb(5–2995) with mean of 205.7; Zn(5–1450) with mean of 162; Cu (2–37) with mean of 11.1 ; Co(2–47) with mean of 14.6 ; Cr(6–64) with mean of 21.6; Ni(1–73) with mean of 15; Cd (0.5 – 11) with mean of 1.3; Mn(24-2217) with mean of 527; Fe(2800-80800) with mean of 35892 and Al(22000-27400) with mean of 11374. The average concentration of Fe, Al, Cr, Ni, Co, Mn and Cu did not exceed geochemical background while Pb, Zn and Cd mean values are higher than background concentration. Soils close to the mines are extremely enriched with Pb, Cd and Zn. The scale of soil contamination is from practically uncontaminated in non- mining areas to very highly contaminated close to the mines in Ugwutangele and Eziator areas, with severe potential ecological risk posed by Cd and Pb in these areas. Pb, Zn and Cd showed similar spatial distribution, on the account of same source (mining), with a pattern of increasing concentration towards the mines.
The abundance of potentially toxic metals is in the order: Fe>Al > Mn > Pb > Zn>Cr > Co>Ni> Cu>Cd.

Enrichment factors were calculated according to the average values of the elements concentrations in the unpolluted earth crust [11]. The result showed that soil enrichments with potentially toxic metals varied with location. The range of the EFs are: Pb (3 to 1555) with average of 89, Cd(0 to 625) with average of 63, Zn (2 to 131) with an average of 16, Cr(1 to 2) with an average of 2, Ni(1 to 8.2) with an average of 3, Co (2 to 24) with an average of 7, Cu(2 to 13) with an average of 4, Mn (0.8 to 32.8) with an average of 7, Fe(1 to 8) with an average of 4 and Al which was used as reference metal has the value of 1.

The class of soil enrichment factor is from minimal to extreme enrichment. The extremely enriched soils correspond with mining impacted areas located in the southwest and northwest parts of the study area. The soils in these areas are extremely enriched with Pb, Cd and Zn, significantly enriched with Co, Cu, Ni and Fe, and highly enriched with Mn. Non- mining areas are not enriched with potentially toxic metals.

The soil pollution varied considerably between mining and non-mining areas. The highest index of pollution was obtained for soils in the southwest and northwest parts (Fig.2) where the pollution is associated with the mining of ore mineral that contains Pb and Zn as predominant metals. The general pollution status range between low to medium (PLI= 0.03 to 1.4).

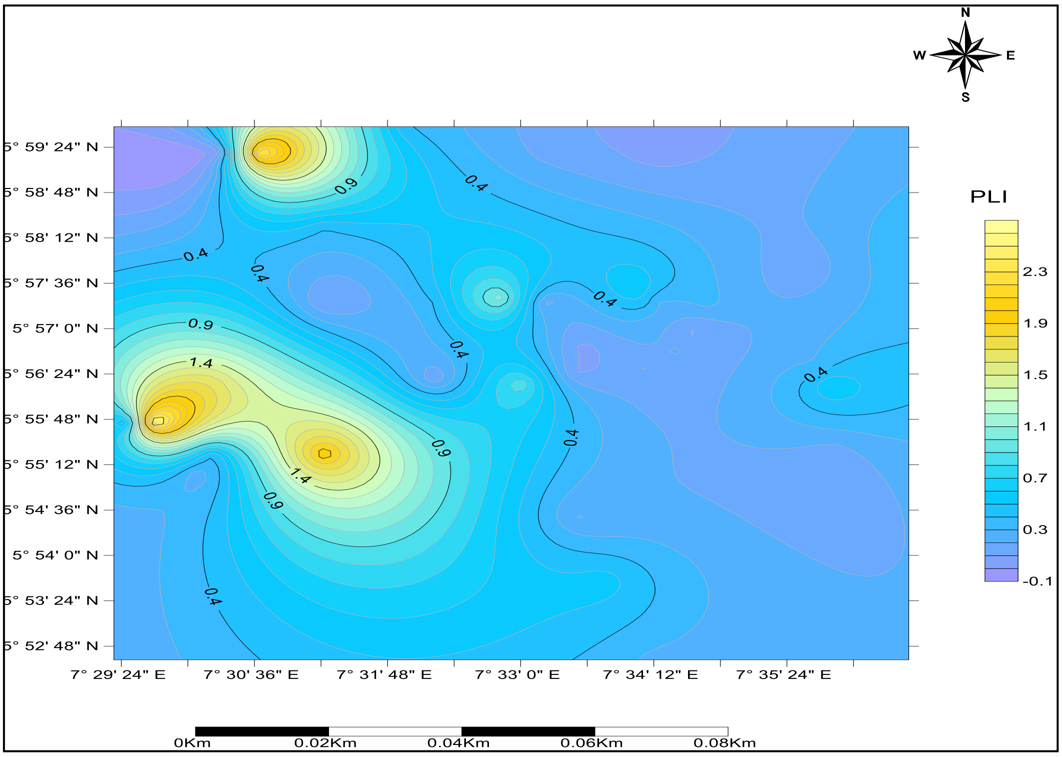

Fig 2. Soil Pollution Map of Ishiagu

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Ecological risk(Er) posed by potentially toxic metals in the study area varied with location and the metal in question. The scale of risks posed by Pb and Cd ranged from low (Er< 40) in non-mining areas to severe risks(Er>320) within mine vicinity. The ecological risks of Zn, Mn, Ni, Cr, Co and Cu in the entire area are categorized as low (Er <40). The potential ecological risk of contamination also varied with location and ranged from low to very high potential risks (RI = 3 to 3801)(Fig. 3).

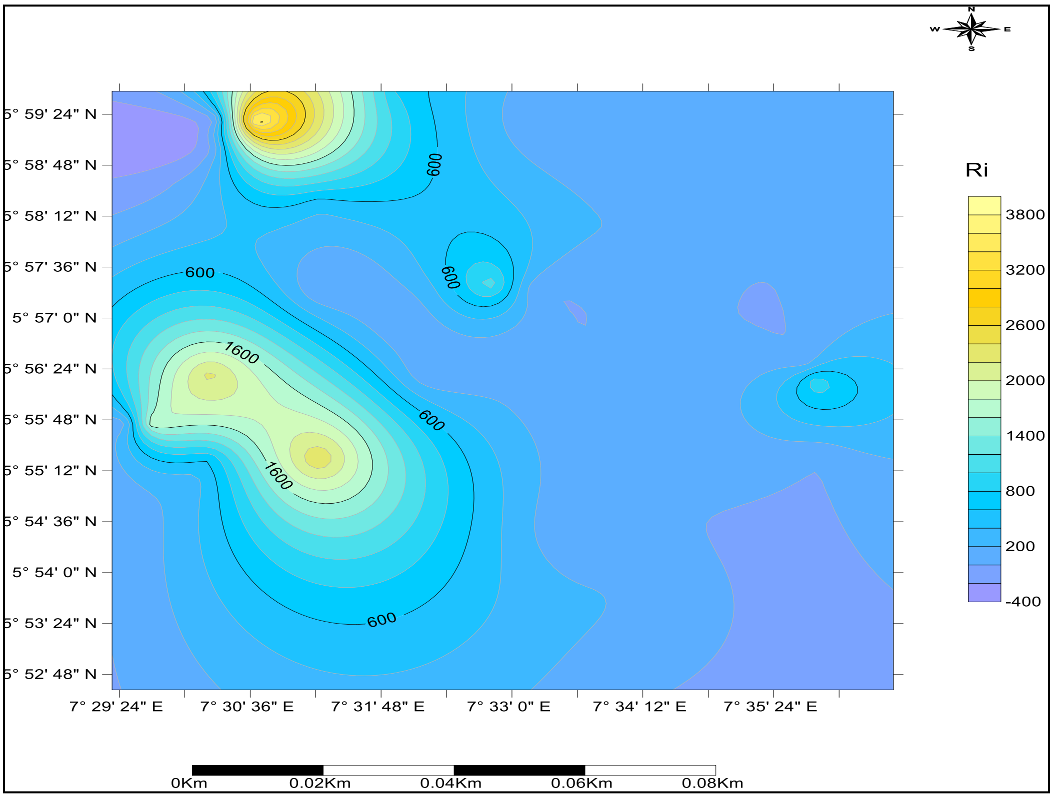

Fig 3. Potential Ecological Risk (RI) map.

The spatial map shows the RI of potential toxic metals in a large portion of the study area to be low (≤. 150) while considerable to very high risk areas occur close to the mines in Ugwutangele and Eziator areas. The average contribution of individual metals to RI is shown in Fig. 4.

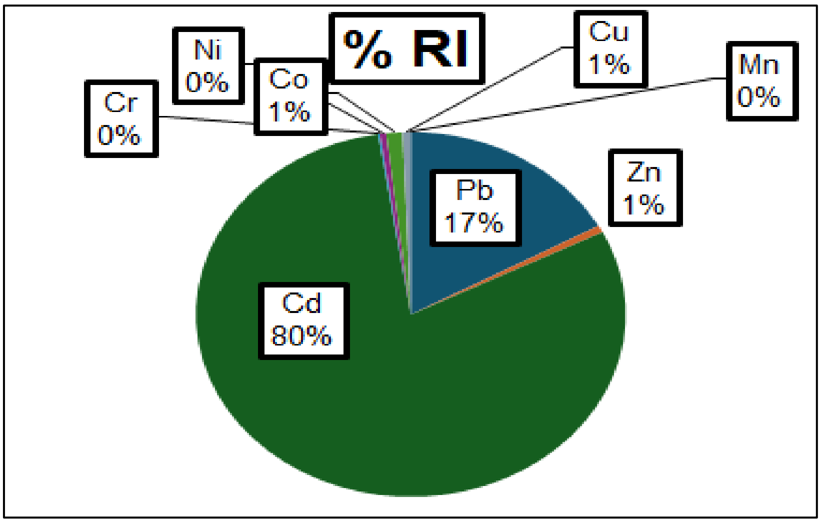

Fig 4 Contribution of Individual Heavy Metals to RI

IV. CONCLUSION

This study showed that Fe is the most abundant potentially toxic metal in the study area soil. It was observed that Fe, Al, Cr, Ni, Co and Cu average concentrations were less than their geochemical background (average crustal level) while Pb, Cd and Zn were higher than their background levels. Soils in Ishiagu area are minimally to extremely enriched with Pb, Cd and Zn, with the extremely enriched soils being soils around the mines in Ugwutangele and Eziator. The order of potentially toxic metals enrichment in the soil is: Pb> Cd> Zn> (Co,Mn)>Cu>Fe>Ni>Cr>Al. The soils close to the mines are polluted with Pb and Cd, where both metals also pose very high ecological risk. It is recommended that the cultivation of arable crops (especially rice, known to accumulate Cd and Pb) close to the mines be avoided to guard against human exposure to toxic metals.

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