Soil and Groundwater Contamination at an Active Mine Site in Kwang Rayfield Jos Plateau State Using Electrical Resistivity and Heavy Metal Analysis

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Abstract

A 2-D electrical resistivity survey and heavy metal analysis was carried out at an mine site in Kwang Rayfield, Jos, Plateau state to investigate soil and groundwater contamination. This survey was carried out using the Wenner-Schlumberger configuration. The 2D electrical resistivity was carried out along three profiles; two profiles at the mine site and one profile taken far away from the mine site to serve as the control profile. The apparent resistivity data obtained was iteratively inverted using RES2DINV software to generate the 2D resistivity sections. Relatively low resistivity values within the subsurface of each profile followed the order Profile 1 > Profile 2> Profile 3. The results revealed that the subsurface beneath P2 is more resistive than P1 and this could be because there was no mining activity as of the time of the survey. Profile 3 revealed relatively high resistivity values at the top soil and it could be due to the pressure on the field as result of people playing football. The 2D electrical resistivity survey was able to show lateral and vertical resistivity variations beneath the profile and regions of low resistivity that indicate possible contamination subsurface material with metals. Contents of heavy metals in soil and water was determined using X-ray Fluoroscopy machine and Atomic absorption spectrometer respectively. Heavy metal concentration in soil samples revealed the presence of heavy metals with the concentration of Strontium, Manganese, Lead, Zinc, Copper, Chromium, Vanadium, Tin, and Nickel lower than the permissible limits. Some heavy metals were not detected in the soil samples; Nickel in S1; Copper, Chromium, Vanadium and Tin in S2; and Copper, Chromium, Vanadium, Uranium, Calcium, Potassium, Tin, and Nickel in S3. The heavy metal analysis on water samples revealed the presence of heavy metals with Lead concentration more than the permissible limit given by WHO (2017) and SON (2015); and Copper concentration more than the guideline limit given by SON (2015). The low resistivity observed in Profile 1 where active mining was taking place and the presence of these heavy metals indicates possible heavy metal contamination of water and soil (on the surface and within the subsurface) at the mine site.

Keywords: Electrical Resistivity, Mining, Heavy metal analysis, Water, Soil, Contamination

Introduction

Mining is one of the industrial activities that cause the greatest and most persistent alterations in nature (Passariello *et al.*, 2002). Although metal mining can bring much economic prosperity, it can cause environmental problems when located at close proximity to inhabited areas. Mine waste is commonly disposed on the earth's surface in rock dumps and spoils piles, and the barren remains of processing are contained in tailings. Such materials are often a major source of heavy metal pollution in the local environment due to discharge and dispersion into nearby agricultural soils, food crops, and stream systems (groundwater and surface water) (Tordoff *et al.*, 2000). Soil quality is affected by the incorporation of mining materials generating changes in pH, electrical conductivity, heavy metal concentration, etc. (Stamatiadis *et al.*, 1999). The quality of water resources is also compromised during the phase of active mining, but it is often the case that the most adverse impact is felt once exploitation of the mine has been called off (Banks *et al.*, 1997). In mining regions, the exploitation pits may intercept groundwater and require pumping during exploitation (Cidu *et al.*, 2001). The rebound after the mine closure degrades the quality of groundwater, which may not be suitable for further uses (Van Tonder *et al.*, 2007). The most obvious effect of mining on ground water quality occurs in mining below the water table, either in underground workings or open pits. This provides a direct conduit to aquifers. Ground water quality is also affected when waters (natural or process waters or wastewater) infiltrate through surface materials (including overlying overburden waste or other material) into ground water (Thakur *et al.*, 2013).

Remediation technologies of potentially toxic metal-contaminated environments are complex and may involve a combination of physical, chemical, and biological methodologies (Siegel, 2002), for correct assessment of risk/toxicity level of a polluted soil and to predict its decrease after the application of remediation techniques. It is crucial to establish the extent and entity of the pollution in soils and waters as well as to produce data on soil properties affecting pollutants mobility (i.e. soil texture, porosity and permeability, organic matter

content, mineralogy, and pollutants extractability).

Tin ore or Cassiterite has been mined in several parts of Nigeria including Zaria, Kano, Bauchi, Ilesha and Plateau provinces, with over 80% of the production coming from the Jos Plateau (Ajaegbu *et al.*, 1992). The greater part of the cassiterite and columbite mining industry is concentrated around Jos-Bukuru (which the study area is part of) and Rop Complexes in North-Central Nigeria. Cassiterite has a wide distribution in the drainage system (Macleod *et al.*, 1971) and this has favored the exploitation of the tin fields by a large number of small companies and private operators. Unfortunately, most of these mining activities are unregulated and this has encouraged the insurgence of Artisanal (Small-scale) miners whose activities are largely informal (Mallo, 2012). Unregulated mining, however, is a potential hazard in that it releases harmful substances into the air, soil, and water thereby destroying the environment and endangering lives of both humans and animals.

Geophysical methods, such as two and three-dimensional Electrical Resistivity survey, have been used to investigate structure, layering, and composition of subsurface materials, thus aiding the understanding of many geomorphological and environmental problems (Martınez-Pagan *et al.*, 2009). Electrical resistivity provides an important non-invasive tool in the mapping and evaluation of soil and groundwater contamination (Ahmed and Sulaiman (2001); Akanbi and Eze (2014), Kwarki *et al.*, 2021). Heavy metals are defined as metallic elements that have a relatively high density compared to water (Fergusson, 1990). With the assumption that heaviness and toxicity are inter-related, heavy metals also include metalloids, such as arsenic, that are able to induce toxicity at low level of exposure (Duffus, 2002). In recent years, there has been an increasing ecological and global public health concern associated with environmental contamination by these metals. In addition, human exposure has risen dramatically because of an exponential increase of their use in several industrial, agricultural, domestic, and technological applications (Bradl, 2002). Reported sources of heavy metals in the environment include geogenic, industrial, agricultural, pharmaceutical, domestic effluents, and atmospheric sources (He *et al.*, 2005). Environmental pollution is very prominent in point source areas such as mining, foundries and smelters, and other metal-based industrial operations (Fergusson, 1990; Bradl, 2002; He *et al.*, 2005). Although heavy metals are naturally occurring elements that are found throughout the earth's crust, most

environmental contamination and human exposure result from anthropogenic activities such as mining and smelting operations, industrial production and use, and domestic and agricultural use of metals and metal-containing compounds (He *et al.*, 2005). Soil chemical composition, when combined with electrical resistivity survey, can provide spatial information on soil properties that are critical to plant growth, or be used to assess the movement (e.g., leakage) of contaminants (Martınez-Pagan *et al.*, 2009).

Some studies have been carried out using Electrical resistivity survey and heavy metal investigation in evaluating the extent of soil and ground water contamination. Martınez-Pagan *et al.*, 2009 used Electrical Resistivity Imaging to reveal the spatial properties of mine tailing ponds in the Sierra Minera of south East Spain; Yassir and Alain (2016) assessed the spatial distribution of heavy metals using geochemical methods in DraaLasfer mine area in Marrakech city to characterize the pollution generated by mine activity in the study area. Owolabi et al (2017) carried out geochemical evaluation of wastes and soil samples around cassiterite mine sites in Plateau state, Nigeria. The study was carried out in some mine sites in Jos Plateau state (Rayfield, Gero, Sabongida, Kanar, kuru, Jantar, Bisichi and Barkinladi respectively). The aim of this study is to investigate soil and groundwater contamination at an active Mine site at Kwang Rayfield, Jos, Plateau state using 2D electrical resistivity survey and heavy metal analysis.

Study Area

The study area is bound by Longitude $8°56'21''E$ - $8°56'57''E$ and Latitude $9°51'10''N$ - $9°51'25''N$ in Kwang, Rayfield area of Jos-south L.G.A, Plateau state. The site is situated behind Emmaus Bible center and it is accessible by an untarred road, which is about 10 minutes walk from Cocin Church Kwang Jos-south, Plateau state. Figures 1 and 2 show the location and topographical maps.

The study area has the same climatic condition as that of Jos-Plateau with two major seasons namely; rainy season and dry season. The rainy season starts from April to October and the dry season is between November to March. The harmattan wind causes the coldest weather between December and February. The warmest temperatures usually occur in the dry season months of March and April. The Jos Plateau Younger Granite is underlain by rocks of the Basement Complex. A period of erosion followed the emplacement of the

Younger Granites leading to the formation of Jos Plateau and surrounding plains. The study area lies within the Jos-Bukuru complex and the rocks present here are predominantly of biotite granite rocks, as exhaustively studied by Falconer (1921) and Macleod *et al.* (1971). These rocks include N'gell biotite granite and Jos biotite granite (Figure 3).
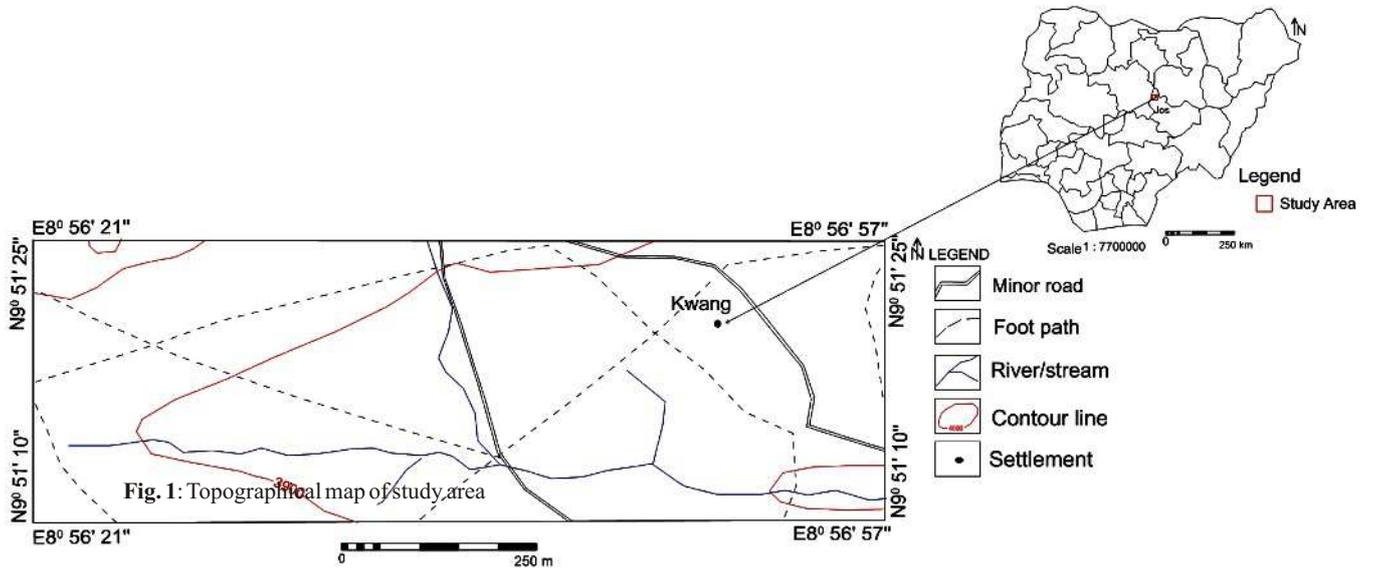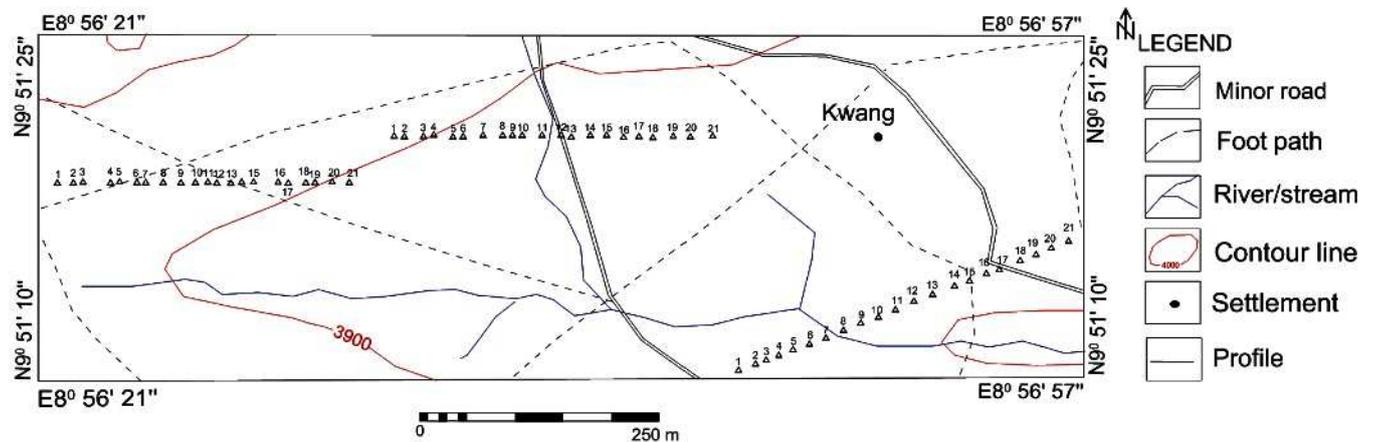
Fig. 1: Topographical map of study area

Fig. 2: Location map of study area showing profiles for 2-D electrical resistivity survey
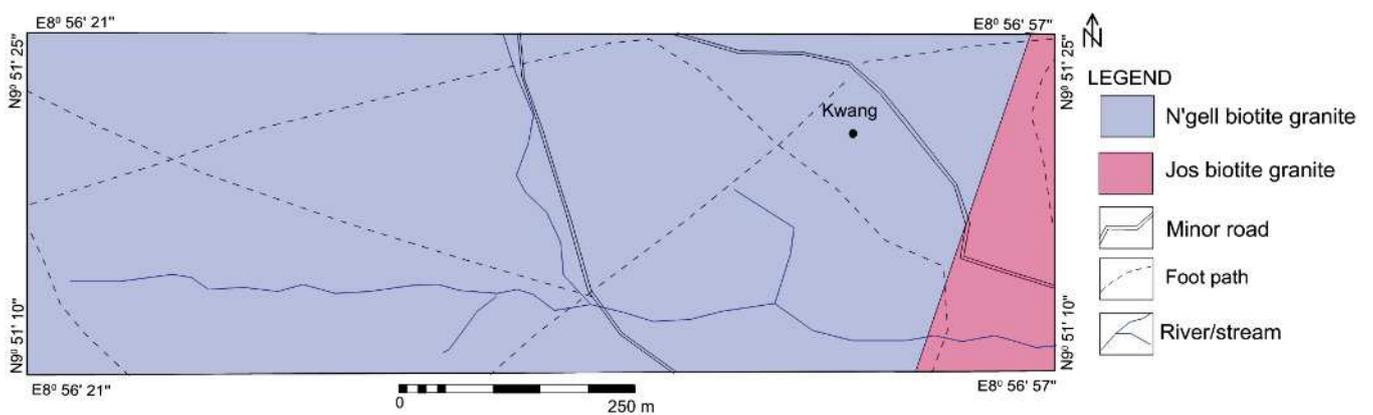
Fig. 3: Geological map of study area

Materials and Method

2-D Electrical Resistivity Survey

2D electrical resistivity survey was carried out using SAS 300C ABEM terrameter to measure resistance along two profiles at the active mine site and one profile which served as control far away from the mine site still within Kwang. The three profile lines were occupied using Wenner-Schlumberger configuration and the arrangement of the electrodes in the field is shown in Figure 4. The profile length was 100 m and the electrode spacing "a" used was 5 m. The maximum n factor (the ratio of the distance between the C1-P1 or P2-C2 electrodes to the spacing between the P1-P2, potential pair) was 7. The measured resistance data collected in the field was converted to apparent resistivity values using:

$$\rho_a = \frac{\Delta V}{I} K \quad \text{...(1)}$$

where $\frac{\Delta V}{I}$ is the measured resistance and K is the geometric factor, which is given by.

$$k = \pi n(n+1) \text{..(2)}$$

n is the distance between the C1-P1 or (P2-C2) electrodes to the spacing between the P1-P2 potential pair and "a" is the potential electrode spacing. The apparent resistivity data was iteratively subjected to inversion using RES2DINVX64 software (after Loke and Barker, 1996) to generate the 2-D resistivity sections. The data was inverted with the standard least squares smoothness-constraint. The forward resistivity calculation was executed by applying an iterative algorithm based on finite difference method. The inversion program divided the subsurface into a number of small rectangular prisms and attempted to determine the resistivity values of the model prisms directed towards minimizing the percentage difference between the logarithms of calculated and the observed apparent resistivity values. The quality of the fit was expressed in terms of the Root Mean Square (RMS) error.

Heavy Metal Analysis

Top soil samples were collected along profiles where the electrical resistivity survey was conducted. Two samples from the mine site and one soil sample along the control profile for heavy metal content determination. The soil samples were air-dried and an X-ray Fluoroscopy machine at the department of Science
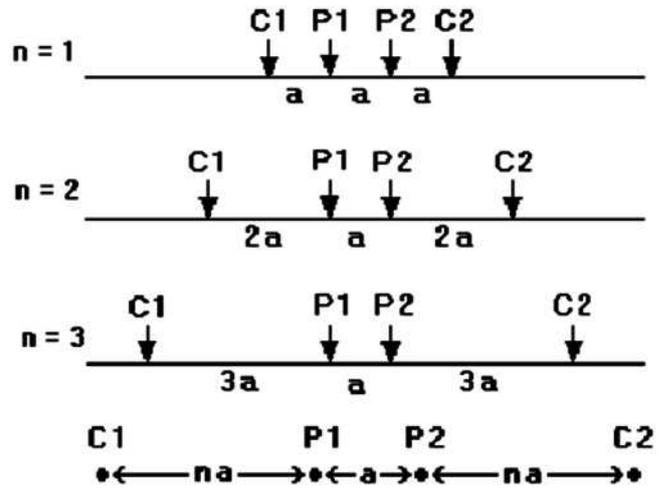

Fig. 4: Electrode arrangement for Wenner-Schlumberger configuration, C1, C2 are current electrodes, P1, P2 are potential electrodes (After, Loke, 2004).

Laboratory Technology University of Jos, Plateau state was used to determine the concentration of Molybdenum, Zirconium, Strontium, Uranium, Rubidium, Thorium, Lead, Zinc, Copper, Iron, Manganese, Chromium, Vanadium, Titanium, Calcium, Potassium, Tin, and Niobium in the soil samples.

Water samples from streams close to the active mine site were also collected and sent to department of Chemistry Abubakar Tafawabalewa University, Bauchi for determination of concentration of Iron, Lead, Manganese, Chromium, Potassium, Copper, Calcium and Zinc using the Atomic absorption spectrometer (AAS).

Result and Discussion

Result

The inverse model resistivity sections are displayed as cross sections of the true resistivity distribution of the subsurface with depth along each profiles. The inverse model resistivity sections are shown in Figures 5-7. These are the interpretation models showing resistivity values varying laterally along the profile and vertically with depth to the maximum investigation depth. Representative resistivity values of earth materials derived from Baimba (1978); Hassan *et al.* (1991) and Loke (2004), Table 1, were used in classifying the geologic layers in the study area. Histograms showing frequency of resistivity ranges for earth materials beneath each profile is presented in Figures 8-10. Concentration of Molybdenum, Zirconium, Strontium, Uranium, Rubidium, Thorium, Lead, Zinc, Copper, Iron, Manganese, Chromium, Vanadium, Titanium,

Calcium, Potassium, Tin, and Niobium in the soil samples were determined and compared with permissible limits from Toth *et al.* (2016), Pendias and Pendias (2000) and Sudhakaran *et al.* (2018) and is presented in Table 2. Concentration of Iron, Lead, Manganese, Chromium, Potassium, Copper, Calcium and Zinc in the water samples were determined and compared with the permissible limits given by WHO 2017 and SON 2015 and is presented in Table 3.
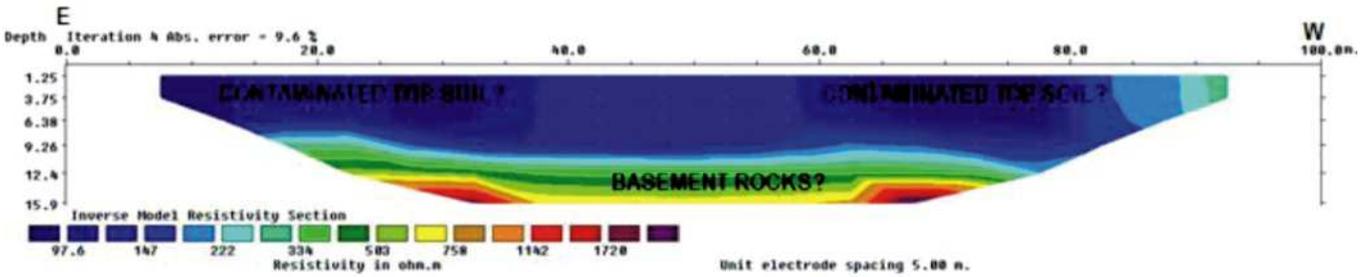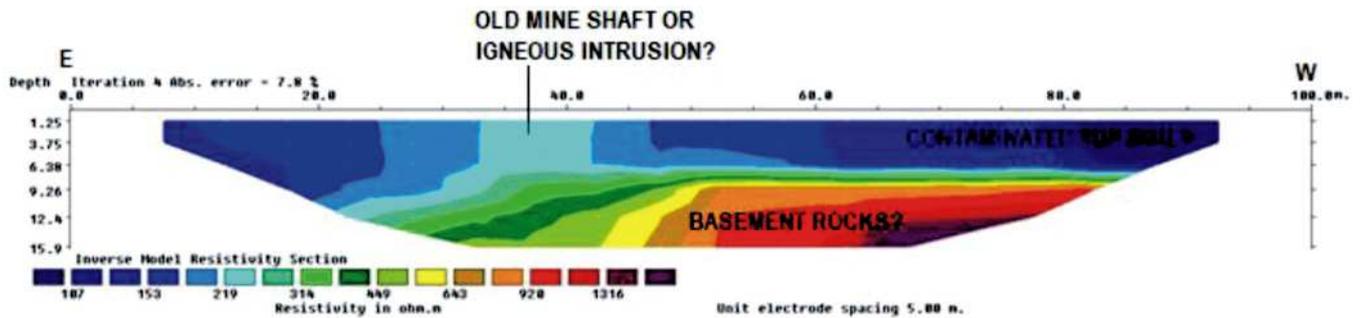

Fig. 5: 2-D resistivity section for Profile one

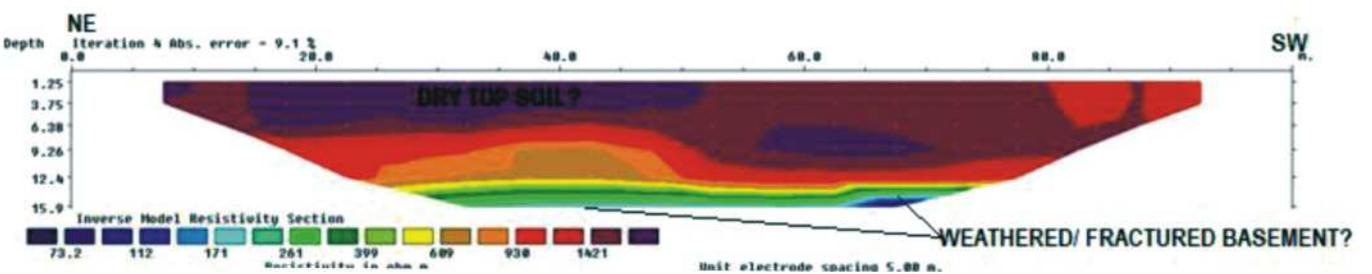**Fig. 6:** 2D resistivity section for Profile two

Fig. 7: 2D resistivity section of Profile three

Table 1: Typical Resistivity values of earth materials (adapted from Baimba (1978), Hassan et al. (1991) and Loke (2004))

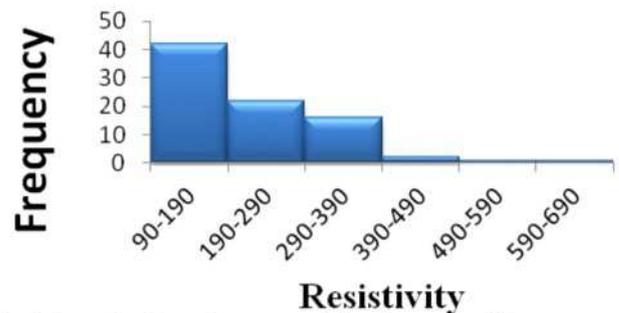| Rock Type	Resistivity (Ωm)
Fresh Ground water	10-100
Clay	1-100
Weathered Basement	50-100
Slightly weathered Basement	200-500
Fresh Basement	<1000

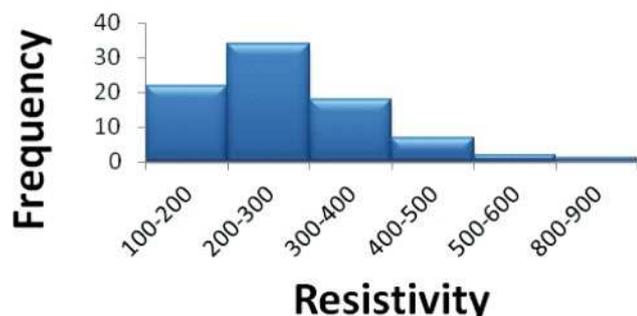**Fig. 8:** Histogram showing resistivity of subsurface materials along profile 1

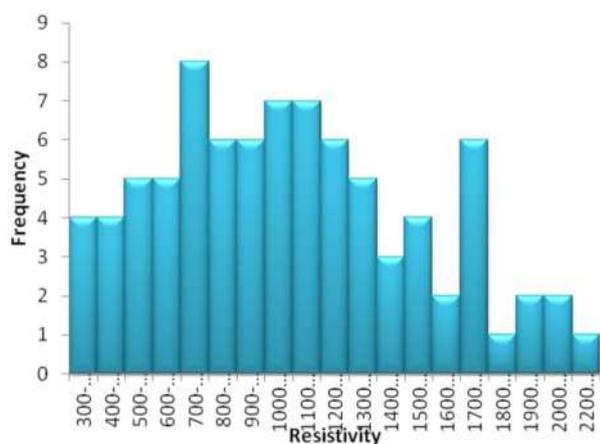**Fig. 9:** Histogram showing resistivity of subsurface materials along profile two

Fig. 10: Histogram showing resistivity of subsurface materials along profile 3

Table 2: Soil texture in the Sokoto-Rima River Basin

Element	S1 (ppm)	S2 (ppm)	S3 (ppm)	Permissible limit (ppm)
Molybdenum	5.623	3.788	7.827	NA
Zirconium	453.015	187.361	419.239	NA
Strontium	17.834	5.026	15.838	200(MPC)***
Uranium	12.743	5.428	0.000	NA
Rubidium	42.060	33.459	61.167	NA
Thorium	24.543	12.062	7.226	NA
Lead	27.530	6.867	15.414	200*
Zinc	33.449	17.895	69.359	250*
Copper	29.344	0.000	0.000	150*
Iron	22314.117	10894.417	57415.039	NA
Manganese	168.120	82.939	153.784	1500(MAC)**
Chromium	85.600	0.000	0.000	200*
Vanadium	52.220	0.000	0.000	150*
Titanium	2381.476	1293.485	2038.427	NA
Calcium	376.542	192.417	0.000	NA
Potassium	2496.686	2351.763	0.000	NA
Tin	39.319	0.000	0.000	50(MAC)***
Niobium	63.941	33.920	80.812	NA
Nickel	0.000	47.782	0.000	100*

S1 – Soil sample collected from Profile 1, S2 – Soil sample collected from Profile 2, S3 – Soil sample collected from Profile 3 (Control soil sample). *Toth *et al.* (2016), **Pendias and Pendias (2000), ***Sudhakaran *et al.* (2018), MAC- Maximum Allowable Concentration, MPC-Maximum Permissible Concentration, NA – Not available

Table 3: Heavy metals in water sample (P1) and Sample (P2) and permissible limit

Element	Profile one(P1) (mg/l)	Profile two (P2) (mg/l)	WHO 2017 (mg/l)	SON 2015 (mg/l)
Lead	0.02203	0.06958	0.01	0.01
Manganese	0.01480	-0.00846	0.400	0.200
Copper	1.03053	0.70172	2.0(HBV)	1.0
Zinc	0.00762	0.00258	NGL	3
Calcium	2.7151	3.3491	NGL	-
Iron	0.1204	0.1177	NGL*	0.3
Potassium	3.00	4.00	-	-
Chromium	0.00	0.00	0.05	0.05

NGV = No guideline value, because it is not of health concern at concentrations normally observed in drinking water, but may affect the acceptability of water at concentration above 300 *μg/L*, NGL*= No Guideline, because it is not of health concern at concentrations normally observed in drinking water, but may affect the acceptability of water at concentration above 300μg/L, HBV = Health based value, Dashes in WHO (2017) and SON, 2015 column indicate no guideline.

Interpretation

2D Electrical Resistivity Survey

The interpretation model of Profile 1 reveal lateral variation in near surface resistivity along profile to an average depth of 8.3 m. Regions of relatively low resistivity near the Earth's surface (95.831? m-200? m) was observed between a horizontal distances of 7 m to 88 m at an average depth of about 11 m. It was also observed between horizontal distances of 26 m to 33 m at an average depth of 6 m and horizontal distances of 63 m to 78 m at an average depth of 5.8 m. This region of low resistivity is underlain by region of high resistivity increasing with depth to a depth of 15.9 m at both ends of the model. The area of relatively low resistivity was observed from a horizontal distance of 7 m to 88 m to an average depth of 11 m. It could likely be contaminated probably due to the mining activities and due to fact that the soil was generally wet (they use water for work). Metals are conductive giving rise to low resistivity. Relatively high resistivity values in the range of 503? to 1720? were observed between horizontal distances of 19 m to 75.4 m with depth ranging from 7.5 m to a depth of 15.9 m. This could be due to weathered to fresh basement rocks. Histogram showing frequency of resistivity ranges of earth materials beneath profile one (Figure 8) show that the lowest resistivity range (90 Ωm -190 Ωm) occurred most frequently and the highest resistivity range (590 Ωm-690 Ωm) occurred least

frequently. This could be because the soil was wet and could contain conductive minerals from the on-going mining activities thus making the subsurface relatively conductive.

The resistivity model for subsurface beneath profile 2 (Figure 6) show that resistivity largely increased with depth from the surface. The subsurface revealed that resistivity varied laterally along the surface to an average depth of 7.78 m. Relatively low resistivity was observed (113? m - 200? m) between horizontal distances of 7.3 m to 33.8 m to an average depth of 9.53 m and between horizontal distances of 46.8 m to 94 m to a depth of 7 m. This region of low resistivity could be contaminated as a result of the metals present in the soil due to the past mining activities there. Region of relatively high resistivity was flanked on both sides by low resistivity between horizontal distances of 33 m and 42 m. This could be an igneous intrusion or an abandoned mineshaft that has been filled with soil. Relatively high resistivity was also observed between horizontal distances of 26 m to 85 m to a depth ranging from 7.2 m to 15.9 m. This could be due to weathered to fresh basement rocks. The Histogram for profile two (Figure 9) show that resistivity range 200 Ωm-300 Ωm, occurred most frequently; 200 Ωm-300 Ωm (the least resistivity range) was next and resistivity range 800 Ωm-900 Ωm (which is the highest resistivity range) occurred least frequently. In addition, it can be inferred from this that the subsurface beneath profile two is more resistive than profile one and this could be because mining activities had been suspended at that location.

The resistivity model for subsurface beneath profile 3 (Figure 7) revealed that resistivity largely decreased with depth. Along the profile, high resistivity values were observed on the top soil. For profile 3, regions with highest resistivity were observed between horizontal distances 7 m to 9 m along the profile to an average depth of about 3.4 m; and between horizontal distances 14.9 m to 52.5 m to an average depth of 6.35 m. This region was also observed between horizontal distances 56.2 m to 70.5 m (possible igneous intrusion) and between depth ranging from 6.38 m and 9.26 m. The interpretation model also revealed that generally there was a decrease in resistivity with depth with the resistivity value below 73.2 ? m and this was observed between horizontal distances 63m to 70m at a depth of about 15.9m. This could be indicative of ground water. Histogram showing frequency of resistivity ranges of earth materials beneath profile three (Figure 10) show that resistivity range of 700 Ωm -800 Ωm, was most frequent; resistivity ranges, 1000 Ωm -1100 Ωm and

1100 Ωm -1200 Ωm followed. The least frequent resistivity range was 300 Ωm-400 Ωm. Profile 3, the control profile was taken at a football field. This location was chosen since there was no record of mining activities there. The relatively high resistivity values at the top soil beneath this profile could be due to increased compaction and cementation due to pressure on the field as result of people playing football.

Heavy Metal Analysis

The heavy metal concentration in the soil samples were determined and compared with permissible limits from Toth *et al.* (2016), Pendias and Pendias (2000) and Sudhakaran *et al.* (2018) and has been presented in Table 2. Table 2 showed that the concentration of some heavy metals determined in the soil samples were less than their permissible values in the soil samples. Some permissible limits for some heavy metals were not available. It can be seen in Table 2, that the concentration of Molybdenum, Rubidium, Zinc, Iron, and Niobium are lower in S1 than the control soil sample. Zirconium, Strontium, Uranium, Thorium, Lead, Copper, Manganese, Chromium, Vanadium, Titanium, Calcium, Potassium, and Tin concentration are greater in S1 than the control soil sample and this implies possible enhancement of these metals in S1 because of the active tin mining activity taking place at location where soil sample was collected. In addition, concentration Molybdenum, Zirconium, Strontium, Rubidium, Lead, Zinc, Iron, Manganese, Titanium, and Niobium are lower in S2 than the control soil sample. While concentration of Uranium, Thorium, Calcium, Potassium and Nickel are more in S2 than the control soil sample. Comparing the concentration of heavy metals in S1 and S2, it was observed that concentration of all heavy metals determined in this study apart from Nickel were more in S1 than S2. This implies that location where S1 was collected is enhanced with these metals because of the active tin mining activity at the time of this study.

Water samples were collected at locations where profiles one and two for the 2-D resistivity survey were carried out. However, there was no water where the third and control profile was taken. The results revealed that the water samples contained Lead greater than WHO (2017) and SON (2015) guideline values in both water samples. Copper concentration in P2 was more than SON (2015) guideline value. In comparison with the guideline values proposed by WHO (2017) and SON (2015) for drinking water quality, Lead concentration in the water sample is above the permissible value by

0.01203mg/l in P1 and 0.05958mg/L in P2. Similarly, it was observed that Copper concentration in P1 is above the SON (2015) guideline value by 0.03053mg/l.

Discussion

In this study to investigate soil and groundwater contamination at a mine site in Kwang Rayfield, Jos, Plateau state using 2D electrical resistivity and heavy metal analysis. The 2D interpretation models and histograms showing the frequency of the resistivity values beneath each profile, revealed that relatively low resistivity values within the subsurface of each profile followed the order Profile 1 > Profile 2 > Profile 3. The study took place during the dry season and the lowest resistivity values were observed within the subsurface of profile 1 were active tin mining activity was still being carried out as at the time of the survey. The results also revealed that the subsurface beneath profile two is more resistive than profile one and this could be because there was no mining activity at that location at the time of the survey. Profile 3, the control profile, taken at a football field, since there was no record of mining activity there revealed relatively high resistivity values at the top soil beneath this profile and this could be due to increased compaction and cementation due to pressure on the field as result of people playing football. This profile recorded the highest resistivity values.

The soil samples collected along the 2D resistivity profiles revealed that the concentration of some heavy metals determined in the soil samples were less than their permissible values in the soil samples. Some permissible limits for some heavy metals were also not available. Concentration of heavy metals in soils not affected by mining activities were used as control or background values in order to evaluate the relative enhancement due to anthropogenic influence (Lu *et al.*, 2007). Zirconium, Strontium, Uranium, Thorium, Lead, Copper, Manganese, Chromium, Vanadium, Titanium, Calcium, Potassium, and Tin concentration are greater in S1 than the control soil sample and this implies possible enhancement of these metals in S1 because of the active tin mining activity taking place at location where soil sample was collected. Uranium, Thorium, Calcium, Potassium and Nickel are more in S2 than the control soil sample. Comparing the concentration of heavy metals in S1 and S2, it was observed that concentration of all heavy metals determined in this study apart from Nickel were more in S1 than S2. This implies that location where S1 was collected is enhanced with these metals because of the active tin mining activity at the time of this study. If mining

activities persists, there is possibility of having an increase in the concentration of these heavy metals above the permissible limit. The heavy metals concentration in water samples collected near profile 1 and 2 revealed the presence of heavy metals with Lead having higher concentration than the permissible limits of these metals according to WHO (2017) and SON (2015) and Copper with greater concentration than SON (2015) guideline value.

Integrating the results of the 2D resistivity survey and heavy metal analysis, it could be said that the resistivity values obtained for the sub-surface beneath the three profiles is related to the presence or absence of tin mining activity at the locations where the profiles were taken. Relatively low resistivity values obtained for the subsurface beneath profile 1 could be because location was generally wet, and the soil and water collected near the profile had the greatest concentration of heavy metals determined in this study. Sub-surface beneath profile 2 had relatively higher resistivity values compared to subsurface beneath profile 1 and sub-surface beneath profile 3 had the highest resistivity values. Heavy metals in water and soil samples were below the permissible limits and some not detected but if mining activities keeps going on, the area could be exposed to heavy metals, which can even be more than the permissible limits and may contaminate soil and water. These contaminants can be transferred in the trophic chain, from soil through plants to animals and humans, which pose danger to human health and the environment (Torres and Johnson, 2001).

Conclusion

This study revealed the possible contamination of top soil, water and subsurface materials at an active mine site by heavy metals. The results revealed that the subsurface beneath profile two is more resistive than profile one and this could be because there was no mining activity at that area as at the time of the survey. Relatively low resistivity values obtained for the subsurface beneath profile 1 could be because location was generally wet, and the soil and water collected near the profile had the greatest concentration of heavy metals determined in this study. Sub-surface beneath profile 2 had relatively higher resistivity values compared to subsurface beneath profile 1 and sub-surface beneath profile 3 had the highest resistivity values. Heavy metal analysis also revealed the presence of heavy metals in soil and water samples. The concentration of heavy metals determined in the soil samples showed that the concentration of some of the

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metals in the soil samples was lower than the permissible limits. Lead and copper were above the standard according to WHO (2017) and SON (2015) in the water samples. There is a possibility of its enhancement in the near future due to the daily anthropogenic contributions of man through lotto mining and cassiterite reworking which could expose the study area to heavy metals, which can even be more than the permissible limits and may contaminate soil and water further.

References

Ahmed, A.M., and Sulaiman, W.N. (2001). Evaluation of Ground water and Soil pollution in a Landfill using Electrical Resistivity Imaging Survey. *Environmental Management*, 28(5), 655-663.

Ajaegbu, H.I., Adepetu, A.A., Ajakpo, J.E., Ihemegbulem, V.C., Jumbo, S.E., Olaniyan, J.A., Okechukwu, G.C. and Schoeneich, K. (1992). "Jos Plateau Environmental Excursion Guide" Jos Plateau Environmental Resources Development Programme (J.P.E.R.D.P.). Department of Geography, University of Durham., Durham, England.

Akanbi, E. S and Eze, S. E (2014). 2-D Electrical Resistivity Survey and Heavy Metal determination of Water Samples as Indicators for Ground Water Pollution at a Waste Dump site in Rock Haven Jos, Plateau State, Nigeria. *Nigerian Journal of Physics* 25 (1). 92-96.

Baimba A.B. (1978). Resistivity and refraction seismic methods for groundwater exploration at Zango, Kaduna State. Unpublished M.Sc. Thesis Ahmadu Bello University, Zaria, Nigeria, 1978.

Banks, D., Younger, P. L., Arnesen, R. T., Iversen, E. R., and Banks, S. (1997). Mine Water Chemistry: The Good, the Bad and the Ugly. *Environmental Geology*, 32, 157-174.

Bradl, H. (2002). Editor. *Heavy Metals in the Environment: Origin, Interaction and Remediation Volume 6.* London: Academic Press.

Cidu, R., Biagini, C., Fanfani, L., La Ruffa, G., and Marras, I. (2001). Mine closure at Monteponi (Italy). Effect of the Cessation of dewatering on the Quality of shallow Groundwater. *Applied Geochemistry*, 16, 489 - 502.

Duffus, J.H. (2002). Heavy metals-a meaningless term? *Pure and Applied Chemistry.* 74(5).793-807

Falconer, J.D. (1921). The Geology of the Plateau Tin Fields. Bull. Geol. Survey Nigeria, No.4, Kaduna.

Fergusson, J.E. (1990). *Editor*. The Heavy Elements: Chemistry, Environmental Impact and Health Effects. Oxford: Pergamon Press; 1990.

Hassan, M., Ajayi, C.O. and Ojo, S.B. (1991). A Basement structure determined from Geoelectric mapping of the Kubanni River Basin, Zaria. *Nigerian Journal of Physics*, 3: 166-173.

He, Z.L., Yang, X.E. and Stoffella, P.J. (2005). Trace elements in agroecosystems and impacts on the environment. *Journal of Trace Elements in Medicine and Biology*, 19(2-3).125-140.

Loke, M.H. (2004). Electrical 1maging Surveys for Environmental and Engineering Studies- a practical guide to 2D and 3D surveys. Penang Malaysia. (mhloke@tm.net.my,drmhloke@yahoo.com). Downloaded from http://www.abem.se

Loke, M.H. and Barker, R.D. (1996). Rapid least-squares inversion of apparent resistivity pseudosections by a quasi Newton method. Journal of Geophysical Prospecting 44, 131–152.

Lu, S.G., Bai, S.Q. and Xue, Q.F. (2007). Magnetic properties as indicators of heavy metals Pollution in urban topsoil: a case study from the city of Luoyang, China. *Geophysics Journal International,* 171, 568-580.

Macleod, W.N., Turner, D.C. and Wright, E.P. (1971). The Geology of the Jos Plateau, Geological Survey of Nigeria. Bulletin 32.Vol.1.

Mallo, S.J. (2012). The Socio-economic impact of artisanal mining in Kuru (Naraguta sheet 168) Plateau State North Central Nigeria. Continental. J. Engineering Science, 7(3). 27-32.

Owolabi, A.O., Opafunso, Z.O. and Lavide, L. (2017). Geochemical Evaluation of Wastes and Soil Samples Around Cassiterite Mine Sites in Plateau State, Nigeria. International Journal of Science and Technology, 6(5), 808-817.

Passariello, B., Giuliano, V., Quaresima, S., Barbaro, M., Caroli, S. and Forte,G. (2002). Evaluation of the Environmental Contamination at an Abandoned Mining site. Microchemical Journal, 73, 245–250

Martınez-Pagan, P., Cano, A.F., Aracit, E., and Arocena, J.M. (2009). Electrical Resistivity Imaging revealed the Spatial Properties of Mine tailing Ponds in the Sierra Minera of Southeast Spain. Journal of Environmental and Engineering Geophysics, 14(2), 63-76

Pendias, A.K. and Pendias, H. (2000). Trace elements in soils and Plants. Florida, United States: CRC, Press, Boca Raton, 303, 10-11

Siegel, F. R. (2002). Environmental Geochemistry of Potentially Toxic Metals. Heidelberg: Springer.

Stamatiadis, S., Doran, J. W., and Kettler, T. (1999). Field and Laboratory Evaluation of Soil Quality Changes resulting from Injection of Liquid Sewage Sludge. Applied Soil Ecology, 12, 263-272.

Standard Organisation of Nigeria (2015).Nigerian Standard for Drinking Water Quality, Abuja, Nigeria.

Standard Organization of Nigeria (SON) (2015). Guidelines for drinking Water Quality.

Telford, W.M. (1976). Applied geophysics, Cambridge University Press.

Sudhakaran, M., Ramamoorthy, D., Savitha, V. and Balamurugan, S. (2018). Assessment of trace elements and its influence on physico-chemical and biological properties in coastal agroecosystem soil, Puducherry region, Geology, Ecology, and Landscapes, 2(3), 169 – 176, DOI: 10.1080/24749508.2018.1452475

Thakur, B.K., Gupta, V. and Chattopadhyay, U. (2013). Arsenic groundwater contamination related socio-economic problems in India: Issues and challenges. Knowledge systems of societies for adaptation and mitigation of impacts of climate change environmental science and engineering. 163-182.

Tordoff, G. M., Baker, A. J. M., and Willis, A. J. (2000). Current Approaches to the Revegetation and Reclamation of Metalliferous Mine wastes. Chemosphere, 41, 219–228.

Toth, G., Hermann, T., Da Silva, M. R. and Montanarella, L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International, 88, 299-309.

Van Tonder, G. J., Usher, B. H., Dennis, I., andVermeulen, P. D.(2007). Predicting rebound in a deep collier in South Africa. Mine Water and the Environment, 26(2), 79–87.

World Health Organization (2017). Guidelines for Drinking Water Quality. Fourth edition incorporating the first addendum. Geneva, Switzerland. ISBN 978-92-4-154995-0, 307-442.

Yassir, B. and Alain, P. (2016). Evaluation of the Impact of Mine activity on Surrounding Soils of DraaLasfer Mine in Marrakech Morocco. African Journal of Environmental Science and Technology 10(1). 44-49.