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Geoelectrical and Geochemical Assessment of Soil and Groundwater Contamination Induced by Heavy Metals from a Closed Battery Factory in Ibadan, Southwestern Nigeria

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Abstract

Electrical resistivity profiling and geochemical analyses of soil and groundwater were carried out around an closed battery factory in Ibadan, southwestern Nigeria with a view to delineating conductive zones possibly due to heavy metal contamination. The resistivity data were acquired along eight profiles using the dipole-dipole electrode array and interpreted using 2D inversion procedures. Groundwater and soil samples were collected respectively from hand-dug wells/boreholes and trial pits located near conductive zones observed on the inverted 2D resistivity sections. Geochemical analyses were conducted on the samples for Lead, Cadmium, Zinc and Copper using Atomic Absorption Spectrometry, to determine their concentrations. The study revealed heavy metal contamination in the vicinity of the abandoned battery factory. The concentrations of Zinc and Copper in the soil and groundwater are within WHO permissible limits. While the concentrations of Lead and Cadmium are above the WHO limits in the groundwater in some parts, they are exceedingly higher in soil for Lead in part, and Cadmium in all of the study area.

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Keywords

Resistivity profiling, conductive zones, heavy metal contamination, atomic absorption spectrometry, WHO permissible limits.

Introduction

Heavy metals are a group of metals and metalloids that have relatively high density and are potentially hazardous even at low concentrations (ATSDR 2008; Jomova and Valko, 2011). They are toxic substances which are often present in the environment at low levels in soils, plants and groundwater, and can be dangerous at concentrations beyond the permissible limits. Sources of heavy metals to the environment are either natural or anthropogenic. The natural sources include weathering of metal-bearing rocks and volcanic eruptions while the anthropogenic sources include mining, agriculture, pharmaceuticals, traffic, domestic effluents, smelting, foundry, and other metal-based industrial operations (Elueze *et al.*, 2001a; Stihi *et al.*, 2006; Jantschi *et al.*, 2008; Elueze *et al.*, 2009). Chemicals found in the environment may contain some amounts of heavy metals which may accumulate locally in soil or be transported over long distances in water to locations where they pose health risk.

Heavy metal contamination of soil and groundwater has become serious public concern due to their persistence in soil and potential long-term toxic effects on human health. Slight changes in their concentration above the acceptable levels may result in serious environmental and subsequent health problems (Daniel *et al.*, 2016; Vatandoost, 2018). The presence of heavy metals in soil can adversely affect wildlife, soil ecology, plant growth, agricultural product quality and groundwater quality, and ultimately constitute health risk to human through the food chain via direct ingestion, inhalation and dermal absorption (Zeng *et al.,* 2015, Islam *et al.,* 2016).

Human exposure to excess concentration of heavy metals may lead to health risks, as they tend to accumulate in the fatty tissue and affect the central nervous system and the internal organs(Waisberg *et al.,* 2003). Risk of exposure increases near industrial sites which utilize heavy metals and their compounds, and places where they have been improperly disposed (Gilbert and Oladele, 2009; Adeagbo, 2011; Oyediran and Aladejana, 2011; Oyeleke *et al.*, 2016). Governments have launched methods of remediation to curtail environmental pollution by heavy metals through the various regulatory agencies, such as the World Health Organization (WHO), United States Environmental Protection Agency (USEPA) and European Union (EU) (Ahmad *et al.*, 2011).

The area around an abandoned battery factory, in Ibadan, southwestern Nigeria, is fast developing into residential estates, hence the need to ascertain the concentrations of heavy metals that might have accumulated in the soils and groundwater of the area, as it might affect the health of the settlers. Wastes emanating from lead-acid battery factories are known to cause contamination agricultural ecosystems in their vicinity (Liu *et al.*, 2014).The factory produced lead-acid batteries basically by secondary smelting of lead which involved carbon reduction of lead compounds to raw lead, and discharged its wastes to the neighbourhood over a period of 16 years. Since Lead, Cadmium, Zinc and Copper are the major materials used in the manufacture of the batteries, they are expected to be present in the wastes/effluents discharged from the battery factory into the neighbouring environment. These metals have been reported to be potential pollutants of the soils, sediments and groundwater in the vicinity of the battery factory (Elueze *et al.*, 2001a).

Lead and Cadmium are among the ten chemicals listed by WHO as major public health concern (WHO, 2016). Lead is toxic and harmful even in small amounts, and can be inhaled in dust from battery factory, lead paints and waste gases from leaded gasoline (Gregoriaadou *et al.*, 2001;Sing and Sing, 2010). High concentration of lead in the body can cause death or permanent damage to the central nervous system, brain and kidneys (Hanaa *et al.*, 2000). commended value (3μg/L) in 7.46% of the samples analyzed with mean concentration of 17 μg/L and varies from 14 to 21 μg/L. recommended value (3μg/L) in 7.46% of the samples analyzed with mean concentration of 17 μg/L and varies from 14 to 21 μg/L. Contamination of drinking water with high level of copper may lead to chronic anemia (Acharya *et al.*, 2008). In this study, copper is the only metal that was not detected in all the sampling areas presumably due to the low cupper related industrial and mining activities in the sampling areas. Since the WHO (2008) maximum admissible limit of copper in drinking water was well above the method detection limit; there was no health related risk due to the presence of copper in drinking water of the study areas. Contamination of drinking water with high level of copper may lead to chronic anemia (Acharya *et al.*, 2008). In this study, copper is the only metal that was not detected in all the sampling areas presumably due to the low cupper related industrial and mining activities in the sampling areas.

Since the WHO (2008) maximum admissible limit of copper in drinking water was well above the method detection limit; there was no health related risk due to the presence of copper in drinking water of the study areas.

The main sources of Cadmium are industrial activities such as electroplating, pigments, plastics, stabilizers and battery industries. Cadmium is highly toxic at high concentrations and is known to have been responsible for several cases of poisoning through food. It occurs mostly in association with zinc and causes high blood pressure and kidney damage (Nassef *et al.*, 2006; Rajappa *et al.*, 2010). Zinc plays a vital role in the physiological and metabolic process of many organisms as well as protein synthesis, but can be toxic to the organism at high concentration. Human exposure to high concentration of zinc for a long time can result in heart disease and stroke (Rajkovic *et al.*, 2008). High concentration of Copper in drinking water may lead to chronic anemia. Its exposure is particularly risky in children due to its accumulative nature (Acharya *et al.*, 2008).

Application of geoelectrical method to investigate heavy metal contamination can provide subsurface information about contaminated zones more rapidly than other methods. The method is non-invasive, time-saving and cost-effective. The connection between soil and groundwater contamination and the anomalously low resistivity associated with it enables the detection and delineation of conductive zones attributable to the presence of heavy metals and other contaminants (Songyu *et al.*, 2008; Casado *et al.*, 2015; Islami *et al.*, 2018). Sampling for confirmatory geochemical tests can then be conducted only on the soils and/or groundwater sampled from the suspected zones to determine the degree of contamination.

This study therefore employed geophysical and geochemical methods to detect contamination by heavy metals and assess its extent in the soil and groundwater in the vicinity of the closed battery factory. The objectives are to delineate subsurface zones of anomalously low resistivity possibly caused by heavy metal contamination, determine the concentrations of the heavy metals in the soil and groundwater sampled within the study area, and compare with the recommended WHO permissible limits.

The study area is located off Ibadan-Iwo road, within latitudes 7º 25′ 50″N - 7º 25′ 56″N and longitudes 3º 58′ 59″E - 3º 59′ 03″ E (Fig. 1). It is accessible via Akobo and Wofun ends of Adebayo Alao-Akala Way. The topography is generally undulating, ranging from 650 m 800 m above the sea level. It is mainly drained by River Oluwa which flows eastward and discharges into River Omi. The drainage pattern is dendritic. The climate is humid with most of the annual rainfall (1500 mm) occurring from May to October. The area lies within the Precambrian basement complex terrain of southwestern Nigeria (Rahaman, 1989), and is underlain by undifferentiated gneiss complex (Fig. 2).

Materials and Methods

The electrical resistivity profiling was carried out using the dipole-dipole electrode array, with the aid of a resistivity meter, along eight profiles, six of which were ran in the E-W and two in the N-S direction. The profiles were 100-150 m long. The survey used electrode spacing, a=5 m and expansion factor, n varied from 1 to 6. The apparent resistivity data were inverted by using computer-aided 2D inversion procedures (Loke, 2017) to generate the 2D resistivity sections of the subsurface on which conductive zones with anomalously low resistivity values were identified.

Groundwater samples were collected from five hand-dug wells (W1-W5) and three boreholes (W6-W8), located near suspected conductive zones observed on the inverted 2D resistivity sections, using pre-cleaned 1 litre polythene plastic bottles after allowing the water to run for about 5 minutes. The soil samples were collected from four test pits (TP 1-TP 4) dug, by using hand auger, at depths ranging from 2 m to 5 m within the conductive zones identified on the 2D resistivity sections, and kept in polythene bags. The water and soil samples were then prepared for geochemical analyses involving Atomic Absorption Spectrometry (AAS) to determine their concentrations of Lead, Cadmium, Zinc and Copper.

The results of the tests were compared with the WHO permissible standards for drinking water and soil (WHO, 2017) to assess the degree of subsurface contamination attributable to the effluents traceable to the battery factory. Fig. 3 shows the positions of the hand-dug wells and trial pits on the profiles.

Fig.1 Location map of the study area.

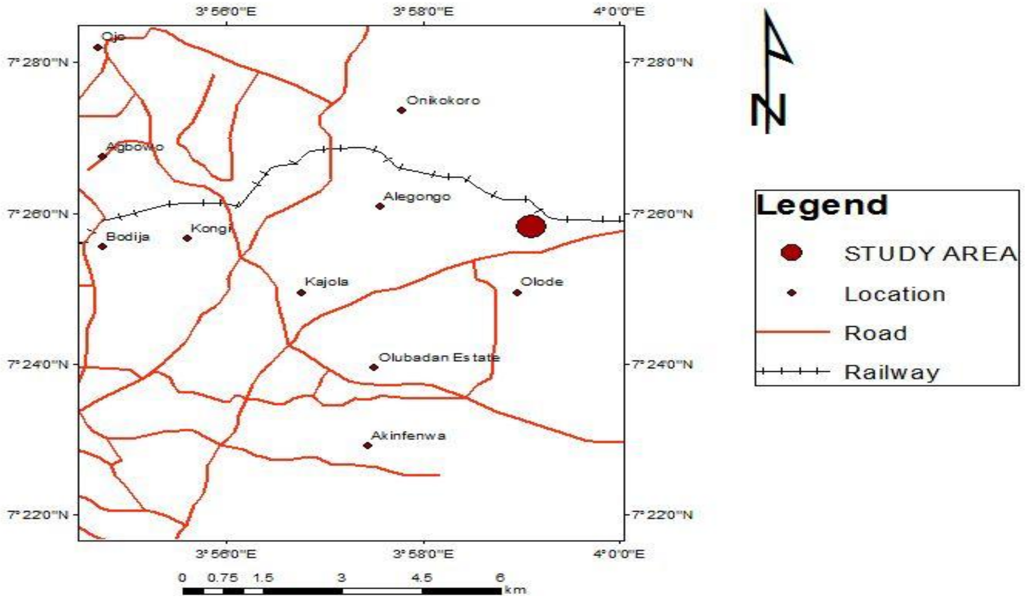


Fig.2 Geological map showing the study area

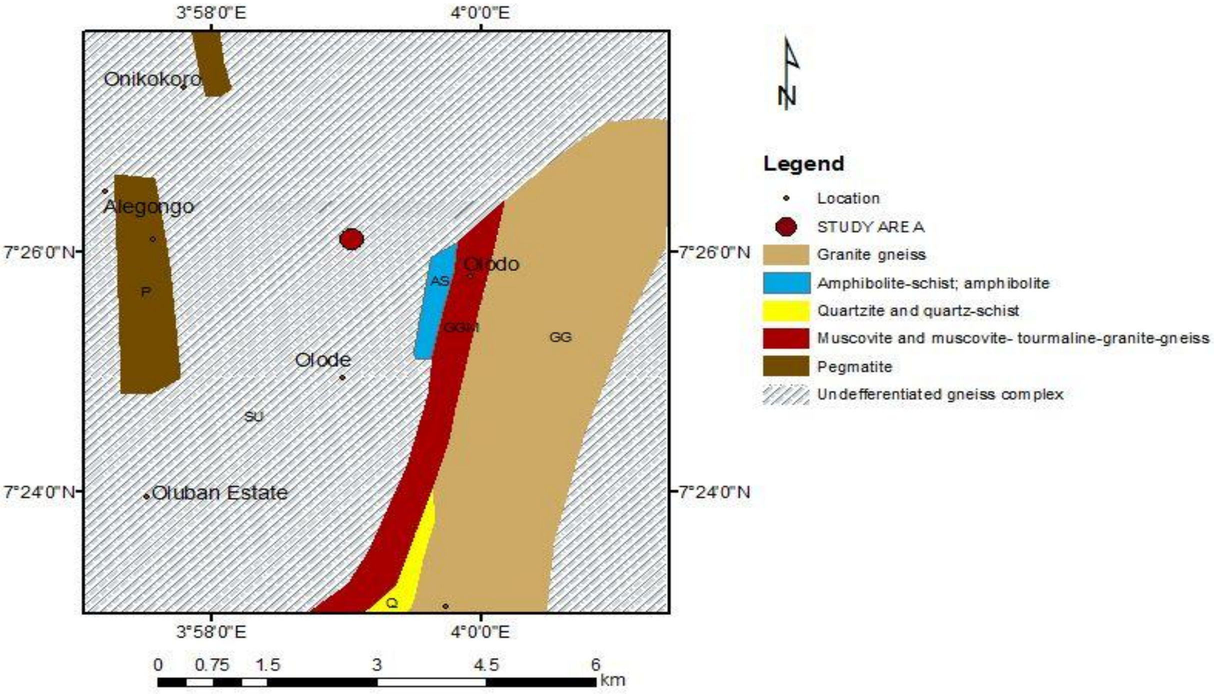
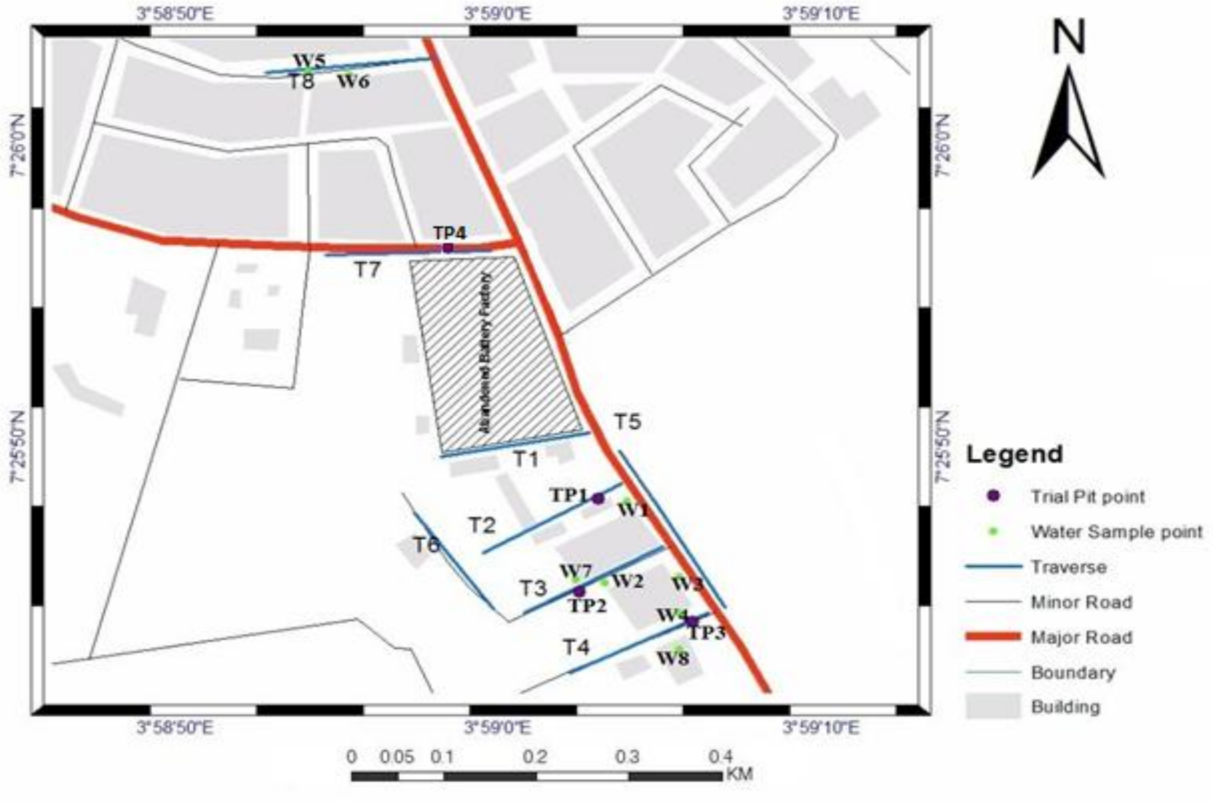


Fig.3 Field layout of profiles and sampling points



Results and Discussion

The 2D resistivity section beneath Profile 1 (Fig. 4) reveals clay overburden with resistivity ranging from 10 to 25 Ωm. The bedrock resistivity varies from 34 to 96 Ωm and indicates intense weathering and fracturing. There is no resistivity anomaly indicating any form of soil contamination. The resistivity of the clay overburden beneath Profile 2 ranges from 10 to 40 Ωm (Fig 5). The conductive zone, with anomalously low resistivity of 6-8 Ωm, within the lateral distance 15-45 m and depth 2-6 m indicates contamination suspected to be heavy metal. The bedrock resistivity varies from 60 to 120 Ωm suggesting intense weathering and fracturing.

The overburden beneath Profile 3 has resistivity ranging from 12 to 48 Ωm characteristic of clay (Fig. 6). The bedrock resistivity varies from 36 to 95 Ωm suggesting of intense weathering, and appears fractured beneath 10 m at lateral distances 35-55 m and 75-100 m. The anomalously low resistivity values of 7-10 Ωm occurring at lateral distances 90-95 m and 105-135 m and depth 2.5-7m indicate conductive zones attributable to heavy metal contamination. The resistivity of the overburden beneath Profile 4 ranges from 12 to 100 Ωm (Fig. 7). The bedrock appears to have been intensely weathered and fractured with resistivity varying from 115 to 358 Ωm. The anomalously low resistivity zone beneath depth lateral distance 0-45 m may be suggestive of contamination.

Profile 5 is underlain by clay overburden with resistivity less than 100 Ωm (Fig. 8). Resistivity of the bed rock ranges from 154 to 344 Ωm indicating intense weathering and fracturing.

Table.1 Concentrations of heavy metals and EC of water samples from the study area

Sample location	Conc. of Zinc (ppm)	Conc. of Copper (ppm)	Conc. of Lead (ppm)	Conc. of Cadmium (ppm)
W1	0.00	0.01	0.02	0.00
W2	0.63	0.00	0.00	0.00
W3	0.26	0.00	0.01	0.01
W4	0.31	0.01	0.01	0.00
W5	0.21	0.00	0.00	0.00
W6	0.43	0.01	0.04	0.00
W7	0.23	0.04	0.02	0.01
W8	0.30	0.01	0.01	0.00
WHO	3.00	2.00	0.01	0.003

WHO = World Health Organization maximum permissible levels for drinking water (2010) TP = Trial pit

Table.2 Concentrations of heavy metals in soil samples compared with WHO standards

Sample location	Conc. of Zn (ppm)	Conc. of Cu (ppm)	Conc. of Pb(ppm)	Conc. of Cd (ppm)
TP 1	9.41	3.80	40.00	5.00
TP 2	21.20	10.20	105.00	5.00
TP 3	14.20	6.30	60.00	5.00
TP 4	14.90	6.80	68.00	5.00
WHO	50.00	30.00	85.00	0.30

WHO = World Health Organization maximum

Fig.4 2D Resistivity section beneath Profile 1

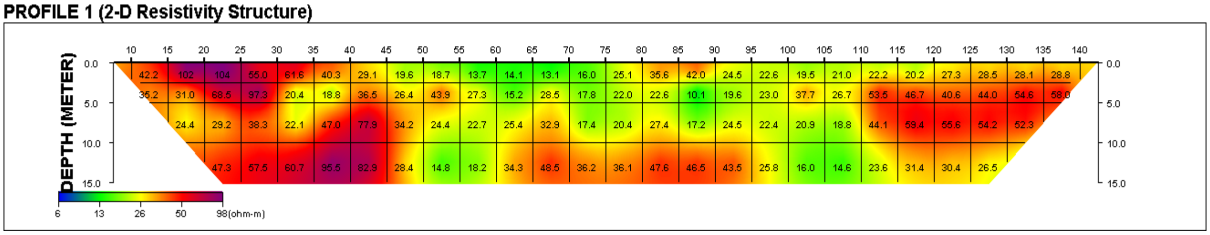


Fig.5 2D Resistivity section beneath Profile 2

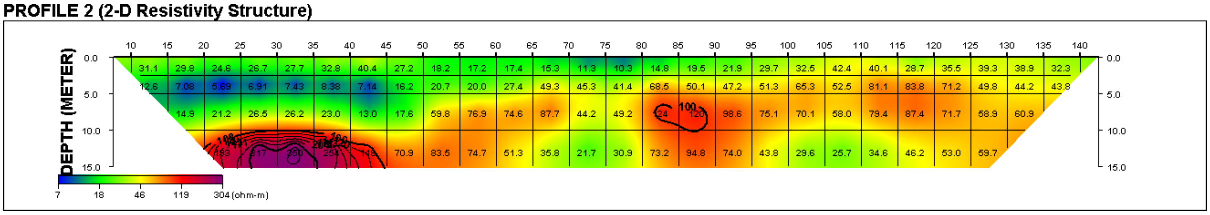

PROFILE 2 (2-D Resistivity Structure)

Fig.6 2D Resistivity section beneath Profile 3

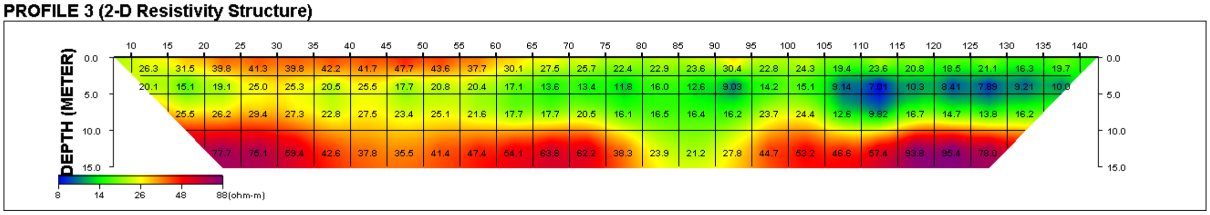

PROFILE 3 (2-D Resistivity Structure)

Fig.7 2D Resistivity section beneath Profile 4

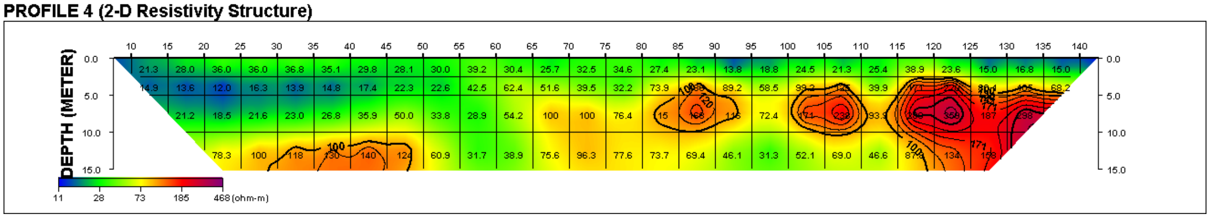

PROFILE 4 (2-D Resistivity Structure)

Fig.8 2D Resistivity section beneath Profile 5.

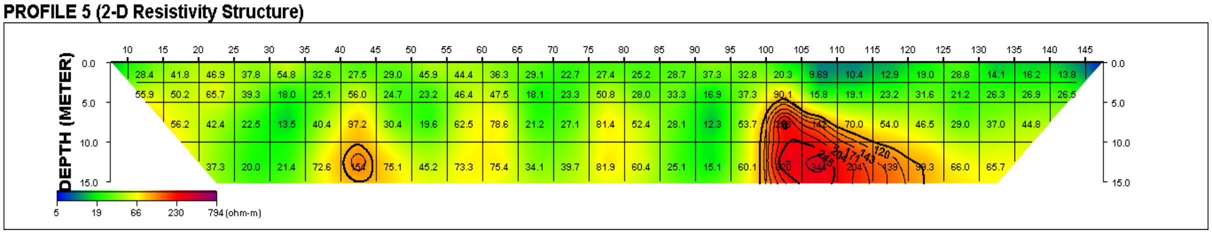

PROFILE 5 (2-D Resistivity Structure)

Fig.9 2D Resistivity section beneath Profile 6

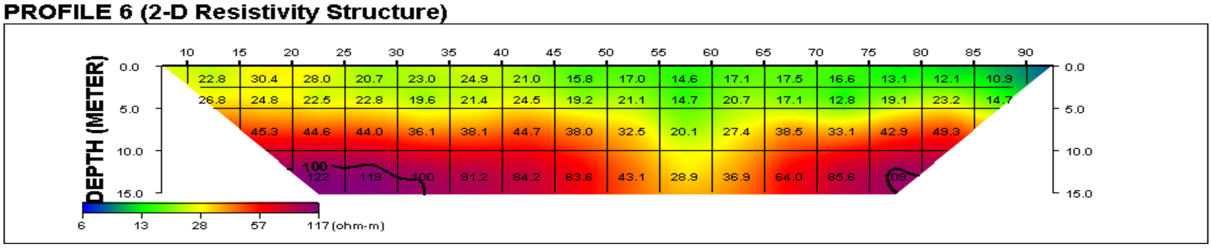

PROFILE 6 (2-D Resistivity Structure)

Fig.10 2D Resistivity section beneath Profile 7

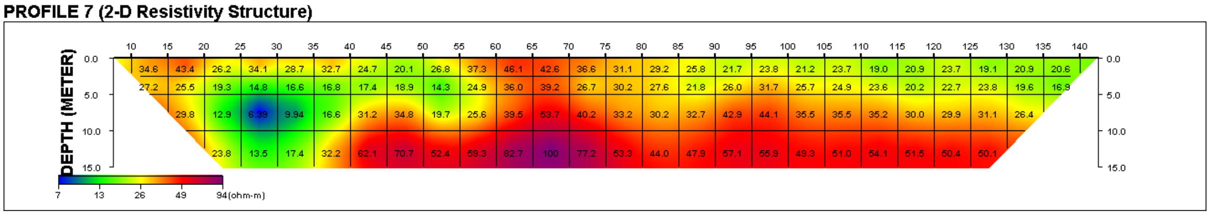
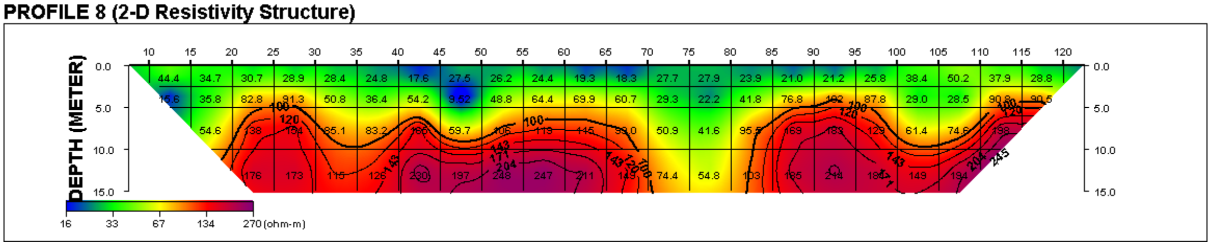


Fig.11 2D Resistivity section beneath Profile 8



The conductive zones low within the top 2.5 m at lateral distance 105-115 m and the end of the profile indicate contamination. The resistivity of the overburden beneath Profile 6 is less than 100 Ωm characteristic of clay (Fig. 9). The overburden thickness is 5-7 m. The bedrock has resistivity varying from 33 to 122 Ωm indicating intense weathering and hydration. It appears fractured at lateral distance 53-65 m at depths beyond 5 m. There is no indication of contamination.

The 2D resistivity section beneath Profile 7 (Fig. 10) reveals an overburden resistivity ranging from 14 to 24 Ωm characteristic of clay. The bedrock resistivity ranges from 33.2 to 100 Ωm and indicates intense weathering and hydration. The anomalously low resistivities less than 10 Ωm recorded at depth 5-12 m within the lateral distance of 25-32m indicate contamination presumably due to heavy metal.

The resistivity of the overburden underlying Profile 8 ranges from 21 to 55 Ωm (Fig. 11). The bedrock has resistivity varying from 42 to 248 Ωm indicating intense weathering, and appears fractured beneath distance 70-80 m. The anomalously low resistivity at depth 2-5 m within lateral distance 40-50 m suggests possible heavy metal contamination.

The results of the hydro-geochemical analyses for heavy metal concentration conducted in water samples collected from hand dug wells (W1-W5) and boreholes (W6-W8) within the study area are presented in Table 1 with the World Health Organization maximum permissible limits for drinking water (WHO, 2017). Zinc was not detected in W1 while Copper was not detected in W2, W3 and W5, and their concentrations, where they were detected, are well below the WHO permissible limits for all the water samples. Hence, there is no health-related risk due to the presence of Zinc and Copper in groundwater of the study area. Lead was not detected in W2 and W5 but its concentrations in W1, W6 and W7 exceed the WHO permissible limit. Cadmium was detected only in W3 and W7 with concentrations above the WHO permissible limit. The groundwater from these wells thus requires treatment to prevent associated potential health risk via consumption.

The concentrations of zinc and copper in the soil samples are below the WHO permissible limits for heavy metals in soils (WHO, 2017). Lead concentration is lower than the WHO maximum permissible limit except in TP 2 (Table 2). The concentration of Cadmium of 5.0 mg/kg for all the soil samples is exceedingly higher than the WHO acceptable limit for soils. The suspected contamination of the soils is believed to have resulted from direct deposition of particulate matter contained in the gaseous emissions discharged from the treatment plant. The considerable concentrations of lead noticeable in the soil from TP 2, and cadmium in all the soils may pose health threat as they may be taken up by plants and transferred to human via ingestion or slowly migrate into aquifers in the vicinity with time.

The results of the 2D resistivity survey reveal subsurface contamination, presumably caused by heavy metals, in the vicinity of the closed battery factory. The concentrations of Zinc and Copper in the soil and groundwater are within WHO permissible limits. The concentrations of Lead and Cadmium in the groundwater are above the WHO permissible limits for drinking water in some parts of the study area. Lead concentration in part of the study area is above the WHO permissible limits for soils while Cadmium concentration is exceedingly higher in all of the soil.

The considerable concentrations of Lead and Cadmium in the soil and groundwater may pose serious health risk. The heavy metals in the groundwater can be treated while those in the soil can be bound chemically using phosphate salts or plants known to bio-accumulate heavy metals could be introduced to pick up the metals.

Permissible limits for soils (2010)

TP = Trial pit

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