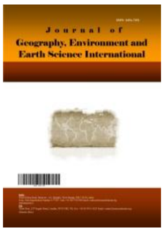

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Groundwater Contaminants Investigation in a Basement Area of Nigeria Using 2D Electrical Surveying Methods

Sofolabo Adekunle [a*] and Ochu Emmanuel Chinedu [a]

[a] *Geophysics Research Unit, Department of Physics/Applied Geophysics, University of Port Harcourt, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author SA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author OEC managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Some of the common methods of monitoring and mapping groundwater contaminants is by extracting and analyzing samples of the groundwater obtained from wells within the expected investigation area, although lots of limitations are encountered in this type of investigation technique (point wise method) due to the nature of most subsurface layers, which are heterogeneous and anisotropic in nature and acquiring information using this method is comparatively difficult due to the few points acquired for investigation. Common and most recent method used to overcome such type of limitation and improve ground monitoring cost-effectively, is the use of Direct Current Resistivity measurements. This method gives a comprehensive characterization of the electrical properties of the subsurface layers (volume) needed. This paper investigates the usability and advantages of the resistivity method as a better method technique in monitoring groundwater contaminants in basement area or terrains under different seasons, in monitoring programmes. The work comprises field investigations at several sanitary landfills around the basement area of Ado-Odo town, in Ogun State, Nigeria, using Wenner array configuration (tomography) technique. From the results obtained, the level/degree of contaminants are easily

**Corresponding author: E-mail: adekunle.sofolabo@uniport.edu.ng, aosofolabo@gmail.com;*

identified and evaluated within the subsurface layers. We therefore concluded that the use of resistivity survey method gives an improved, better and appropriate information, generally suitable for mapping and monitoring of conductive groundwater contaminants in basement area.

Keywords: Contaminants; groundwater; monitoring; wenner; configuration; tomography.

1. INTRODUCTION

Geophysical methods and Hydrogeological techniques are commonly used to investigate or assess the potential of groundwater in any given area, although geophysical investigations give more quick, improved and effective means of obtaining the distributed information of the subsurface hydrogeology [1]. The techniques of groundwater resource mapping and evaluation of water quality using geophysical methods has generally increased astronomically within the last decade due to the use of enhanced and rapid electronic devices with advanced technology as well as the development of new modeling solution system [2,3,4]. The use of different hydro-geophysical techniques are common and available, electrical resistivity method remains the most popular techniques due to its low cost of execution, simple operation technique and its high efficiency ratio in areas with high resistivity contrast, such as overburden weathered layers and bedrocks [5]. The use of electrical methods is particularly suitable for groundwater studies due to difference contrasts in hydrogeologic properties, such as permeability and porosity, which can easily be correlated with electrical resistivity values of the subsurface layers. Geo-electrical techniques are basically concerned with obtaining measurement of electrical resistivity of subsurface layers, which often gives information of the various geological layers, the structures and possible groundwater presences [6,7,8,9]. Resistivity of subsurface layers is related to various geological properties, such as the porosity, permeability, fluid and mineral contents, and level of water saturation.

Some limitations are often encountered when investigating subsurface contamination using tracer tests techniques in order to obtain a clearer and enhanced picture of the groundwater flow patterns and their corresponding velocities. A major critical point in tracer tests technique is the distance of the observation wells and points of infiltration, as tracer pulses or signal s can be lost in the formation between observatory wells, due to heterogeneous flow pattern. Overcoming such limitation of tracer tests or point investigations, in a cost effective way, is the use of a Direct Current (DC) resistivity method, which are very useful in characterization of the subsurface layers physical properties, both vertically and laterally, covering large volume of the ground, thereby improving the monitoring technique [10-12]. The Direct Current resistivity method is one of oldest known geophysical methods, which have been used over time for investigating presence of leachates in landfill environs and studying of other environmental challenges [9,13]. The use of resistivity methods for investigating the presence of contaminants in subsurface formations is based on the knowledge that the resistivity of the saturated soil basically depends on the groundwater resistivity and properties of the porous matrix, thus creating the ability and potential of detecting leachate present, resulting in changing the resistivity of the subsurface layers due to changes in the concentration of contaminants (dissolved ions) in the groundwater. The resistivity method is most effective and suitable for relative measurement, and monitoring of leachate flow in the subsurface [14].

In complex hydrogeology area, monitoring of contaminants flow is assess by the use of high density systems and for area with very high fluctuating groundwater table, which will enable the system to give a vertical cross-section of the concerned area. While low-density systems are effective for hydrogeological environments with fewer and shallow layers but with stable groundwater table, or area with less detailed information (both in time and space). The use of Continuous Vertical Electrical Sounding (CVES) system is generally preferable for tracer tests and commonly recommended, because of the density of measurements required and the ability for automatic measurement. Major precaution require in the use of tracer tests in resistivity measurements, is in the estimation of the needed amount of tracers based on the size and depth of the aquifer, as well as the estimated groundwater flow [15-17]. The use of high concentration of tracers will give detectable resistivity changes even in deep aquifers, while too high concentration tracers may cause unwanted differential flows.

2. THE STUDY AREA

The survey was conducted in Ado-Odo/Ota town, a borders town between Ogun State and metropolitan Lagos State (Fig. 1). The local government area is the second largest in Ogun State, with its headquarter at Ota main town with coordinates 60°41'00''N 30°41'00''E and at Latitude/Longitude 6°37'25'' N/ 3°5'11'' E (Fig. 2), with a total landmass area of about 878 sq-km. Ota main town possesses the same geologic characteristics with many other parts of the state, with basement complex rock and the pre-Cambrian age basically made up of the older and younger granites (Fig. 3) especially in the northern part of the state, while the younger and older sedimentary rock of tertiary and secondary ages are common in the southern parts [18]. The region possesses a typical climate of tropical rain-forest with two main climatic conditions namely; the rainy season (commonly from April to October, with little a month interruption), and the dry season (Running through November till February). The rainfall duration usually runs for more 90 days, resulting in a humid climate due to the high level of rainfall, which often amount to about 250cm^3 in a year [19].

Groundwater flows generally follows the topography nature of the area surface with seasonal variations in water levels, usually characterized by rising (Increasing) water levels between November and March (Wet season), while between May and September (Dry season), there is reducing (Declining) water levels. The red circles indicate the 4 locations where field investigations were carried out in the study area (Fig. 4).

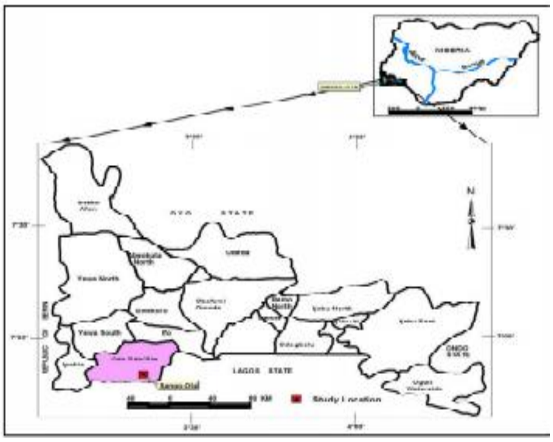

Fig. 1. Map of Ogun State showing the Study Area of Ado-Odo/Ota [19]

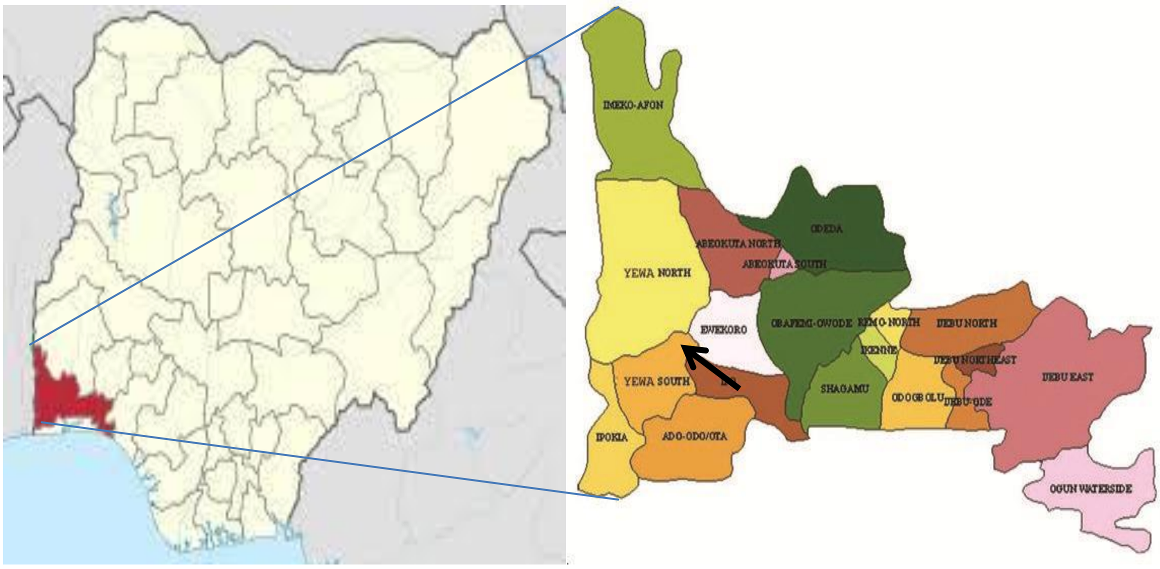

Fig. 2. Map of Nigeria insert with map of Ogun State showing Ado-Odo/Ota Local Government Area (Wikipedia.org)

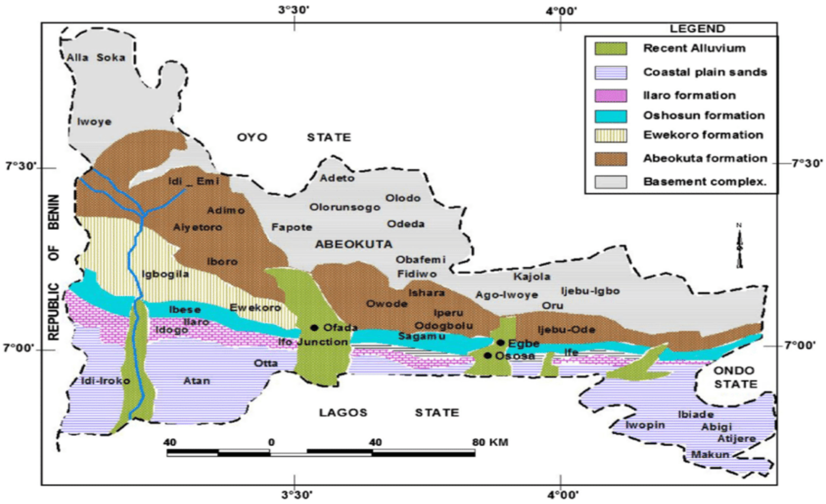

Fig. 3. Geological content map of Ogun State showing different formations

Fig. 4. Map of Study Area showing the four locations (P_1, P_2, P_3 and P_4) of Study in Ado-Odo/Ota Metropolitan

3. MATERIALS AND METHODS

3.1 Materials

The following materials were used for the study, this include Electrical Resistivity meter, Garmin-Global Positioning System (GPS), Compass, Processing softwares (mainly Res2Dinv and WinRes).

3.2 Methods

The Wenner array was used to determine the presence of lateral variation of the leachates. The Wenner array configuration used (Fig. 5) was designed to monitor the presence of leachate/contaminants in the subsurface using the lateral variation of the level of the leachate/contaminants through monitoring of the electrical conductivity anomaly.

Where the resistivity values is obtained using

$$\rho_a = 2\pi a \frac{V}{I}$$

For the 2-dimensional imaging, the Wenner array method was conducted along four profiles, namely Profile 1, 2, 3 and 4. The technique used involved injecting direct current into the subsurface layers (ground) through a pair of current electrodes (AB), while the potential difference was measured via another set of potential electrode pair (MN) as shown in Fig. 5. A constant electrode spacing of na, (where n = 1,2,3,4 and 5 respectively) were used for each of the current and potential electrodes spacing sequentially for each of the profile.

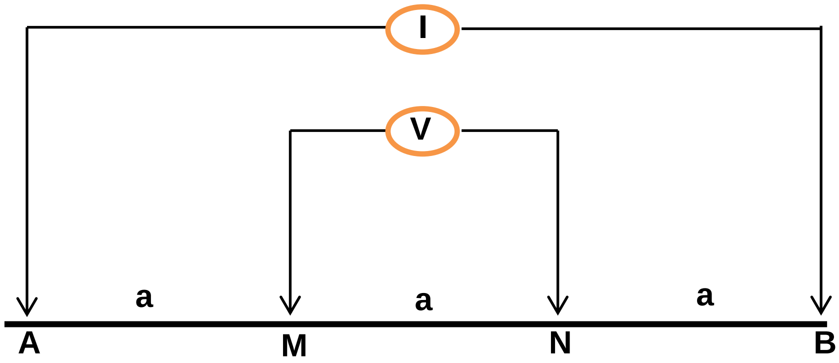

Fig. 5. Wenner array configuration

For the first electrode spacing of 1a, the spacing distance of both the current and potential electrodes are made equal, while subsequent measurement was done by shifting the electrodes at equal distance for successive measurement readings along a total spread of 100 m. This procedure was repeated for each of the electrode spacing of 2a, 3a, 4a, and 5a, respectively and separately. The electrode spacing 'a' used for the field work is equal to 3m.

After acquiring the data, the data were quality-checked an inverse modelling technique was used to obtain and interpret the variation in the resistivity values of the leachate plume, while the data obtained from the Wenner configuration measurements was uploaded into the available software (Res2Dinv) to process and obtained the 2D tomographic section. After the standard processing and interpretation procedure performed, the final result obtained are displayed.

4. RESULTS AND DISCUSSION

4.1 Results

The results obtained from the inversion of the Wenner-array data obtained along the individual profiles 1, 2, 3 and 4 are shown in Figs. 6, 7, 8, and 9respectively. Profile 1 was acquired in a SW- SS trend across the dumpsite (Study Area), while Profile 2 is located at the southeastern end of the study area, measuring 100 m in length. Profile 3 was acquired in a NE–SW trend direction of Profile 2; the Profile is located at the southwestern end of the study area, also measuring 100 m in length. While Profile 4 is located at the eastern end, 1 km away from the dumpsite, with an 100m measurement in length. The inverted resistivity models obtained for the respective profiles are shown as follows.

4.2 Discussion

Profile 1: 2D section from the resistivity inversion obtained after 30 iterations with a 5.4% Root Mean Square (RMS) error is shown as a pseudo section in Fig. 6. The apparent resistivity, measured in ohm-meter (Ωm), is plotted against the pseudo-depth (in metres). A zone with low resistivity value of >8.7 Ωm, shown in dark blue colour, is observed near the surface at the South Western part of the section, with depth ranges from 0.375m to 7.20 m. This value indicates that the leachate plume had penetrated the subsurface layer and polluted the groundwater presence in this zone, when calibrated against the surrounding areas. While at the Northern and Western part of the section, A high resistivity zone of >8453 Ωm is observed near the surface with depth ranging from 0.375m to 4.21 m. This high resistive zone near the surface represents the uninvaded zone by the leachate. While the zone, coded in red color, with a high resistivity value of >8453 Ωm, is essentially interpreted as basically composed of fine sands. From a depth of 0.375m–7.20 m, the zone with resistivity values ranging >23.4 Ωm, and coded in light blue colour is interpreted as being underlain by silty sand.

Profile 2: The 2D pseudo-section from the inversion obtained after 30 iterations, with a 7.9% RMS error is shown in Fig 7. A zone with low resistivity value of >14.6 Ωm, coded as dark blue color, identified close to the surface at depth ranging from 0.375m to 3.1 m, indicates zone already invaded by leachate plume, showing that the topsoil has been contaminated. While the zone with high resistivity value of >2176 Ωm, and

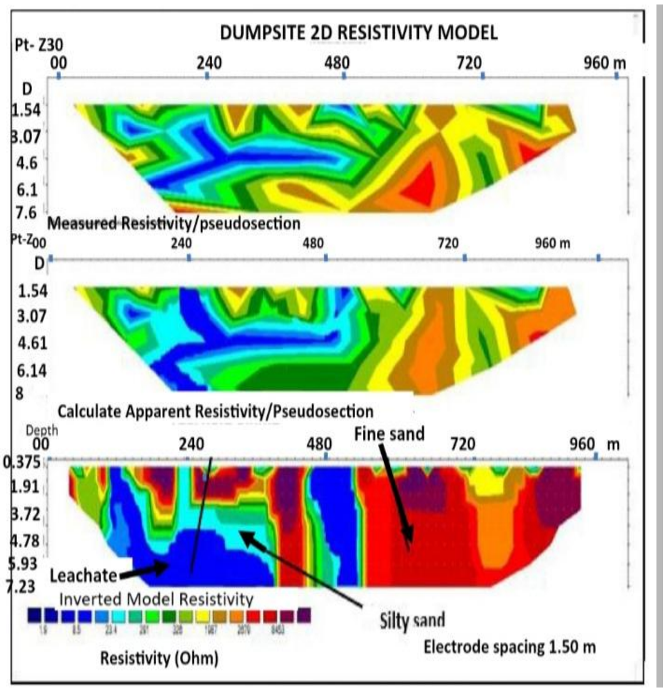

Fig. 6. The 2D inversion of the Wenner-array data obtained along profile 1, showing the variation in resistivity of the subsurface layers. The section with red colors shows subsurface area with high resistivity zone, while blue colors represent area with least resistivity zone

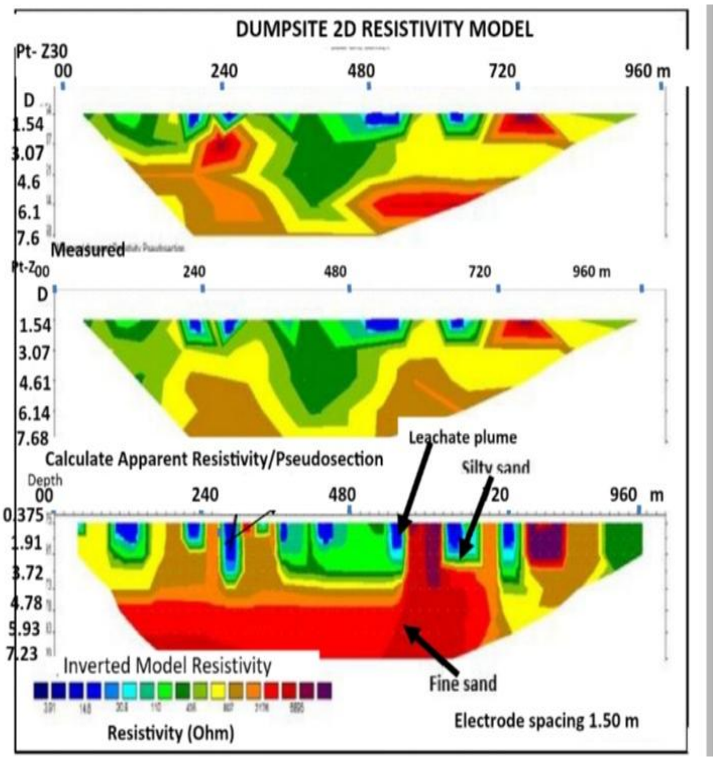

Fig. 7. The 2D inversion of the Wenner-array data obtained along profile 2, showing the variation in resistivity of the subsurface layers. The section with red colors shows subsurface area with high resistivity zone, while blue colors represent area with least resistivity zone

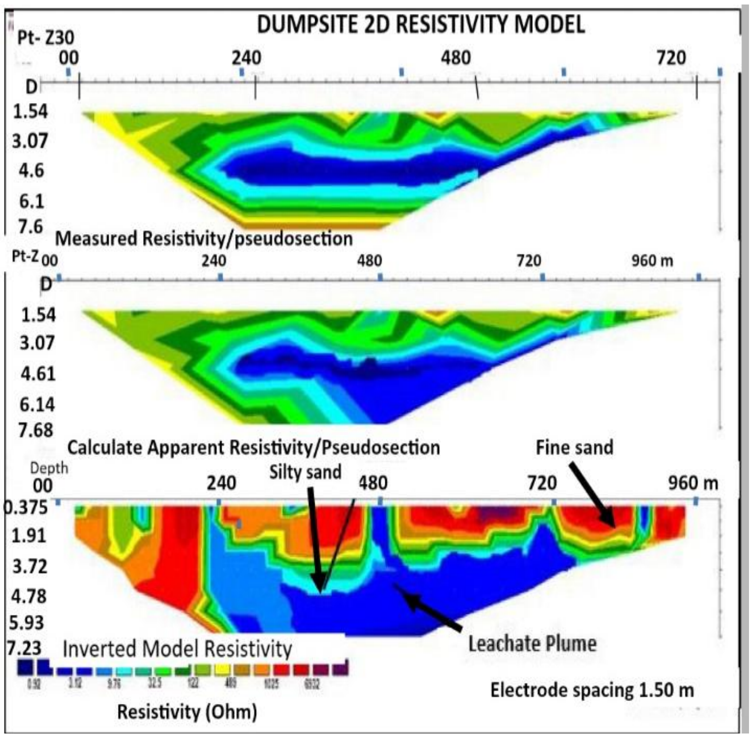

Fig. 8. The 2D inversion of the Wenner-array data obtained along profile 3, showing the variation in resistivity of the subsurface layers. The section with red colors shows subsurface area with high resistivity zone, while blue colors represent area with least resistivity zone

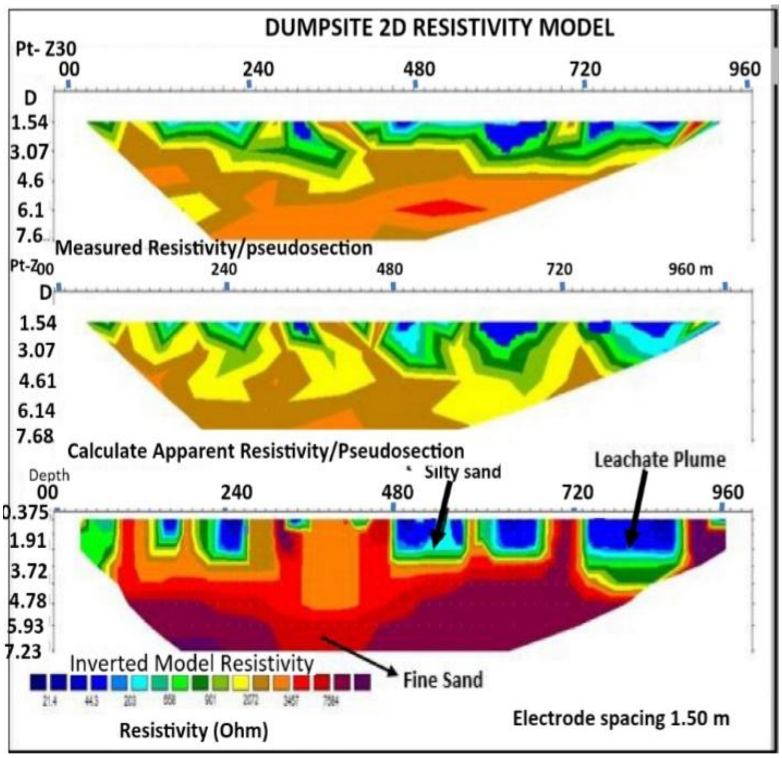

Fig. 9. The 2D inversion of the Wenner-array data obtained along profile 4, showing the variation in resistivity of the subsurface layers. The section with red colors shows subsurface area with high resistivity zone, while blue colors represent area with least resistivity zone

coded red colour, near the top surface with depth ranging from 0.375m to 3.7 m to the West and East of the section, shows that the zone is polluted as a result of the presence of high resistive chemical compounds. The migration near the surface is an indication that it is less dense, thus the lithology can be inferred as fine sands. The zone with low resistivity value of >20.8 Ωm, and coded as light blue color, identified close to the surface, indicates the presence of silty sand, which probably hindered the further penetration of the leachate into the subsurface.

Profile 3: The pseudo section shows the resistivity inversion results obtained after 30 iterations, with 8.5% RMS error as shown in Fig. 8. The zone with low resistivity value of >3.12 Ωm and coded in dark blue color, close to the surface with depth ranging from 0.375m to 7.2 m, indicates that the leachate plume has penetrated beyond the topsoil, directly into the subsurface layers, thus polluting the underground formations. While the zone with high resistivity value of >1025 Ωm, and coded red color, which occurs near the surface with depth ranging from 0.375m to 5.3 m at the eastern part of the section, shows that the zone is (being interpreted as being high resistive zone near the surface), is less dense and, thus interpreted as fine sands. At a depth ranges from 0.375m to 5.1 m, a resistivity zone with resistivity value of about 9.76 Ωm, and color-coded light blue, indicates zone of silty sand, thus showing a highly contaminated environment as a result of the leachate plume infiltration.

Profile 4: The inverted pseudo section (Fig. 9) shows the resistivity inversion results after 30 iterations with 29.6% RMS error. From the pseudo section result, the zone with low resistivity value of >44.3 Ωm, coded blue in colour, isolated close to the surface with depth ranging from 0.375m to 3.3m, indicates area of the topsoil that the leachate plume has contaminated. While the zone with high resistivity value of > 7584 Ωm, coded purple colour, existing near the surface and also occupied the bottom of the section with depth ranging from 0.375m to 7.20 m from South to Eastern part of the section, indicates the presence of a denser material with the leachate displacing them as they penetrated downwards in the dominantly clayey sandstone layers. The light blue coloured zone seen around a depth of 1.91m along the top layers indicates silty sand; which generally impedes the migration of the leachate plume, thus the subsurface groundwater area is not yet affected by the presence of the leachate plume in this area. The red-coloured zone found at the bottom indicates an unpolluted zone of fine sand lithology.

4. CONCLUSION

The study has shown effective use of electrical surveying methods in investigating the presence and effects of contaminants on ground water in a basement environment. The method deployed is an effective, simple and low cost technique of monitoring the presence of lateral contaminants in underground water. This resistivity method of investigating or monitoring the presence of leachate plume in groundwater shows that it is a valuable and effective complement to groundwater sampling using tracer tests. The result obtained can also be used to estimate flow pattern and flow velocity of the aquifers, as well as the subsurface geological conditions of the environs.

CONSENT

"All authors declare that 'written informed consent was obtained for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office/ Chief Editor/Editorial Board members of this journal."

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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