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Assessment of Heavy Metals in Mine Soil and Tailings from Jos, Nigeria

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Assessment of Heavy Metals in Mine Soil and Tailings from Jos, Nigeria

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Abstract. Jos is a mining town in Nigeria; mining activities has been going on in the area for more than a 100 years. Although, the mining and other related activities have brought about economic, social growth and infrastructural development in the area. Unfortunately, mining activities has been linked to the enhance in the level of heavy metals in the soil and other geological formations in the environment. To ascertain the heavy metals (HM) burden in the soil due to tin mining activities at Rayfield-Du area of Jos, HM concentrations were evaluated in soil samples collected from the mine site. The HM concentrations in the soils were evaluated using the Energy Dispersive X-ray Florescence (EDXRF) spectrometer system. The analysis of eight HM (Cr, Co, Ni, Cu, Zn, As, Cd, and Pb) concentrations showed that they are above the Nigerian reference level except for Co and Ni. The pollution and ecological risk indices of the HM concentrations were classified as low for the mine soils.

1. Introduction

The negative impact of tin mining or any other minerals on man and his environment cannot be over-emphasized. Although, mining brings a lot of economic and sometimes infrastructural benefits to the immediate mine community and the nation at large, it however, brings threat to humans and animals lives. This threat emanates from the pollution the mining activities bring to the ecological habitats and also the changes in the land scape. Abandoned and active mining pits affect the water table via changing the upstream course brought about by lowered base level. The lowered base levels are a major cause of gully erosions. The pits may also serve as death traps for unsuspecting animals and humans. These hazard is mostly suffered by the immediate community and the mine workers. Furthermore, the environmental pollution that accompanies tin mining stems from the release of chemo toxic and radiotoxic chemicals that are released to the environment during the mining and milling of minerals. A waste product such as mine tailings and sludge rich in heavy metal and radioactive bearing mineral are the major cause of the environment pollution resulting from mining. The tin ore itself is a radioactive mineral that contains Zircon, Monazite, Xenotime and Thorite [1]. These are uranium, thorium and heavy metal bearing minerals. Heavy metals associated with tin mine tailings include: Zn, Pb, Cu, Sn, and Ni. These metals are toxic to plants and animals when their concentration in farm soil surface and underground water is more than their natural distribution in these geological formations. The evaluation of these HM in geological formations such as

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soil water etc. in the environment is very important as it will reveal the level of environmental toxicity. The health effect associated with such toxicity can be avoided if remediation actions and reclamation of such formations are carried out. Hence, from environmental and public health perspective, it is important to determine the level of HM in the environment.

Mining activities may thus be a major threat to ecological habitat of man and animals. In this light, continuous monitoring of the extent of contamination of soil in mining area is very important as part of the impact assessment of the activities of miners on the environment, and on the miners and the general public health of the people living around the mine field at Rayfield- Du area of Jos Nigeria.

2. The study area

Jos is the capital of Plateau, Nigeria whose location is depicted in Figures1 and 2. The study area is located within the coordinate: latitudes 9˚30' and 10˚10' N and longitudes 8˚15' and 9˚15' E and roughly 4062 feet above sea level. Figures 1 and 2. The climate is controlled by tropical dry and wet conditions with annual rainfall and temperature ranging between 1500 – 2000 mm and 20˚C – 25 ˚C correspondingly [2]. The geography is characterized by series of highlands of variable heights and flat land. Furthermore, short trees, tall shrubs and grasses defines the vegetation of the area. The geological arrangement of the area is largely made up of almost entirely plutonic and volcanic rocks belonging to four main age groups. Sediments are restricted to valley alluvium.

The British company then known as the Royal Niger Company (RNC) was birthed in 1848 and obtained licenses from the British government to mine tin in the Plateau in 1908 as Nigeria was still under the British Colonial occupation. By 1909, the RNC began mining and through the British government placed a ban on all local mining. In 1913 the RNC started giving licenses to other mining companies to operate. This lead to rapid increase in Nigeria tin output. The RNC in 1909 was producing about 458 tons of tin which rose to 8174 tons after 1919 when more companies were licensed. Consequently, licensed area after mining also increased from 373 km^2 to about 900 km^2. These brought workers of many tribes and nationality to the Jos Plateau and eventual revolution to the technical skills of the people and the organization of mining labour and management. Furthermore, the economic and infrastructure fortune of the Plateau and Northern Nigeria soared [3]. Rail lines were built from Lagos to Zaria for the sole purpose of exporting tin. By independence in 1960, Nigeria was the sixth largest producer of tin worldwide [3].

Throughout the pre independent era, unfortunately, no law was enacted by the colonial leaders to control mining activities in Nigeria. Large area of mining lands were consequently devastated due to mining activities. The environmental destruction slowed down due to the discovery of oil in Oloibiri in 1956 [4]. This discovery lead to the diversion of government interest away from solid mineral mining to oil exploration. Consequently, the fortune of the tin mining and milling industry began to decline and presently remained so to a large extent. In addition, the decrease in the global demand for tin, and the almost three year of civil war leading to the departure of foreign expatriate in the tin mining companies were other factors that lead to the decrease in production of tin and dwindling fortune of the industry [4, 5]. Presently solid mineral account for less than 1% of Nigeria gross domestic products. The lack of government interest in tin mining over the years has made mining regulations in the Plateau inadequate, thus, many unregulated and illegal mining are, scattered across the Plateau. The devastating impact of these unregulated mining in the environment is unquantifiable. This has led to a host of ecological problems such as flood, erosion and loss of farm lands. These present untold hardship and economic loss to the inhabitants of the Jos Plateau area.

This study was aimed at evaluating the concentrations of selected heavy metals i.e. Chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), and lead (Pb) in the soils, tailings and minerals soils from an active tin mining field at Rayfield – Du, Jos South area of Plateau State, Nigeria.

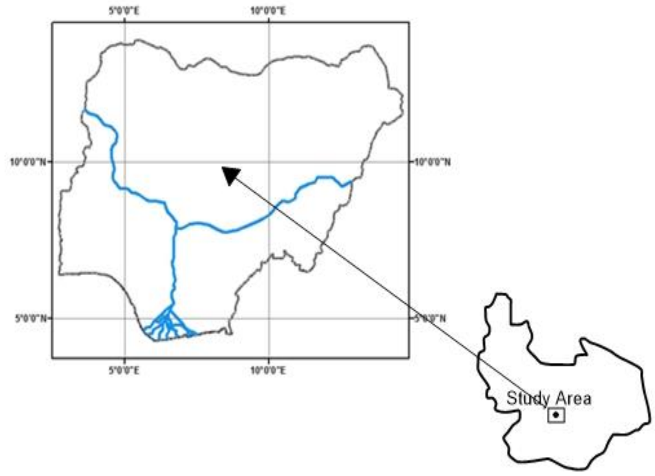

Figure 1. Map of Nigeria showing the study area.

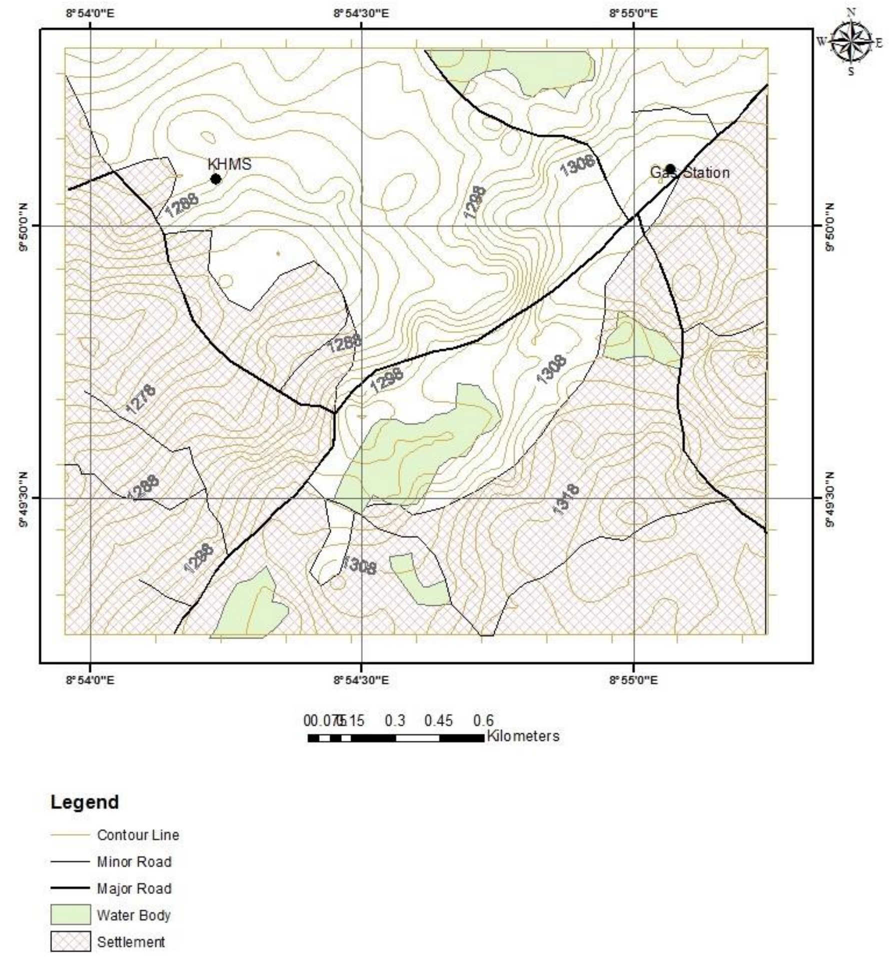

Figure 2. Map of the study area.

3. Materials and method

Ten (10) soil samples were collected from different locations evenly distribute across the active mine at Rayfield – Du Jos, Nigeria through the use of a digger and hand trowel in polythene bags. The soils samples were taken between a depths of 20 cm from the top of the soil.

For the Energy Dispersive X-ray Florescence (EDXRF) analysis 20g of homogenized dried sample of sand and tailing was used. Binder made up of PVC dissolved in toluene was added to the sample carefully and compressed with a hydraulic system to form pellets. The resulting pellets of dimensions were then loaded into the sample chamber of the X-ray Florescence (XRF) spectrometer for quantitative and qualitative heavy metal content analysis. The EDXRF was a Minipal4 with a Model No DY-1055 and was made by PAN ANALYTICAL which was installed August, 2008 at National Geosciences Research Laboratory (NGRL) Kaduna, Nigeria. The qualitative analysis determines the type of heavy metal presents in the sample while the quantitative analysis used the net intensities in the spectrum of the heavy metal to evaluate their respective concentrations. The major heavy metals of interest were: Chromium (Cr), copper (Cu), zinc (Zn), lead (Pb), cobalt (Co), arsenic (As), cadmium (Cd), and nickel (Ni).

The concentrations of trace and major elements in the tin mine site Rayfield – Du Jos, Plateau were determined through the Energy Dispersive X-ray Fluorescence (EDXRF) technique. For this analysis, the pulverised soil samples were sundried for 96 hours until a near constant weight was obtained. Weighed 0.01 kg of the pulverised and dried soil were carefully and pressed into circular pellets in a hydraulic press under a pressure of about 20 tonne. The pellets each of diameter about 30 ± 3 mm were then loaded into the sample chamber of a PAN analytical Minipal4 model PW1055 EDXRF spectrometer for trace and major elemental oxide analysis. The actual concentration of the analyte in the sample was calculated using the relation:

$$C_{Sam\_Actual} = \frac{C_{Sam\_Calib} * D_f * V_n}{M_{Sam}}$$

where;

$C_{sam\_actual - Actual}$ –Actual concentration of sample
C_{sam_calib} – Sample concentration (calibration curve)
D_f – Dilution factor
V_n – Nominal volume
M_{sam} – Mass of sample

4. Results and discussion

Heavy metals (HM) have been associated with the mineral ores found and mined in the Jos Plateau area. The HM analysis of the ten (10) soils (S (3), M (4), and T (3) representing normal soil, tailing and mineral soils respectively) collected from the mine under study are presented in Table 1. From the result, the mean concentrations of the eight investigated heavy metals in S, M and T soils were: 35.77, 296.82, 360.82, 51.43, 3.80, 1.84, 1.29, 0.43 (mg/kg); 280.58, 222.62, 140.96, 342.19, 3.91, 0.88, <0.01, 0.79 (mg/kg); and 93.93, 173.71, 239.54, 278.48, 4.12, 2.48, <0.01, 1.33 (mg/kg) for Cr, Cu, Zn, Pb, Co, As, Cd, and Ni respectively. The total average concentrations of the HM for all soils collected are given in the table as well. Of all the metals investigated only Cr, Cu, Zn and Pb was commonly detected above the detection level (<0.01 mg/kg) in all the soil samples, while the concentrations of the remaining HM (Co, As, Cd, and Ni) were below detection level (BDL) in some soil samples.

To assess the level of contamination of each species of metals, soil and the entire mining area, the HM contamination (CI), pollution load (PI), ecological risk index (E), and the total potential ecological risk indices were adopted.

The contamination index CI_i of the i^{th} metal was computed according to the equation [6]:

$$CI_i = {C_i}/{C_{0i}}$$

where C_i is the measured concentration of the i^{th} HM and C_{0i} is the concentration of background/reference value of the i^{th} HM. For this research, the reference value adopted for the HM was the Department of Petroleum resources (DPR, 2002) reference values for maximum allowable concentration HM in Nigerian soil. The DPR background values are given in Table 1. Also, the values for the concentration index of the HM are given in the table. The values showed that all the HM considered have concentrations in excess of the reference value (i.e. $CI > 1$), except for Co and Ni.

The pollution load index for all the heavy metals in each soil samples were evaluated via the equation [7]:

$$PI = \left(\prod_{i=1}^{n} CI_i\right)^{\frac{1}{n}}$$

where *n*, is the number of associated metals considered. The value of *PI* is used to classify the HM pollution according to the following categories:

i. For $PI < 1$ no pollution

ii. $1 \leq PI < 2$ moderate pollution

iii. $PI > 3$ extreme pollution

The PI is the index that is commonly used for comparing the level of HM pollution for a given site. From Figure 3, the *PI* of the considered HM were low in both normal soil (S) and mineral soil (M) while in the tailings samples, the HM pollution was moderate. This also is an indication of possible concentration of heavy metal in the tailings during the mineral extraction processes. For the mine, the PI is slightly below 1 and thus, it is concluded that that there is no heavy metal pollution.

The ecological risk factor (E_i) due to a particular heavy metal pollution refers to concentration level that might affect soil biological processes, and plant functional structure. According to Edori and Kpee [7], the E_i can be calculated via the equation:

$$E_i = T_i C_i$$

here, T_i is the toxic response factor for a specific HM. The values of the toxic factors of all the metals considered are presented in Table 1, the E_i values are categorized according to the following tiers: for $E_i < 40$, the potential ecological risk is regarded as low; for $40 \leq E_i < 80$, the risk is said to be moderate; for $160 \leq E_i < 320$, the risk is said to be very high. The ecological risk of the considered heavy metals in each category of soil and site can be assess via the use of the total potential ecological risk index (*RI*). The RI can be calculated according to the equation [6]:

$$RI = \sum_{i=1}^{n} E_i$$

The RI are graduated also according to the following rules: for $RI < 150$, the risk is designated as low; $150 \leq RI < 300$; the ecological risk is said to be moderate; while for $300 \leq RI < 600$, the risk is defined as considerable and for $RI > 600$, the risk is classified to be very high.

The potential ecological risk index of all the HM considered were found to be low except for Cd which has a moderate risk value Table 1. Also the total PI and RI results (Figure 3 and 4), showed that its value in S and M samples can be categorized as low risk while, its value in the T sample can be categorized as moderate. The entire mine, based on the species of HM considered the potential ecological risk can be considered low.

Table 1. Heavy metal concentration in S, M andT soil samples and pollution indices.

Soil Category	Heavy Metal Concentration (mg/kg)							
	Cr	Cu	Zn	Pb	Co	As	Cd	Ni
S5	12.00	260.45	600.30	21.00	3.80	1.84	0.01	0.02
S6	40.30	380.00	320.00	88.87	BDL	BDL	2.56	0.84
S8	55.00	250.00	160.00	44.41	BDL	BDL	BDL	BDL
M1	387.54	200.24	104.40	450.20	BDL	BDL	BDL	BDL
M3	486.33	350.24	70.87	87.76	BDL	BDL	BDL	1.20
M4	2.43	180.00	130.46	680.00	7.48	0.88	BDL	BDL
M8	246.00	160.00	258.12	150.78	0.35	0.88	BDL	0.38
T1	58.34	21.00	4.64	450.45	BDL	BDL	2.11	0.05
T4	53.46	170.00	130.21	85.00	BDL	BDL	2.85	BDL
T8	170.00	330.12	583.77	300.00	BDL	4.12	BDL	2.60
Mean (All)	151.14	230.21	236.28	235.85	3.88	1.93	1.88	0.85
TV (DPR)	100	36	140	85	20	1	0.8	35
CI_i(All)	1.51	6.39	1.69	2.77	0.19	1.93	2.35	0.02
T_i	2	5	1	5	5	10	30	5
E_i(All)	3.02	31.97	1.69	13.87	0.97	19.30	70.59	0.12

BDL-Below detection level; TV- Target Value; DPR- Department of Petroleum Resources

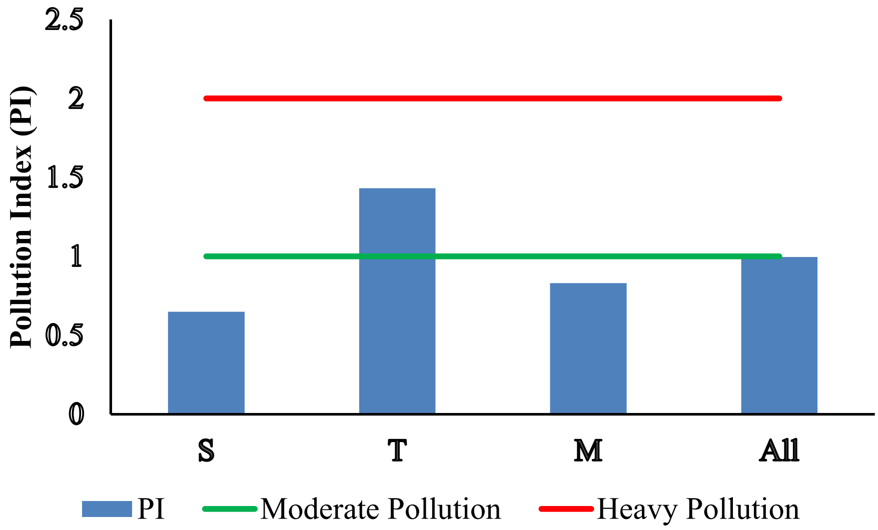

Figure 3. Pollution index of HM in the S, T and M soils.

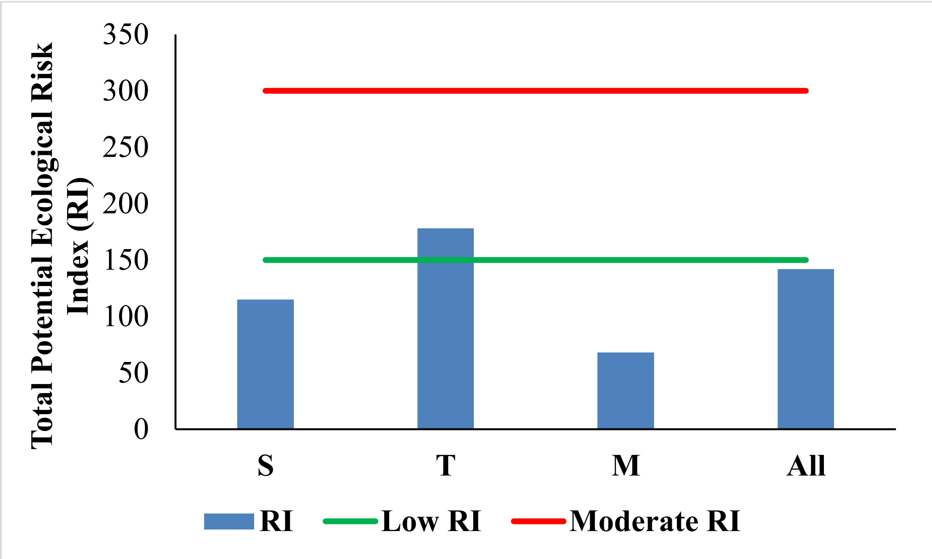

Figure 4. Potential ecological risk index of the HM in soil.

5. Conclusion

The analysis of eight heavy metals (Cr, Cu, Zn, Pb, Co, As, Cd, and Ni) concentrations showed that they are above the Nigerian reference level except for Co and Ni. Also employing the index model, the pollution and ecological risk indices of the heavy metals concentrations were classified as low for the Rayfield-Du mine in Jos, Nigeria.

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