Original Research Article

GROUND WATER CONTAMINANTS INVESTIGATION IN A BASEMENT AREA OF NIGERIA USING 2D ELECTRICAL SURVEYING METHODS

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ABSTRACT

The most common method of monitoring and mapping ground water contaminants is to extract and analyze a number of ground water samples from wells in the investigation area. However, there are a number of limitations with this type of point-wise investigation, as it is hard to acquire an adequate picture of a heterogeneous and anisotropic subsurface using a few points. To overcome the limitations of point investigations and to improve ground monitoring in a cost-effective way, direct current resistivity measurements, which give a characterization of the electrical properties of a subsurface volume is used. This paper investigates the usability of the resistivity method as a better technique in monitoring groundwater contaminants in glaciated terrains and under different seasons, in long-term monitoring programs. The work comprises of field investigations at several sanitary landfills around basement area of Ado-Odo town, in Ogun state, Nigeria, using Wenner array configuration (tomography). It can be concluded that the use of resistivity survey measurements gives better and appropriate information suitable for mapping and monitoring of conductive groundwater contaminants.

Keywords: Contaminants, Groundwater, Monitoring, Wenner, Configuration, Tomography

1. INTRODUCTION

Hydrogeological and geophysical investigations are often conducted to assess the groundwater potential of any given area but geophysical investigations gives a more rapid and cost-effective means of deriving distributed information on the subsurface hydrogeology (Kearey and Brooks, 1991). The use of geophysical methods for both groundwater resource mapping and water quality evaluation has increased dramatically over the last decade due to rapid advances in electronic technology and the development of numerical modeling solutions (Olayinka (1991), Ndlovu *et al*. (2010), and Metwaly *et al*. (2009)). Although various hydro-geophysical techniques are available, electrical resistivity still remains the most popular method because of its low cost, simple operation, and efficiency in areas with high contrasting resistivity, such as weathered overburden and the bedrock (Telford and Sheriff, 1990). Electrical methods are particularly suitable for groundwater studies because hydrogeologic properties, such as porosity and permeability, can be easily correlated to electrical resistivity values of the subsurface. Geo-electrical techniques are essentially concerned with the measurement of electrical resistivity of subsurface materials, which preferentially provides information on the different geological layers, structures and the associated occurrence of groundwater (Van Overmeeren (1989), Dahlin *et al*. (1999), Nowroozi *et al*. (1999), and Meju (2005)). Resistivity is related to various geological parameters such as the mineral and fluid content, porosity, and degree of water saturation.

Some limitations are often encountered when investigating subsurface contamination using tracer tests techniques so as to obtain a clearer picture of the groundwater flow patterns and velocities. The location of observation wells between the infiltration points and the discharge point is critical, as tracer pulses can be lost in between the positions of observatory wells, due to heterogeneous flow pattern. To overcome this limitation of point investigations, and thus improve the monitoring technique using tracer tests in a cost-effective way, a Direct current (DC) resistivity method can be deployed, which are very valuable in characterization of the physical properties of laterally and vertically subsurface covering large volume of the ground. The DC resistivity method is one of several geophysical methods, which have been used for a long time for investigating leaching from landfills and for studying other environmental problems. The use of resistivity methods in contamination investigations is based on the fact that the resistivity of the saturated soil depends on the groundwater resistivity and the properties of the porous matrix. This creates the potential to detect leachate, as part of the change in resistivity of the subsurface due to changes in the concentration of dissolved ions (contamination) in the groundwater. The resistivity method is quite suitable for relative measurement, and by that for monitoring for instance leachate flow in the ground (Benson et al., 1988).

For monitoring purposes, high-density systems should be applied in areas with a complex hydrogeology and a very fluctuating groundwater table, as the system gives a vertical cross-section of the area in question. Low-density systems are usually adequate in hydrogeological environments with few layers and a shallow and stable ground water table, or when less detailed information is needed (both in time and space). For tracer tests, the use of CVES-systems (Continuous Vertical Electrical Sounding) is recommended, both due to the density of measurements achieved and to the capability to measure automatically. Before using resistivity measurements within tracer tests, estimations of the required amount of tracer based on the depth and size of the aquifer, together with estimated groundwater flow, are necessary. A high concentration will give dete9ctable resistivity changes even in deep aquifers, but too high a concentration may cause unwanted differential flows.

2. THE STUDY AREA

The survey was conducted in Ado-Odo/Ota town, A borders town Ogun State and metropolitan Lagos state. The local government area is the second largest in Ogun state and it is headquartered at Ota town with coordinates 6^{O}41’00’’N 3^{O}41’00’’E, it has a total land area of about 878 sq-km. Ota possesses the same geologic characteristics with many other parts of the state having the basement complex rock and the pre-Cambrian age which are made up of the older and younger granites in the northern part of the state, and the younger and older sedimentary rock in the tertiary and secondary ages in the southern parts (Iloeje, 1981). The region possesses climate of tropical rain-forest with two main climatic conditions; the rainy season which last for between seven and eight months between April and October with an interruption in August, and the dry season running through November till February. The rainfall experienced is usually more than 90 days. The climate is humid because of all the rainfall which amount to about 250cm^{3} in a year (Ufoegbune *et al*., 2016)

Movement of groundwater follows the surface topography with seasonal variations in water levels characterized by rising water levels during the wet months, from November to March, and declining water levels during the dry months, from May to September. The red circles indicate the 4 locations where field investigations were carried out in the study area.

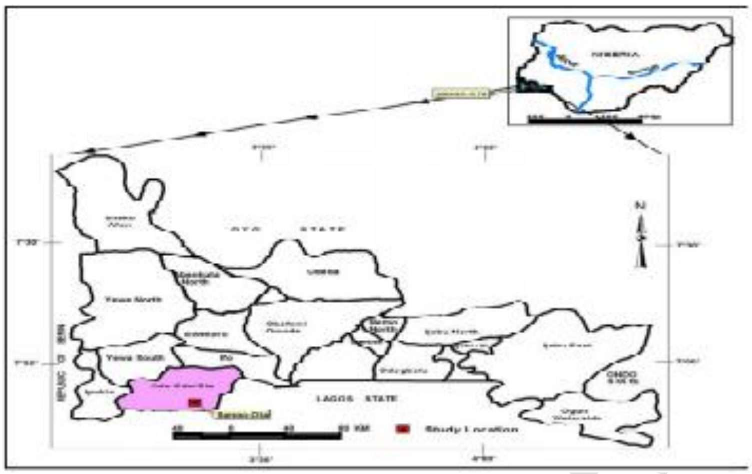

Figure 1: Map of Ogun State showing the Study Area of Ado-Odo/Ota (Ufoegbune et al., 2016)

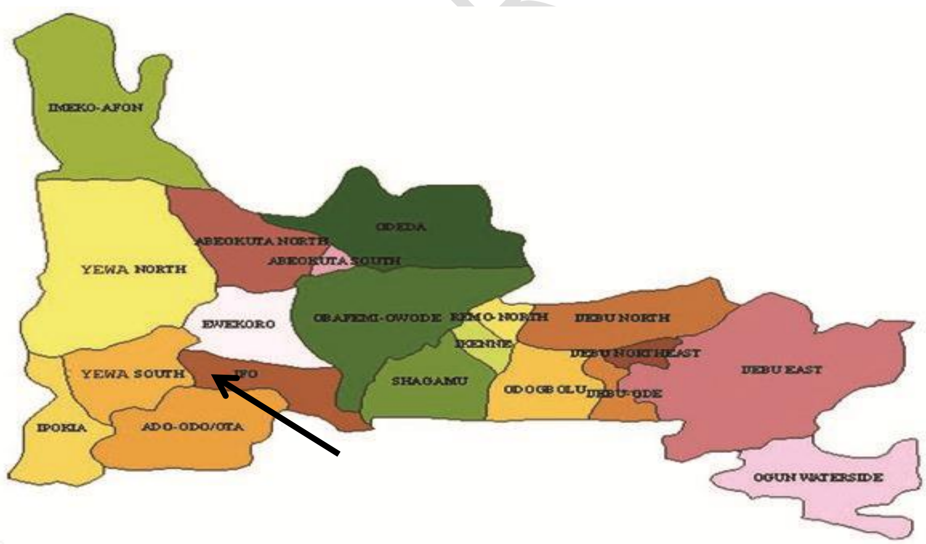

Figure 2: Map of Ogun State showing Ado-Odo/Ota Local Government Area.

Figure 3: Map of Study Area showing the four locations of Study in Ado-Odo/Ota Metropolitan

3. MATERIAL AND METHODS

3.1. MATERIALS

The materials used for the study include field equipment such as Compass, Garmin Global Positioning System (GPS), Electrical Resistivity Meter, Processing software including Res2Dinv and WinRes.

3.2. METHODS

The Wenner array was chosen to determine the lateral variation of the leachates. The Wenner array was designed to monitor the lateral variation of the leachate/contaminants through monitoring of the electrical conductivity anomaly.

For the 2-dimensional imaging, the Wenner array method was conducted along four profiles 1, 2, 3 and 4. In the field, the technique was achieved by sending a direct current into the ground through a pair of current electrodes, while the voltage drop was measured via another set of potential electrode pair. For each profile, a constant electrode spacing of 1a, 2a, 3a, 4a, and 5a each for both current and potential electrode were used sequentially.

For an electrode spacing of 1a, the spacing distance of current and potential electrodes are equal and are shifted at successive readings along the spread of 100 m. The same procedure was repeated for each of the electrode spacing of 2a, 3a, 4a, and 5a, separately. Where 'a' is the electrode spacing, and equal to 3 m.

After acquiring the data over the survey profiles, the variation in the resistivity values is employed in the interpretation of the leachate plume through an inverse modelling. The data obtained from the Wenner configuration were subjected to 2D tomographic interpretation using the Res2Dinv software. The data were quality-checked and input into the software and following standard processing and interpretation procedure the final result was displayed.

4. RESULTS AND DISCUSSION

4.1. RESULTS

The results obtained from the inversion of the Wenner-array data along profiles 1, 2, 3 and 4 respectively are shown in Figures 4, 5, 6, and 7. Profile 1 was acquired in a NE–SW trend across the dumpsite, while Profile 2 is located at the southeastern end of the study area. It is measuring 100 m in length, and runs in the North-Western direction. 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, measuring 100 m in length. It runs in the southeast direction. And Profile 4 is located at the eastern end, 1 km away from the dumpsite, measuring 100 m in length, and runs in the North–South direction. The inverted resistivity models obtained are shown as follows.

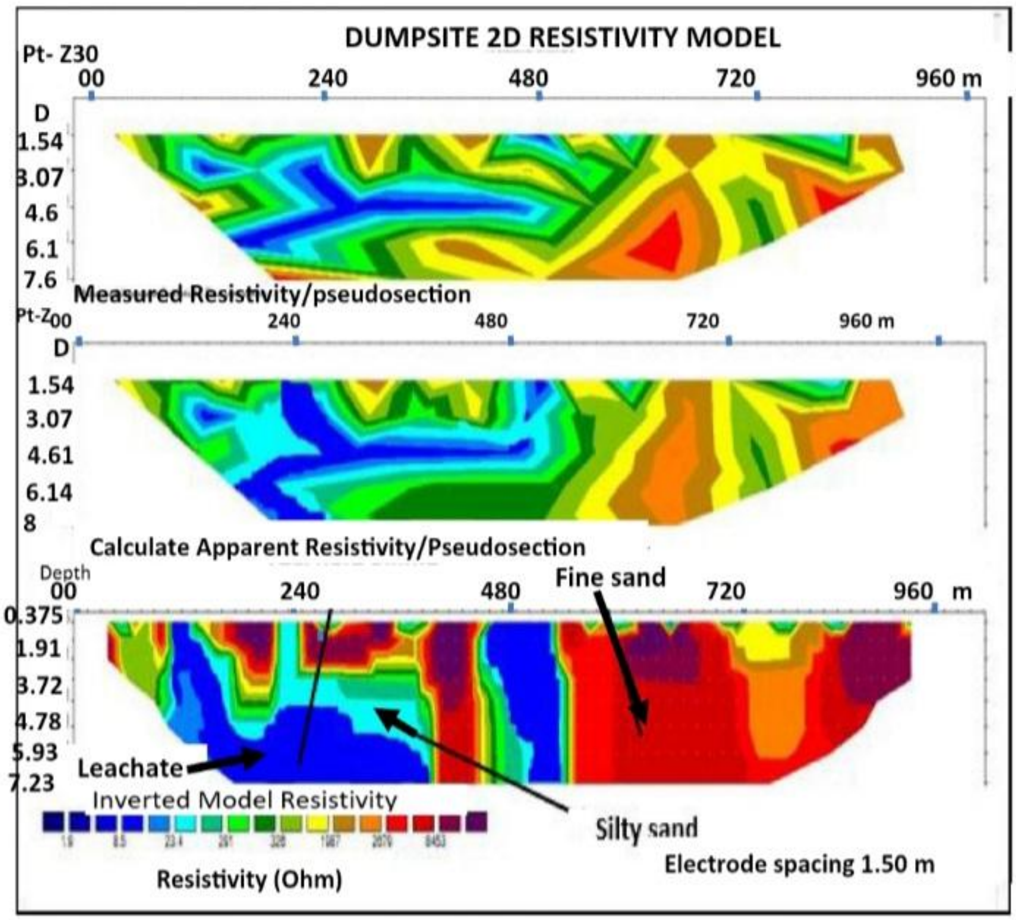

Figure 4: 2D inversion of the Wenner-array data along profile 1 showing variation in resistivity in the subsurface, with blue color representing least resistivity and red color showing highest resistivity zone.

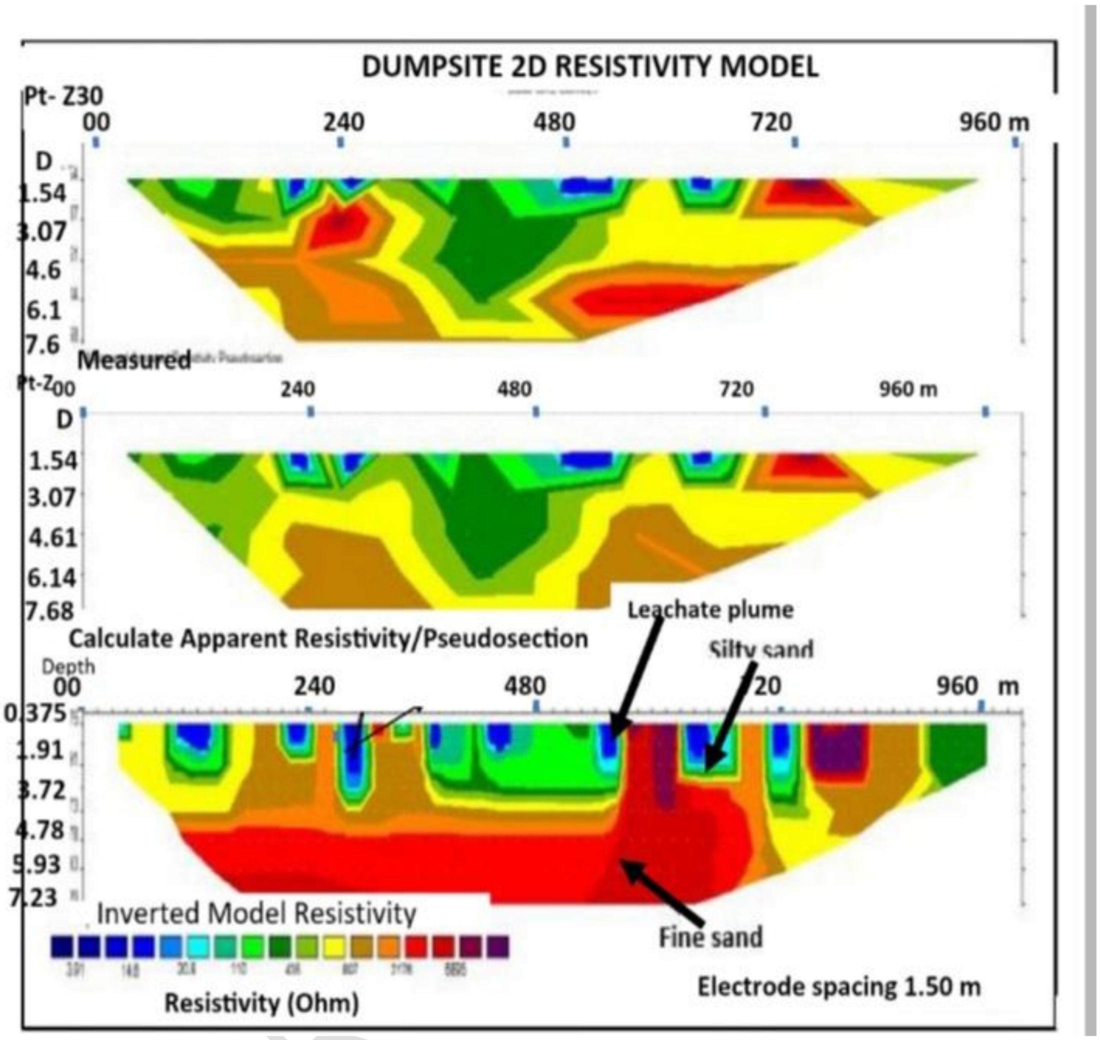

Figure 5: 2D inversion of the Wenner-array data along profile 2 showing variation in resistivity in the subsurface, with blue color representing least resistivity and red color showing highest resistivity zone.

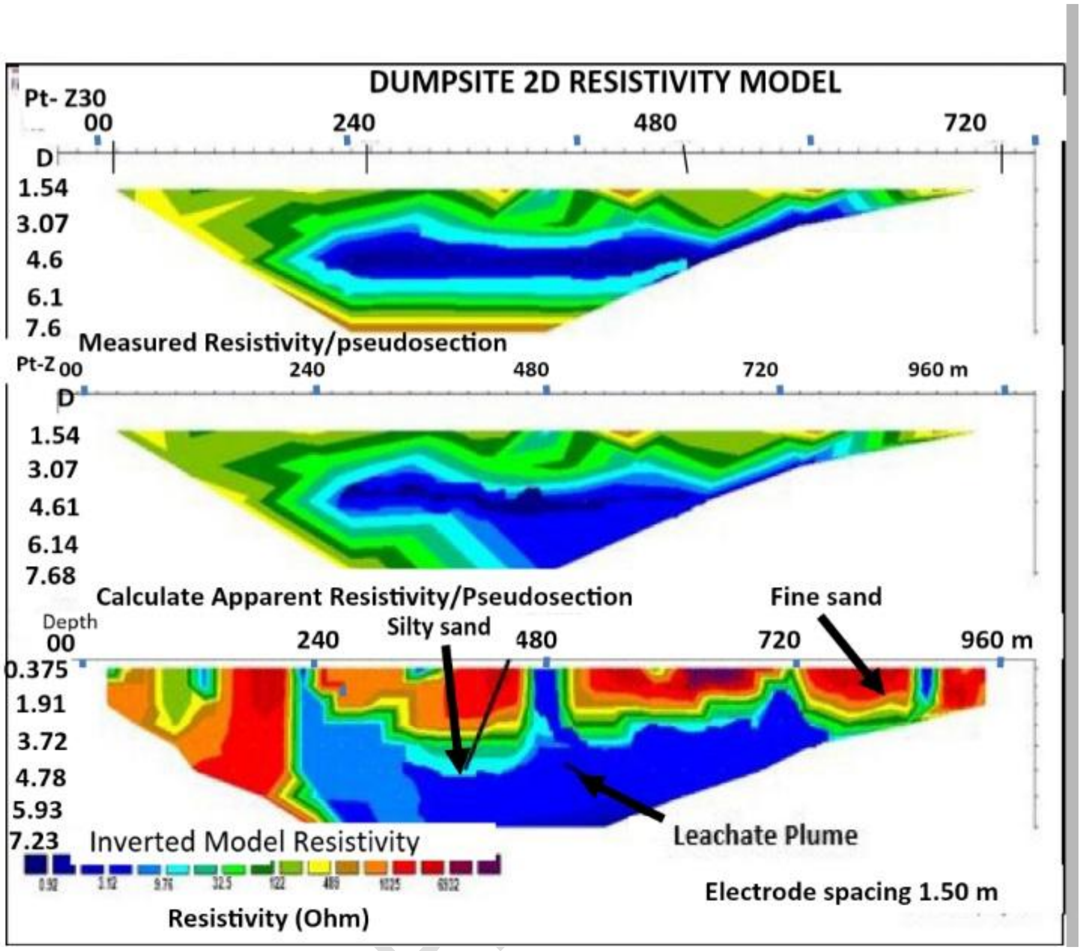

Figure 6: 2D inversion of the Wenner-array data along Profile 3 showing variation in resistivity in the subsurface, with blue color representing least resistivity and red color showing highest resistivity zone.

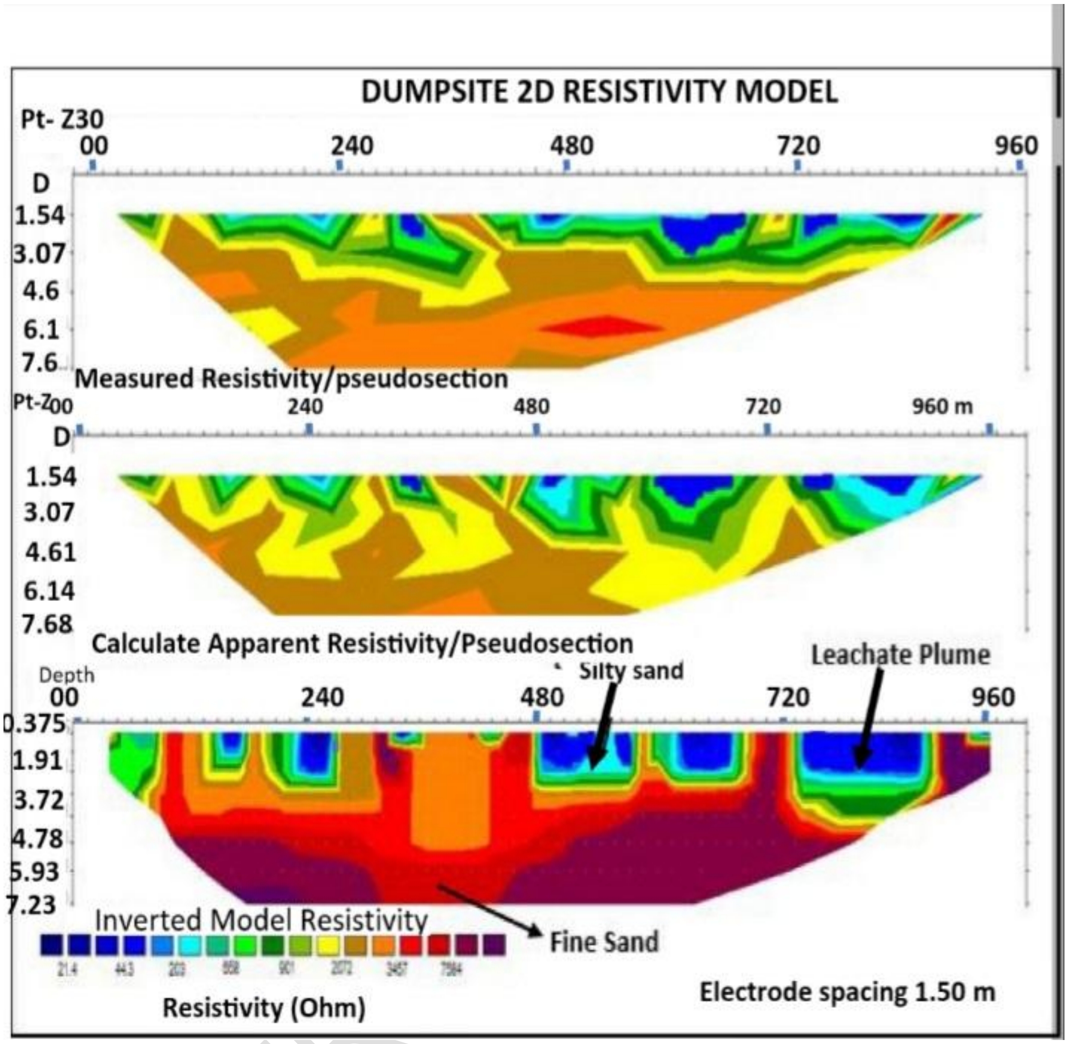

Figure 7: 2D inversion of the Wenner-array data along profile 4 showing variation in resistivity in the subsurface, with blue color representing least resistivity and red color showing highest resistivity zone.

4.2. DISCUSSION

Profile 1: A resistivity inversion was obtained after 30 iterations with a 5.3% RMS error as shown as a pseudo section in Figure 4. The apparent resistivity, measured in ohm-meter, (Ωm) is plotted against the pseudo-depth (in m). A low resistivity zone 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 between 0.375 to 7.20 m. This value indicates that the leachate plume had polluted the groundwater 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 occurs near the surface with depth ranging from 0.375 to 4.21 m. This high resistive zone near the surface represents the uninvaded zone by the leachate. This zone, coded in red color, with a high resistivity value of >8453 Ωm, is essentially composed of fine sands. At depth of 0.375m–7.20 m, a resistivity zone ranging in value of >23.4 Ωm is here coded in light blue colour. This zone is interpreted as being underlain by silty sand.

Profile 2: The 2D pseudo-section from the inversion was obtained after an iteration of 30, with a 7.9% RMS error (Figure 5). A low resistivity zone of >14.6 Ωm was coded as dark blue color. This zone is identified close to the surface at depth ranging from 0.375m to 3.1 m and indicates the zone of leachate plume invasion. In this case, the topsoil has been contaminated. A high resistivity zone with a range of >2176 Ωm, and coded red colour, this existed near the surface with depth ranging from 0.375m to 3.7 m to the West and East of the section. This zone was interpreted as being as a result of the presence of high resistive chemical compounds. The migration near the surface is an indication that it is less dense. The lithology is inferred as fine sands. A low resistivity zone of value of >20.8 Ωm, and coded as light blue color, is identified close to the surface. This indicates the presence of silty sand that probably hindered easy further penetration of the leachate.

Profile 3: The pseudo section shows the resistivity inversion results following 30 iterations, with 8.5% RMS error (Figure 6). A low resistivity zone of >3.12 Ωm and coded in dark blue color. It existed close to the surface with depth ranging from 0.375m to 7.2 m. This indicates that the leachate plume has penetrated beyond the topsoil into the subsurface (underground). While a high resistivity zone of >1025 Ωm, and coded red color, occurs near the surface with depth ranging from 0.375m to 5.3 m at the eastern part of the section. This zone is interpreted as being high resistive near the surface, which is an indication that it is less dense and, thus interpreted as fine sands. Also, at depth ranges from 0.375m to 5.1 m, a resistivity zone with resistivity value of 9.76 Ωm, and color-coded light blue. This zone indicates silty sand, which promotes the leachate plume infiltration thereby enhancing its contamination of the environment.

Profile 4: The inverted pseudo section (Figure 7) shows the resistivity inversion results after iterations of 30 with 29.6% RMS error. From the pseudo section result, a low resistivity zone of >44.3 Ωm, coded blue in colour, was isolated close to the surface with depth from 0.375m to 3.3 m. This area indicates that the leachate plume has contaminated the topsoil. A high resistivity zone of > 7584 Ωm, coded purple colour, existed near the surface. It occupied the bottom of the section with depth ranging from 0.375m to 7.20 m from South to Eastern part of the section. This zone is thus of high resistivity. It represents the presence of a denser material as the leachate displaces them as they move downwards in the dominantly clayey sandstone. The light blue coloured zone indicates silty sand, which impedes the migration of the leachate plume. The migration of the leachate plume has not affected the groundwater in this area. The red-coloured zone found at the bottom indicates 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 is an easy and low cost way of establishing a lateral monitoring of contaminants in underground water. This method also shows that it is a valuable complement to groundwater sampling using tracer tests. The result obtained can be used to estimate flow velocity and flow pattern of the aquifers and subsurface geological conditions.

CONSENT (WHERE EVER APPLICABLE)

"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."

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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