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DELINEATION OF LEACHATE PLUME MIGRATION USING GEO-ELECTRICAL RESISTIVITY ON OTOFURE DUMPSITE IN BENIN CITY, NIGERIA

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Abstract

In Nigeria, thousands of sites have been contaminated by wide variety of wastes due to improper planning and sighting of dumpsites. Most of these dumpsites are located within the city metropolis thereby constituting environmental pollution to both the atmosphere, surface and subsurface. Geophysical investigations involving the use of 2D electrical resistivity imaging (ERI) techniques have been carried out at Otofure dumpsite Southern Nigeria to study the Leachate plume migration from the dumpsite and ascertain if the leachate migration has infiltrated into the groundwater. Five (05) high-resolution 2D electrical resistivity images were acquired using the Wenner array configuration with minimum electrode separation of 5m and profile separations of 20m The roll-along technique was employed to cover all the profile length of 200m each. The acquired data were processed to display the variations of electrical resistivities using the RES2DINV software.
The results from each of the profiles except profile 3, showed that leachate from the dump has migrated to a depth of 39m and this could pose a serious threat to the aquifer in the study area. Even though there has not been any reported outbreak of waterborne disease linked to the dumpsite, it would be in the best interest of the community to recommend decommissioning of site because it has been surrounded by residential settlements.

Keywords: Dumpsite, Electrical Resistivity, Imaging, Otofure, Leachate,

INTRODUCTION

The potential of hazard from unregulated dumpsites in under-developed and developing countries like Nigeria cannot be over emphasized. These activities exposes communities to underground and downstream surface water contamination caused by leachate generated from these waste dumpsites. Combined physical, chemical and microbial processes in a landfill waste-mass act to transfer pollutants from the refuse material to the percolating water [1]. As a result, leachate is generated by excess rainwater percolating through the waste layers.
Leachate from municipal dumpsites are composed of dissolved organic matter (e.g. vinyl chloride, benzene 1,1,1-Trichloroethene); inorganic ions such as ammonium (NH_4^+), sodium (Na^+) and sulphate (SO_4^{2-}) chloride (Cl^-), and heavy metals (manganese (Mn), zinc (Zn), iron (Fe) copper, chromium (Cr), lead (Pb) and cadmium (Cd)) which are harmful [2]. These ionic concentrations coupled with their low resistivity values make electrical delineation of generated contaminant leachate plume plausible [3, 4, 5]. A precise assessment of the extent of transportation of leachate is of paramount importance in the remediation process. It can serve as part of hazard assessment or to assist in placement of monitoring wells [6].
The main direct impact on society of uncontrolled leachate release and migration, is its pollution of groundwater and its subsequence effect on human health when consumed. The health implication ranges from simple skin rash to cancer and ultimately death.
The usefulness of surface geophysical methods for solving a number of problems

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The use of geophysical methods in dumpsite investigations has continued to receive considerable attention. Geophysical methods such as Electrical resistivity [7, 8, 9] Induced Polarization [10], Seismic Refraction, Ground penetrating radar [11] among others have been used in a number of years for pollution and environmental studies. The electrical resistivity method however, has been found very suitable for dumpsite characterization and evaluation. This is because it is cheap, non- invasive, fast and provides good electrical resistivity contrast between the target of interest and the host material [12,13,14]. The technique has proven effective to map the distribution of leachate likewise monitor its possible migration pattern in the soil [15, 16]. Traditional methods like chemical analysis, hydrological and geophysical techniques could be used for the identification and delineation of contaminant plume [10, 11].
The aim of this study is the geophysical characterization around an active open waste dumpsite in Otofure, South-South, Nigeria, with the view to provide geophysical information on the extent of contamination of the groundwater aquifers. This information will be useful in formulating an appropriate land use, management policy and reclaiming the affected land areas and/or re-location of nearby residents Detecting leachate plume migration at the selected municipal dumpsite is one of the steps taken to determine if the aquifer table has been breached and the groundwater is safe for use for neighboring residents.

SITE DESCRIPTION

The site chosen for this study is an open municipal solid waste dumpsite at Otofure Community located in Southern Nigeria. The site covers an area of about 10 hectares (ha). The Dumpsite sits on ridge deposit of laterite sand underlain by a large deposit of sand and silt. The sand has been extensively mined in the area which is evident from the sand exploration pits situated East to South of the Dumpsite.
The study location lies between latitudes N6º27'43.2'' to N6º27' 50.8'' and longitudes E5º35'58.6'' to E5º36'02.1''.

Plate 1: A section of Otofure dumpsite

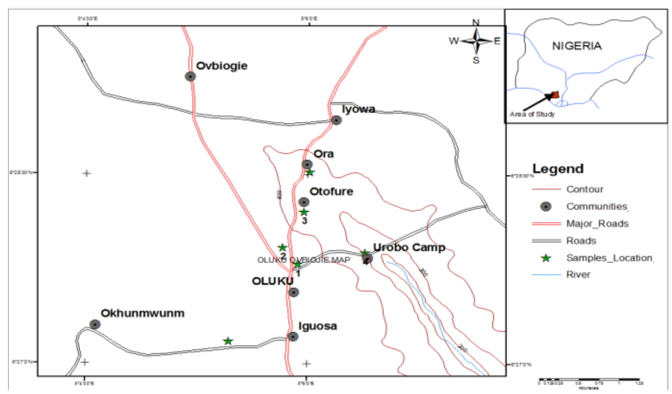


Figure 1: Digitized Map of the study Area [17]

GEOLOGICAL SETTING

The Geology of the study area is characterized in the geology of Niger Delta.
Geology of the area: The Niger Delta is situated in southern Nigeria between latitudes 3° N and 6° N and longitude 5° E and 8° E [18]. It covers an area of 75,000sqkm. It is bounded to the west and northwest by the Western African Shield, which terminates at the Benin hinge line and to the east, by the Calabar hinge line. The Anambra Basin and Abakaliki Anticlinorium mark its northern limit. To the south, it is bounded by the Gulf of Guinea. The Niger Delta Basin to date is the most prolific and economic sedimentary basin in Nigeria by virtue of the size of petroleum accumulations discovered and produced as well as the spatial distribution of the petroleum resources to the Onshore, Continental shelf through deep water terrains.
This is the uppermost unit of the Niger Delta complex. The formation can be easily distinguished based on its high sand percentage (70 – 1000 %). The sand is dominantly massive highly porous and freshwater bearing with locally inter-bedded shale beds, which are considered to be of braided stream origin. The sands are poorly sorted, ranging from fine to coarse – grained and occasionally pebbly and they contain abundant wood, fragments, which become lignitic with depth. Composition, structure and grain size show deposition in a probably upper deltaic environment. The thickness is variable and may be more than (1990 m) in Warri – Degema area. Most companies exploring for oil in the Niger Delta, arbitrarily define the base of the Benin Formation by the deepest fresh - water – bearing sandstone that exhibits high resistivity. The base of the Benin Formation by the first marine foraminifera within shale, as the formation is non-marine in origin [19].

THEORY AND METHODS

A total of five 2D profiles geoelectrical resistivity imaging lines were measured with the aid of Petrozenith Earth resistivity meter. Five (05) profile lines where measured at the Western end of the surveyed site using the wenner array method. The length of the 2D traverses were 200m in length each and the minimum electrode spacing was 5m interval using the wenner array configuration

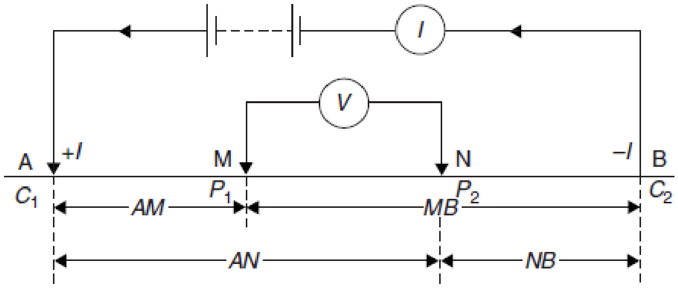


Figure 2: Generalized form of electrode configuration in resistivity surveys.

For a current source and sink, the potential V_P at any point P in the ground is equal to the sum of the voltages from the two electrodes, such that: $V_P = V_A + V_B$ where V_A and V_B are the potential contributions from the two electrodes, A(+I) and B(−I). The potentials at electrode M and N are:

$$V_N = \frac{\rho I}{2\pi}\left[\frac{1}{AN} - \frac{1}{NB}\right] \tag{1}$$

$$V_M = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB}\right] \tag{2}$$

However, it is far easier to measure the potential difference, δV_{MN} which can be rewritten as:

$$\rho V_{MN} = V_M - V_N = \frac{\rho I}{2\pi}\left\{\left[\frac{1}{AM} - \frac{1}{MB}\right] - \left[\frac{1}{AN} - \frac{1}{NB}\right]\right\} \tag{3}$$

Rearranging this so that resistivity ρ is the subject:

$$\rho = \frac{2\pi\rho V_{MN}}{I}\left\{\left[\frac{1}{AM} - \frac{1}{MB}\right] - \left[\frac{1}{AN} - \frac{1}{NB}\right]\right\}^{-1} \tag{4}$$

The observed resistance values were used to compute the apparent resistivity values. A manual data collection technique was employed. The apparent resistivity, ρ, for each R measured was calculated using the equation for Wenner configuration expressed by

$$\rho = 2\pi a V_{mn} / I \tag{5}$$

where a is the electrode spacing, V is the potential difference and I is the current. The equation can be rewritten as

$$\rho = 2\pi a R \tag{6}$$

After acquisition, the data were processed with RES2DINV program, software. The software operates on a non-linear least-square optimization that automatically determines a 2D resistivity model of the subsurface from observed apparent resistivity values. The program divides the subsurface into a number of rectangular blocks with reference to the spread of observed data. In the iterations the modeled calculated data are adjusted to correlate with the observed data. The inversion problem is to find the resistivity of the blocks that will minimize the difference between the calculated and the measured apparent resistivity values. Processing and inversion of resistivity image profile data were performed using RES2DINV code [11, 12]. For each data sets, L1 norm was used for the data misfit and the inversion was carried out using the L1 norm (blocky) inversion method for the model roughness filter [13]. The method uses a finite difference scheme for solving the 2-D forward problem and blocky inversion method for inverting the processed ERT data. RES2DINV generates the inverted resistivity depth image for each profile line. The quality of inversion result was checked by monitoring absolute error (e_{rms}) between the measured and predicted apparent resistivity given by,

$$e_{rms} = \sum_{i=1}^{N}\left[\frac{\log(\rho_{i_{meas}}) - \log(\rho_{i_{calc}})}{N}\right] \qquad (7)$$

where $\rho_{i_{meas}}$ and $\rho_{i_{calc}}$ are the measured and calculated apparent resistivity values at i^{th} data point respectively and N is the total number of data points.

RESULTS

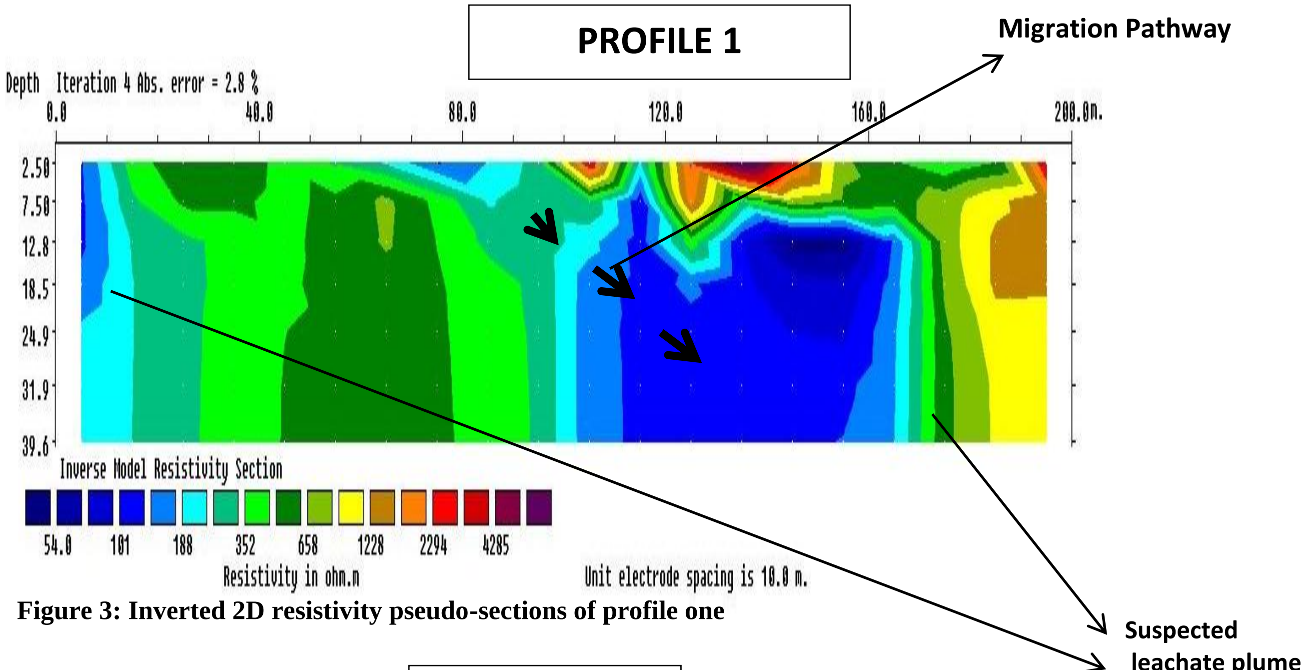


Figure 3: Inverted 2D resistivity pseudo-sections of profile one

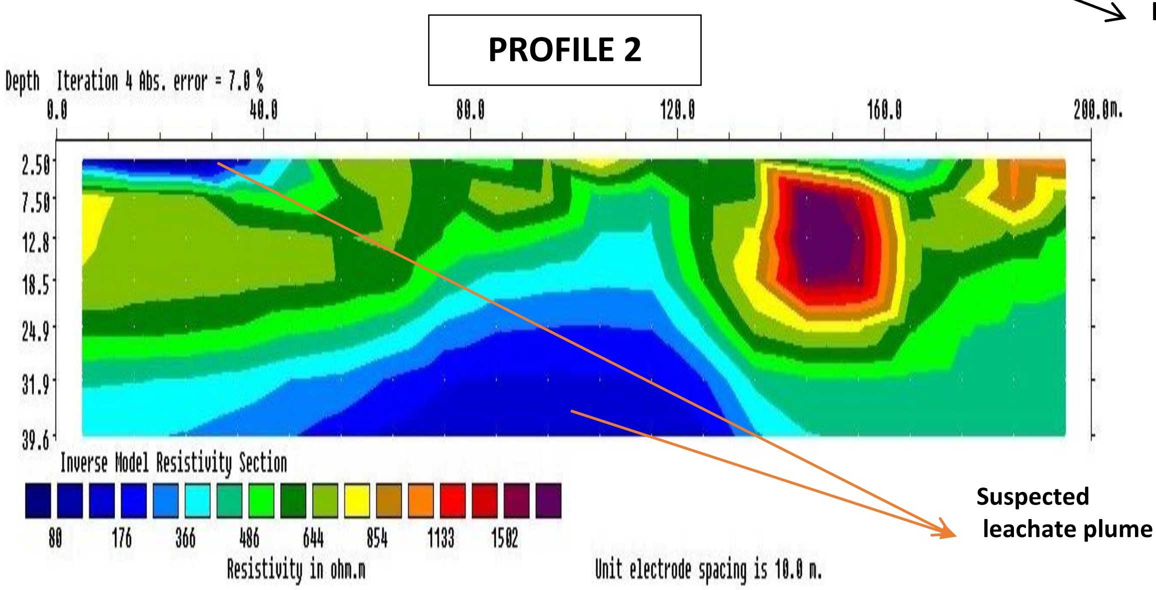


Figure 4: Inverted 2D resistivity pseudo-sections of profile two

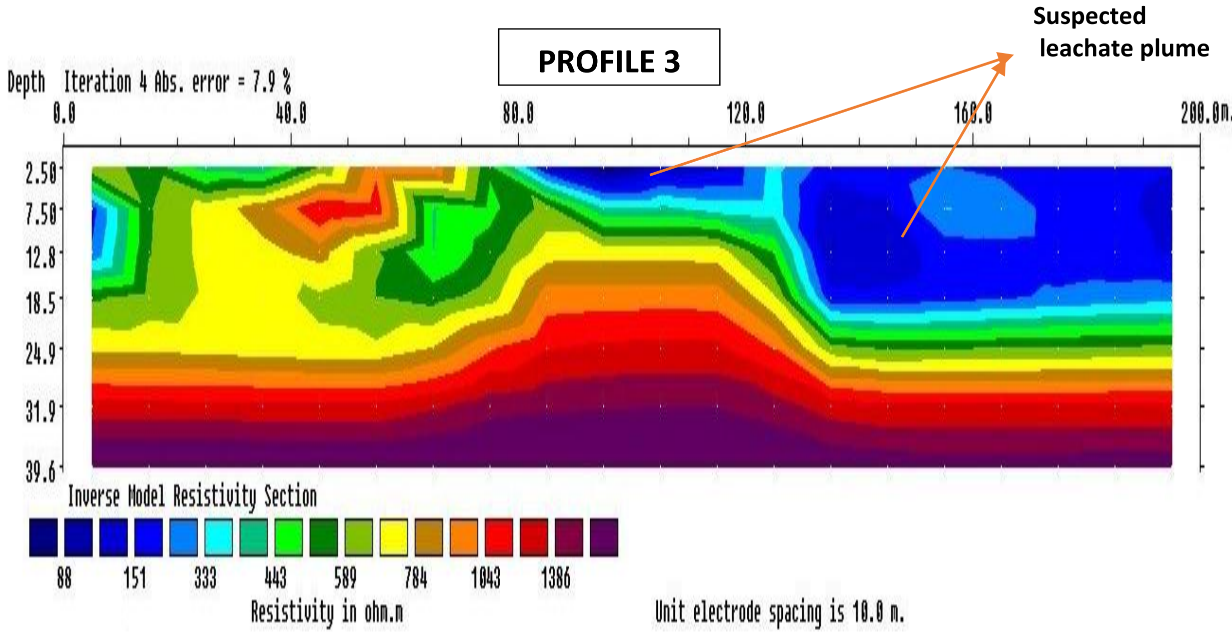
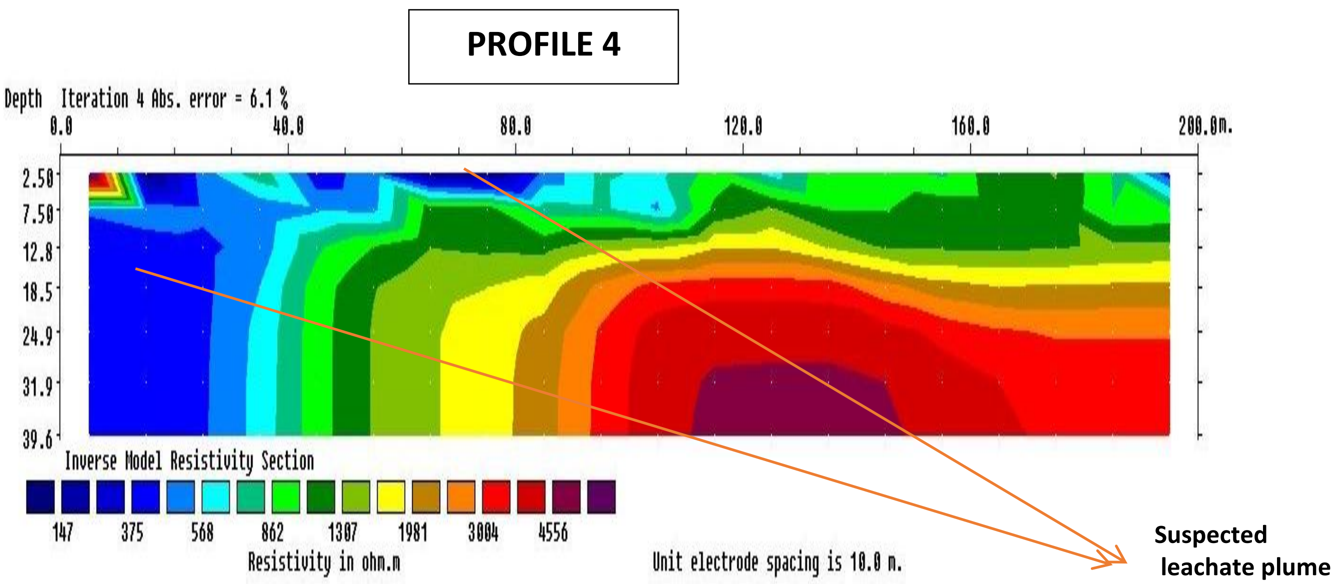
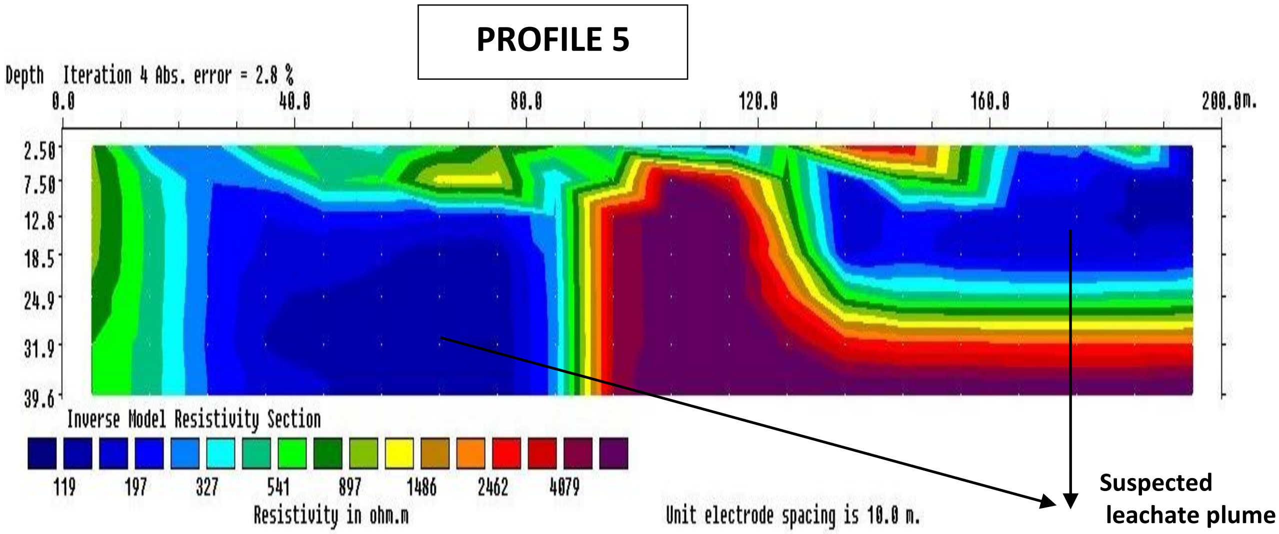


Figure 5: Inverted 2D resistivity pseudo-sections of profile three





DISCUSSION OF RESULTS

The inverted resistivity section is shown in Figure 3 to figure 7 with each profile running from east to west of the dumpsite. The profile length of each profile is 200m with and average depth of 39.6m. The low resistivity values are delineated as suspected leachate plume.

Profile 1 shows an uneven distribution of lithological units the presence of lateritic sand, clay and clayey sand porous sand (impregnated with leachate) are clearly delineated. This profile shows that the leachate has migrated down to 39.6m. the leachate migration path way is clearly seen at the 70m to 90m along the profile length.

The inverted resistivity section in Profile 2 shows 2 layers are clearly delineated The layers are topsoil, clay, laterite, clayey sand with pockets of leachate plume The resistivity of the topsoil varies from 50 to 600 Ωm. The high resistivity value (>1000ohmm) of the topsoil (purple) is an indication of the presence of non-conductive and non-biodegradable waste materials. This profile also show the presence of leachate at the maximum surveyed depth of 39.6m

The inverted resistivity section clearly delineated 2 layers in profile 3. The topsoil consists of accumulation of low porous and permeable sand, laterite and clayey sand. The leachate plume is seen in this profile is seen at the eastern end of the profile down to a depth of about 25m in depth. There is a fine strata of layered compacted clay sand from 28m in depth down to 39.6m which is impervious to the migrating leachate.

The 2-D resistivity structure profile presented in Profile 4 is on average 2m away from the dumpsite and covers a distance of 200m The topsoil/weathered layer has resistivity values varying from 60 to 300ohmm. The low resistivity value recorded especially towards the west of the profile, close to the dumpsite, could be an indication of accumulation of leachate and contamination of saturated clay/sand.

There is also a highly compacted clay sand at the eastern end of the profile from 25m down to the bottom with resistivity >1500ohmm.

Profile 5 shows highly saturated clay and sand with leachate plume up to the surveyed depth at the 20m to 80m and 120m to 200m along the profile length. There is a highly compacted sand with resistivity >4000ohmm at 80m to 120m along the profile length.

CONCLUSION

The geoelectric method was used in the assessment of environmental conditions and groundwater contamination in an active open dumpsite at Otofure Benin City, South-south Nigeria. Five traverses established around the dumpsite were surveyed using electrical resistivity sounding and 2-D profile imaging.

2-D profiles also delineated the subsurface layers and some contamination zones were interpreted within the aquifer units for the study area. These zones occurred as low resistivity with values < 31Ωm and thickness < 5m to 30m in some cases. The leachate plume leaked to the bottom as observed in most of the transverses.

This study has shown clearly that the pollutant has migrated far into the ground, it therefore advisable to carry out regular assessment of the dumpsite and its environs. A multidisciplinary technique of hydrogeological, geochemical and geophysical techniques should be adopted, as a follow up on the dumpsite, to be able to characterize it effectively. The geophysics could include Induced Polarization (IP). Even though there has not been any reported outbreak of waterborne disease linked to the dumpsite, it would be in the best interest of the community to recommend decommissioning of site because it has been surrounded by residential settlements. It should be relocated to properly construct, highly effective hydraulic barrier or engineered liner systems that would provide resistance to migration of contaminants, thereby giving excellent protection to the environment and the public.

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