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Research Paper

Investigation of Groundwater Contamination Using Electrical Resistivity Tomography (ERT) Survey of Dumpsites within Maiduguri and Environs, Borno State, Northeastern Nigeria

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Abstract
Groundwater has been the main source of water for domestic and other uses in the Study Area. This use is under threat as a result of anthropogenic activities such as poor waste disposal practice. Contamination of groundwater under and near waste disposal site happens as a result of infiltration of contaminants through the soil. Pollutants are aqueous liquid called leachate. Leachates are formed when rain falls on dump, sinks into the waste and picks up contaminants as it seeps downwards. Some wastes dumped at the dumpsite over the years are expected to have biodegraded and generated leachate which could have become a point source of pollutant into the soil and groundwater. 2D resistivity imaging survey (tomography survey) was used in the 8 dumpsites to map out the leachate plumes. Three zones of varying resistivity contrast were delineated, the zone of low resistivity interpreted as leachate plumes and decaying waste materials, the zone of moderate resistivity interpreted as sand and clay and high resistivity zone representing dry sand.
Keywords: *Electrical Resistivity Tomography (ERT), Leachate, Waste Disposal, Dumpsite*

I. Introduction

Access to clean water is a basic human right and an essential prerequisite for the economic and sustainable development of any country. Groundwater is generally a key resource for the supply of clean water in arid countries as it is naturally protected against surface-derived pollutions by the sedimentary rock cover. Chemical contamination of groundwater is one of the most serious pollution problems, particularly in arid areas where typically there is a deficiency in water resources. Chemical pollutions and waste solutions in groundwater are not normally identified until some illness has affected the local population or there is a regular sampling and analysis program for the water (Acworth, 2006). The field of environmental geophysics is expanding rapidly with much research now dedicated to the investigation of an increasingly wider variety of problems. In groundwater studies much of the work involves mapping of contaminant plumes, landfills and cleanup sites and here the application of electrical tomography techniques is becoming increasingly important. Over the past three years, electrical tomography surveys have been carried out widely in Germany and the UK and have produced remarkable and in some instances quite unexpected results (Barker,1996). Contamination of groundwater under and near waste disposal site happens as a result of aqueous liquid pollutants called leachate moving through the soil. Leachates are formed when rain falls on dump, sinks into the waste and picks up contaminants as it seeps downwards. Some wastes dumped at the dumpsite over the years are expected to have biodegraded and generated leachate which could have become a point source of pollutant into the soil and groundwater. It is therefore important that the aquifer vulnerability capacity of the layers underlying the dumpsite on groundwater in the area is investigated (Loke, 2004). Leaching of organic and inorganic contamination from dump site is a serious environmental problem as surface water and aquifers are affected.

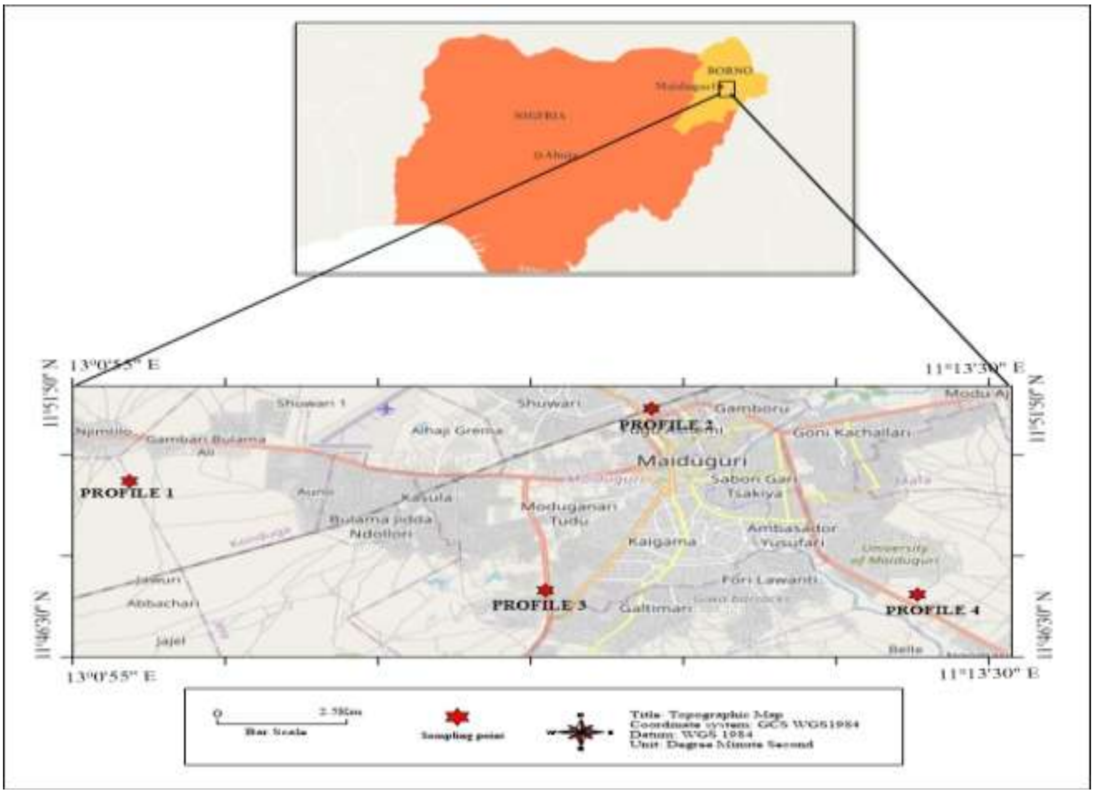


Figure 1: Map ofBorno State Showing the Study Area

GEOLOGY, HYDROGEOLOGY AND STRATIGRAPHY OF THE STUDY AREA

The study area falls within Maiduguri, Northeastern Nigeria within the Nigerian sector of the Chad Basin (Bornu Basin) (Fig. 1). The Plio-pleistocene Chad Formation and the Quaternary Keri-Keri Formation comprised of sandstone are the main sources of groundwater in the Study Area. The main aquifer that is tapped presently is the Chad Formationwhile the second water bearing Keri-Keri Formation is not tapped. Barber and Jones (1960) demarcated the Chad Formationaquifers into three aquifer horizons, which is designated Upper, Middle and Lower aquifers.The Upper Aquifer is composed mainly of fine sand, clay and silts partly interstratified with fluvial sands. The Formation thickens towards Maiduguri axis and thins out towards Potiskum where the Kerri-Kerri Formation is exposed. Groundwater occurs in the Upper Aquifer of the Chad Formation under water table conditions, in perched aquifers, confined and semi-confined conditions at depths of less than 70 meters to 140 meters in the study area. Where it is confined, the pressure rise is not sufficient to produce artesian flow but rises above the aquifer. Recharge to the Upper area is by vertical infiltration of precipitation (Adegoke, 1985), while in the semi-confined horizons is likely via leakage through the hydrogeological 'windows' (Schoeneich and Askira, 1990). Groundwater movement in the Upper zone aquifer varies from place to place depending on whether there is any hydraulic gradient and the configuration of the intervening clayey hydraulic barriers (Consulints, 1976).The Middle Aquifer is the most extensive and important water bearing zone in the entire basin. It is separated from the Upper Aquifer by a clay layer of about 170 m thickness. The aquifers within this zone consist of fine to coarse grained sand. This sand is poorly sorted and locally contains fine gravel as interconnected lenses, intercalated with clays and sandy clays. In addition, the clay beds in the middle zone commonly contain angular quartz grains, giving them a gritty texture. Groundwater occurs only under confined condition in the middle zone and throughout the 15,000 km^2 in the Chad Basin of Nigeria, the pressure is sufficient to cause artesian flow at the land surface. The piezometric surface contours of the Middle zone aquifer show a general NE direction of groundwater flow. It has salinity values from 156 to 2000 ppm (Oteze, 1988). Temperature of groundwater is between 390 and 450^{o}C.The Lower aquifer is about 90 meters thick extending from 420 meters to 650 meters and has very limited lateral extent. It is separated from the Middle aquifer by thick clay deposit. It consists of sand, sandy clay, clayey sand and clay and it is thought that these deposits are lenticular. The sand varies from fine to coarse and is usually poorly sorted. The water in the zone is under sufficient pressure to produce artesian flows up to five meters of positive artesian head. The water is of sodium bicarbonate or sodium-calcium bicarbonate type and has a temperature of 480 to 500^{o}C.Goniet al. 2000 showed that the groundwater level in shallow water table aquifer of the Chad Formation is rapidly declining at the rate of 1.1m/year. The Chad Formation dips gently east and northeast towards Lake Chad in conformity with the slope of the land surface (Goni, 2006). The stratigraphy (Table 1) of the Bornu basin has the Bima Sandstone at the bottom and oldest overlain by the Gongila Formation, the Fika Shale, the Keri-Keri and Chad Formations respectively.

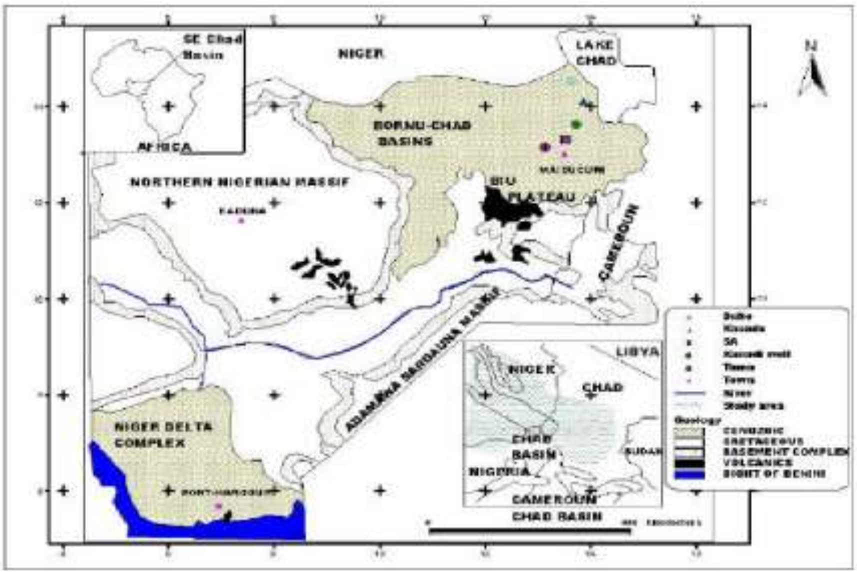


Figure 2: Geological Map of Nigeria showing the Bornu Basin (Modified after Genik, 1992)

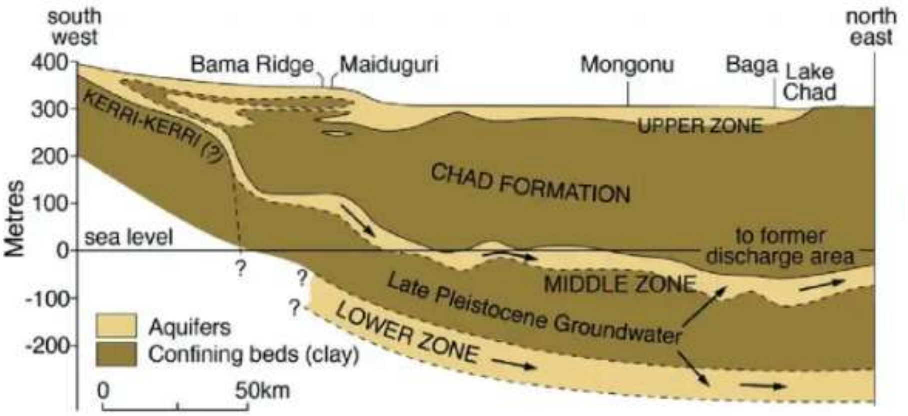
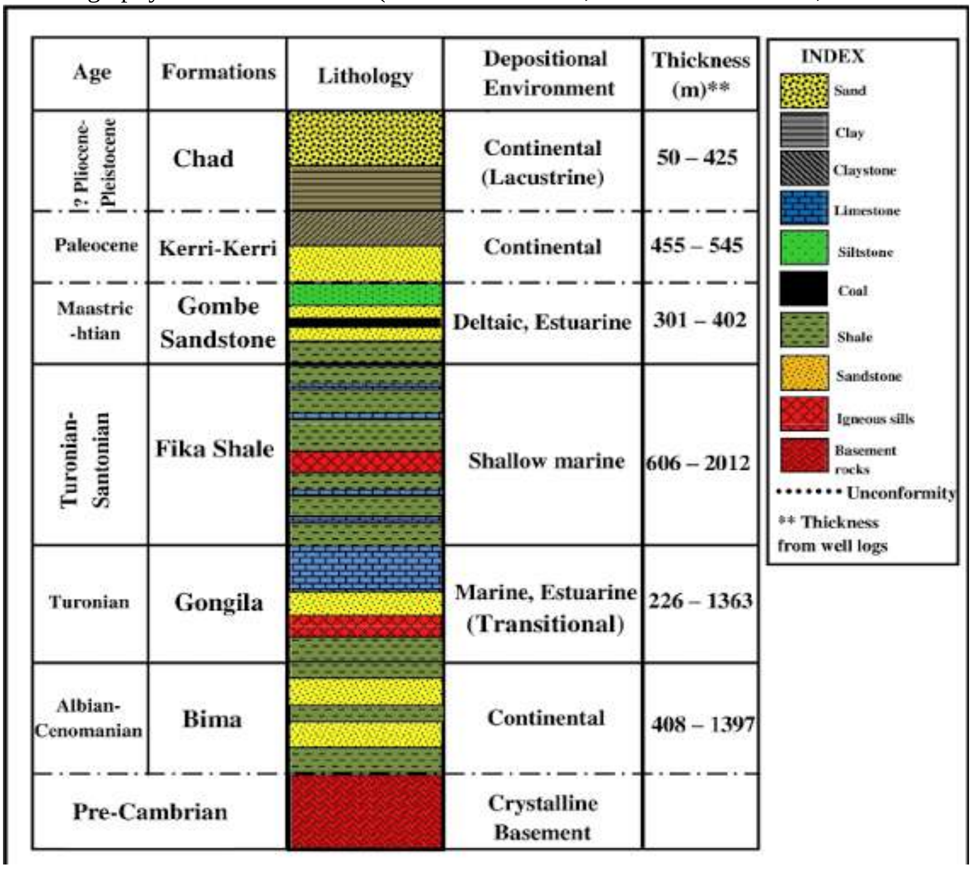


Figure 3: Hydrogeologic Cross-section of the Chad Formation, showing the (Upper, Middle and Lower) primary aquifers in the SW Chad Basin [Adapted from Goni (2006) and Miller (1968)].

The Kerri-Kerri Formation is a continental sequence of Paleocene age deposited under a wide range of environmental conditions, lacustrine and deltaic-type sediments being the most common. The Formation is predominantly arenaceous, consisting loosely cemented sands and grits, clayey sandstone, massive clays and silts; bands of ironstone and conglomerate occur locally. It was laid down on an uneven surface of Basement Complex and Cretaceous rocks and the maximum proved thickness is over 180 meters. The sediments are flat-lying and unfolded except in the north where they are gently down-warped beneath the Chad Formation. Groundwater mainly occurs under water table conditions in Keri-Keri Formation. Occasional clay lenses give rise to perched aquifers in some localities. The saturated portion of the Kerri-Kerri Formation contains large quantity of water, though much of this is not readily available owing to the low permeability of the sediments due to interstitial clay and silt in the sandstones.

Table 1: Stratigraphy of the Bornu Basin (after Okosun 1995; Avbovbo et al. 1986; Carter et al. 1963)



II. Materials And Method

In order to assess the risks and investigate the migration of leachate from the dump site, 2D electrical resistivity tomography was used at some dump sites. Electrical resistivity tomography (ERT) is a geophysical method used to image the subsurface using difference in measured electrical resistivity distribution. These differences in resistivity can be tied to the porosity, fluid content, and degree of water content in the subsurface (Loke, 2004). The data collected in these surveys is then inverted to give an image of the subsurface electrical characteristics. This method was adopted by Pradip et al. 2017;Abdullahi et al. 2011;Cyril, 2013; Ogubazghiet al. 2016;Ugwu and Nwankwoala, 2015;Ganiyu et al. 2015;Asuerimen, 2014;Okpoli,2013; Ehirim and Ebeniro, 2013 and Abdullahi, 2009.The geo-electrical resistivity field data was acquired using the Earth resistivity meter. A conventional setup of the earth resistivity meter basically consist of the following: a constant current source, commonly a battery pack connected to a commutated DC circuit to change polarity of the current source; an ammeter which measures the injecting current; a very sensitive voltmeter that measures the response signal; twenty (21) metal stake electrodes made of steel, which ensures low impedance characteristic; and four cable reels used in connecting the electrodes to the current source and voltmeter, hammer, crocodile clips, measuring tapes, note book and pen were conveyed together with the members of the field team to the site of this research project, for commencement of the geophysical investigation. The internal impedance of the ammeter, connected in series with the current source should be low so as to minimize its effect on the measuring circuit. Similarly, the voltmeter connected in parallel with the ammeter should have high input impedance so as to suppress any effect arising from the ammeter.The electrical resistivity of earth material varies from one another depending on the chemical makeup of the rock (fig. 4).

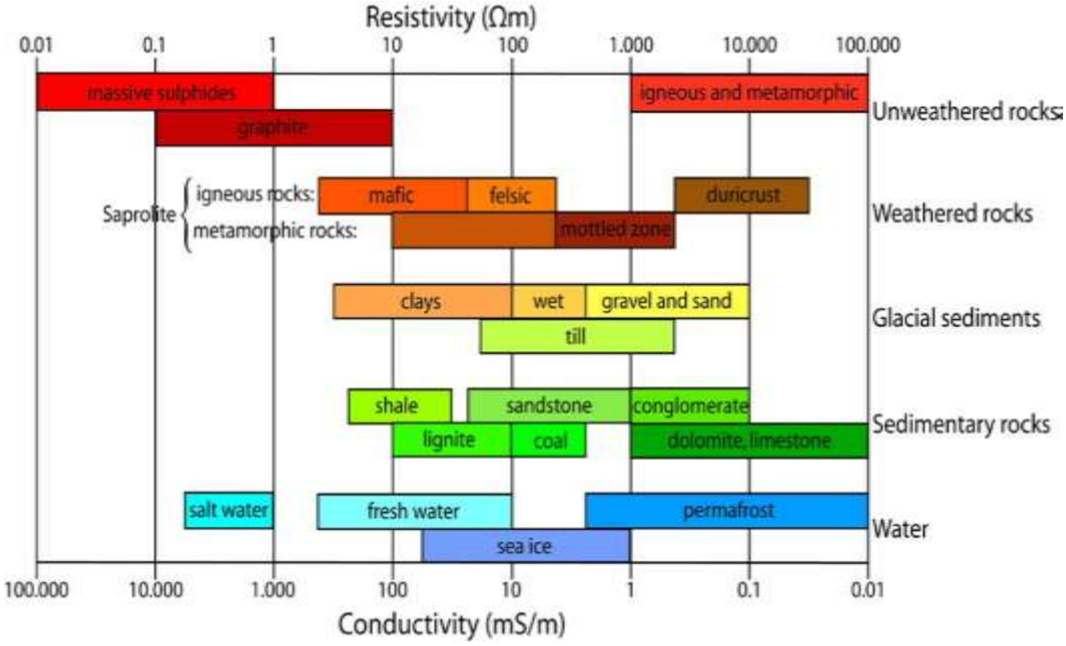


Figure4: Resistivity and conductivity of different earth minerals (Loke, 2001)

The method of measuring subsurface resistivity involves placing four electrodes in the ground in a line at equal spacing, applying a measured AC current to the outer two electrodes, and measuring the AC voltage between the inner two electrodes. A measured resistance is calculated by dividing the measured voltage by the measured current. This resistance is then multiplied by a geometric factor that includes the spacing between each electrode to determine the apparent resistivity. Electrode spacing of 0.75, 1.5, 3.0, 6.0, and 12.0 m are typically used for shallow depths (<10 m) of investigations. Greater electrode spacing of 1.5, 3.0, 6.0, 15.0, 30.0, 100.0, and 150.0 m are typically used for deeper investigations. The depth of investigation is typically less than the maximum electrode spacing. Water is introduced to the electrode holes as the electrodes are driven into the ground to improve electrical contact. To obtain a good 2D picture of the groundwater, the coverage of the measurements must be 2D as well. A possible sequence of measurements for the Wenner electrode array for a system with 21 electrodes is shown in (Fig. 5). The first step is to make all the possible measurements with the Wenner array with an electrode spacing of "1a". For the first measurement, electrodes number 1, 2, 3 and 4 are used. Note that electrode 1 is used as the first current electrode C1, electrode 2 as the first potential electrode P1, electrode 3 as the second potential electrode P2 and electrode 4 as the second current electrode C2. For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until electrodes 18, 19, 20 and 21 are used for the last measurement with "1a" spacing. For a system with 21 electrodes, note that there are 17 (20-3) possible measurements with "1a" spacing for the Wenner array. After completing the sequence of measurements with "1a" spacing, the next sequence of measurements with "2a" electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is "2a". For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 15, 17, 19 and 21 are used for the last measurement with spacing "2a". The same process is repeated for measurements with "3a", "4a", "5a" and "6a" spacing. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke 1998). Note that as the electrode spacing increases, the number of measurements decreases. The number of measurements that can be obtained for each electrode spacing, for a given number of electrodes along the survey line, depends on the type of array used.

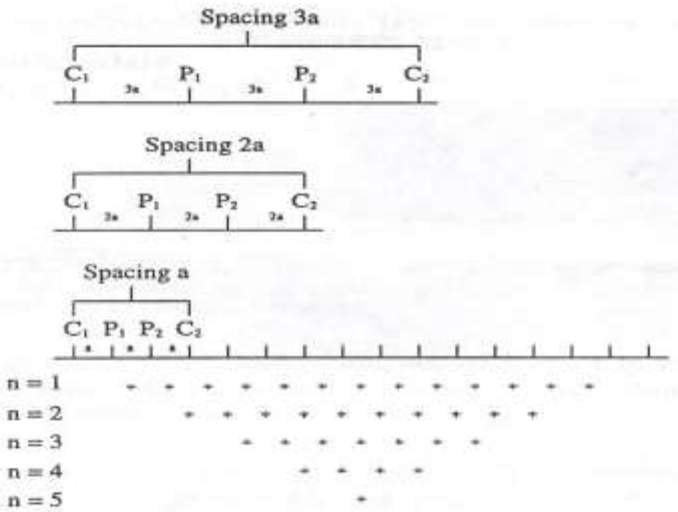


Figure 5:Principle for building up of a pseudo-section (Loke, 2001)

Interpreting the 2D resistivity data consists of two steps: a physical interpretation of the measured data, resulting in a physical model, and a geological interpretation of the resulting physical parameters. The large-scale data were interpreted with the state-of-the-art interpretation technique, called the 2D smoothed damped least squares inversion algorithm (Loke and Barker, 1996). The results obtained based on 2D inversion of field data and information, were interpreted to determine lithology of the area and the contaminated zone. The 2D model used by the programme divides the subsurface into a number of rectangular blocks, to determine the resistivity of the rectangular blocks that will provide an apparent resistivity pseudosection that agrees with the actual measurements. For the Wenner and Schlumberger arrays, the thickness of the first layer of blocks is set at half times the electrode spacing. The raw field data were processed using RES2DINV. This is a computer programme that automatically determines a two-dimensional (2D) resistivity model for the subsurface for the data obtained from electrical survey. It is a window basedprogramme. A common method for presentation of 2D resistivity data is the drawing of pseudosections. A pseudosection is made by plotting the data points in a diagram, using the length axis for the distance along the surveying line and the depth axis for the electrode separations. The distance for the electrode configuration midpoint is thus plotted against the electrode separation for each measured data point, letting the latter reflect the measurement depth. The corresponding apparent resistivities for the plotted points are then used to contour the variation in apparent resistivity along the surveying line. The pseudosection thus obtained reflects the variation of resistivity in the ground in a qualitative way, and approximate structures and depths to layer interfaces may be estimated. It should be noted that the pseudosection is simply a 2D equivalent of the plotted field data points in a linear depth scale. In this context, drawing of pseudosections needs computer assistance to be practicable due to the large amount of data. The PSEUDO.EXE and ERIGRAPH.EXE software have been developed for automatic drawing of pseudosections in grey scales or colors, using linear interpolation between data points. Linear interpolation involves no smoothing of data, and hence gives a good indication of the data quality. Twelve different colours or grey levels are used for plotting data. Each data point used for drawing the pseudosection is indicated in the section by a dot. Presenting DC-resistivity data in color plots may be disputable as the data do not contain any spectral information. However, presenting D.C. resistivity data in color plots makes it easier to see the variations in resistivity. This is important because, small changes in resistivity in one part of a long profile may be significant even if there is a very large variation along the profile. The selection of resistivity interval limit is of major importance when presenting data, as the perception of the plotted data is strongly controlled by the colors. A suitable selection of limits enhances the geological variation while unsuitable selection of limits may hide important information or enhance irrelevant features. A geological reference was used to optimize the data presentation. The programme was developed for plotting DC resistivity data measured with a multi-electrode array, implying electrode spacings are always an integer multiple of the smallest electrode spacing used. Furthermore, profile distance coordinates are assumed to fall into the same positions as data for the smallest electrode spacing or halfway between them. For long profiles the data matrix used for the interpolation routine will not be sufficient for plotting the whole profile at once. In cases where the data do not fit, it is automatically divided into small enough portions for the interpolation routine, and plotted one portion after the other in the same section. In this way there is no limit to the number of data points in the direction along the profile. There is however, a limit to the number of data points in the depth direction, which depends on the array size specified before compiling the programme, but for DC-resistivity data the number of different electrode spacings is normally very limited.

III. Results And Discussion

Two profiles on each dumpsite of every location were taken for this study. These locationsareDamboa Road, Bulumkutu Railway, Shuwari,Wulari, Bulumkutu, Kumshe, Mashidimami and Behind New Male Hostel A, University of Maiduguri all located within Maiduguri Metropolis of Borno State. Thus, a total of sixteen (16) profiles were captured on the eight (8) dumpsites across the Study Area (Fig. 6).

Fig. 6: The dumpsites where the ERT data are obtained

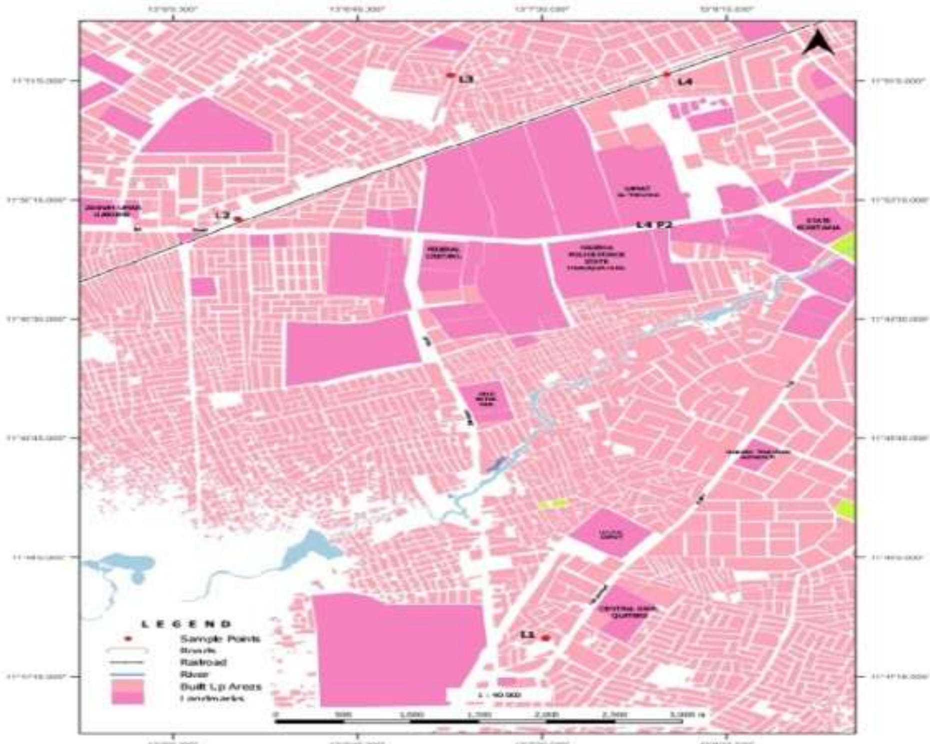


Figure 7:ERT Survey Sites within Maiduguri (Map gotten from the Department of Urban and Regional Planning, University of Maiduguri, 2022)

The inversion result for each profile (Figures 8 to 15) shows the images of the pseudosections (geoelectric sections) obtained from the processed data. The results show three distinct sections for each profile (Figures 8 to 15). The first image is a plot of the measured (observed) apparent resistivity pseudosection. The second image is the calculated apparent resistivity pseudosection and the third image is the true resistivity model obtained after a definite number of iterations of the inversion programme.

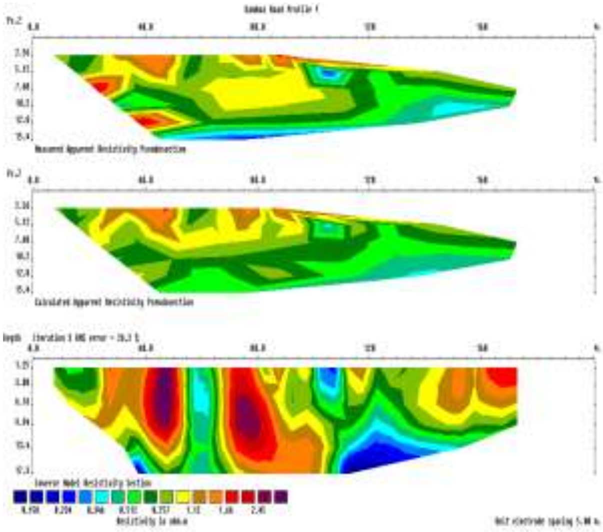


Fig. 8a: ERT obtained at Damboa Road profile 1

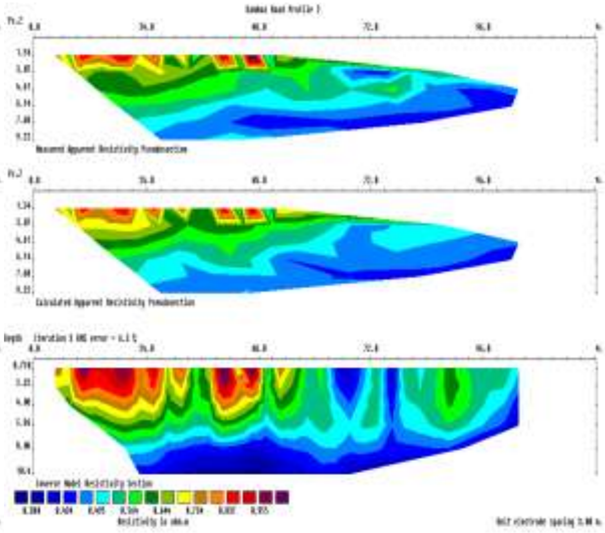


Fig. 8b: ERT obtained at Damboa Road profile 2

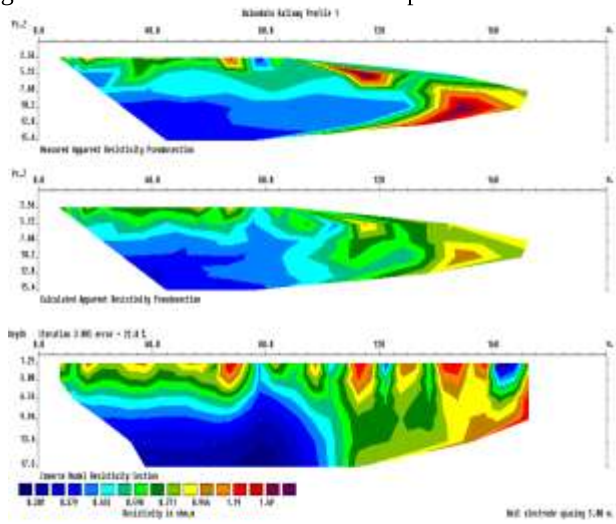


Fig. 9a: ERT obtained at Bulumkutu Railway profile 1

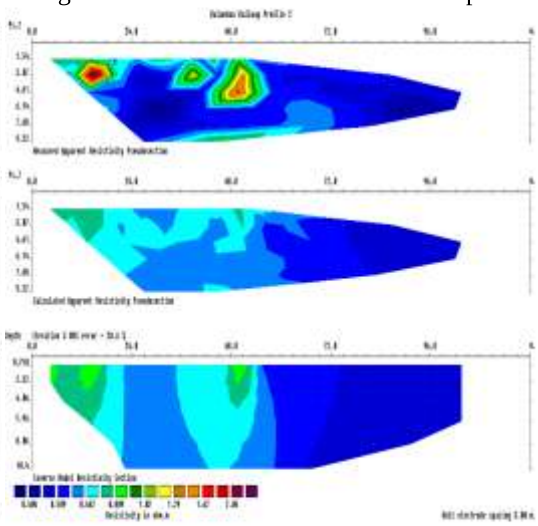


Fig. 9b: ERT obtained at Bulumkutu Railway profile 2

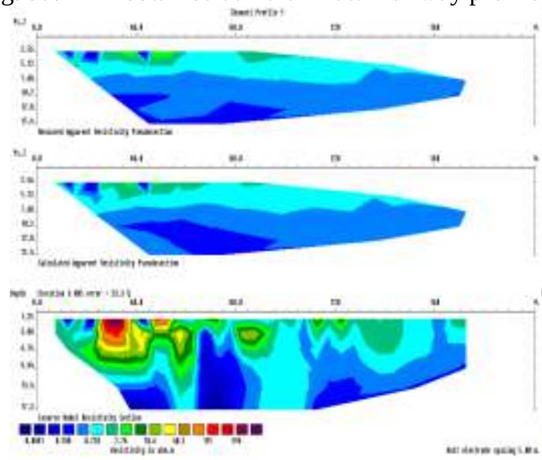


Fig. 10a: ERT obtained at Shuwari Profile 1

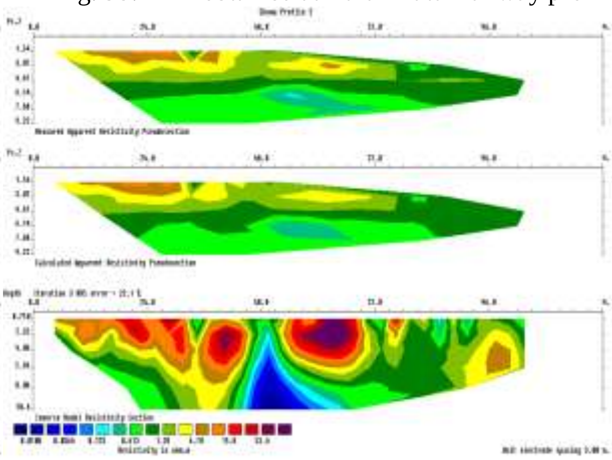


Fig. 10b: ERT obtained at Shuwari Profile 2

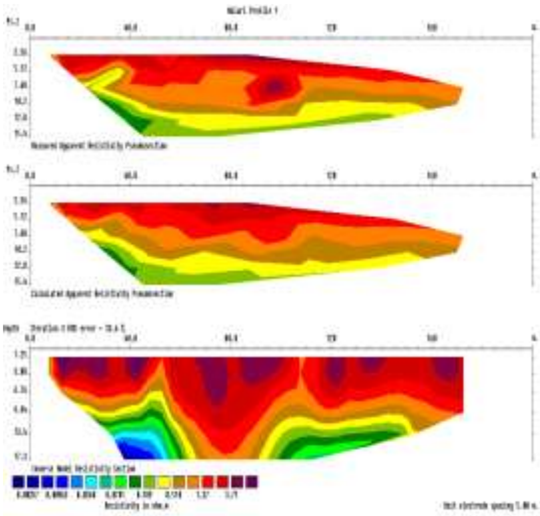


Fig. 11a: ERT obtained at Wulari Profile 1

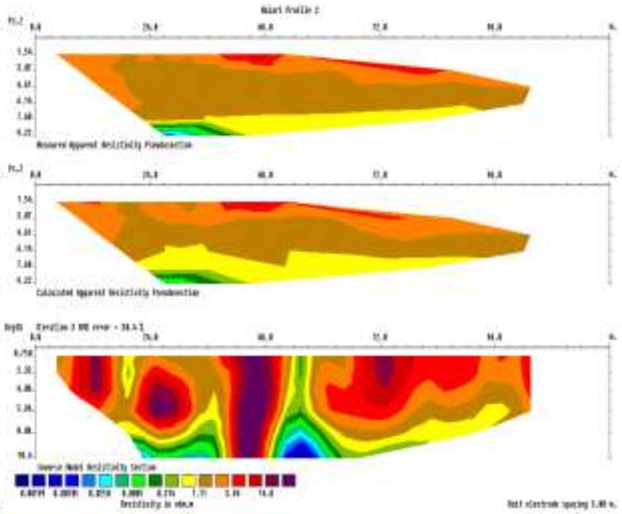


Fig. 11b: ERT obtained at Wulari Profile 2

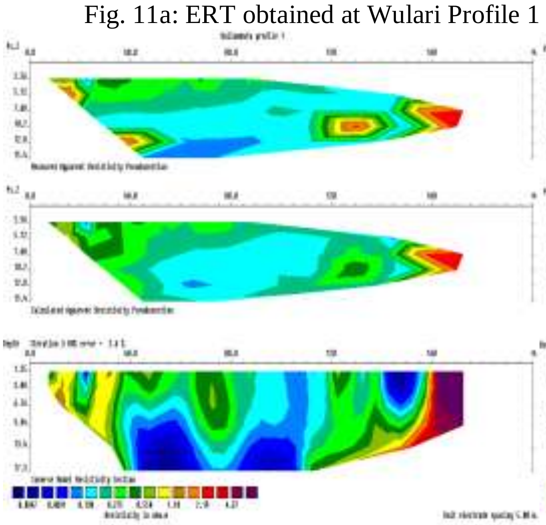


Fig. 12a: ERT obtained at Bulumkutu, Profile 1

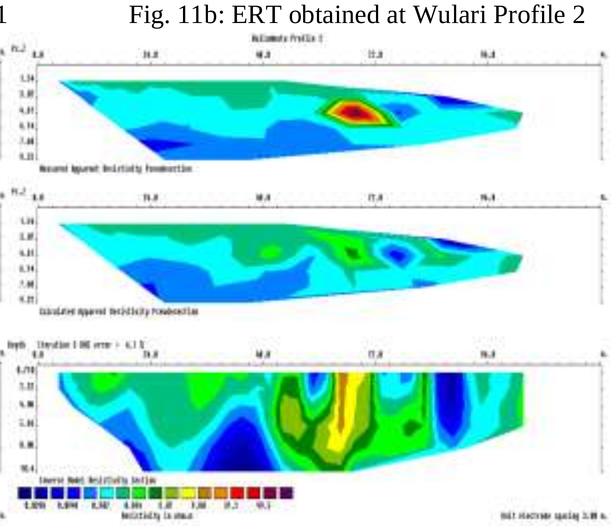


Fig. 12b: ERT obtained at Bulumkutu, Profile 2

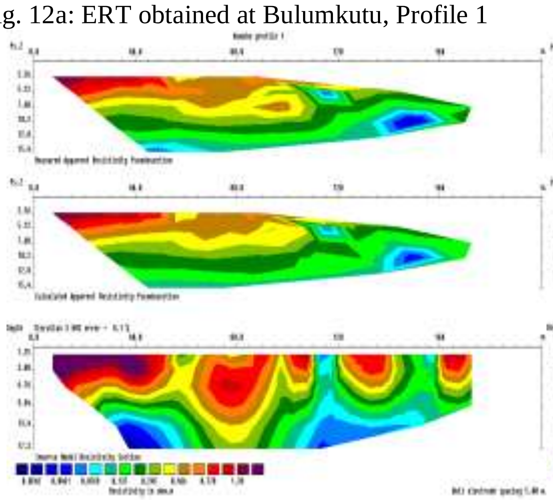


Fig. 13a: ERT obtained at Kumshe profile 1

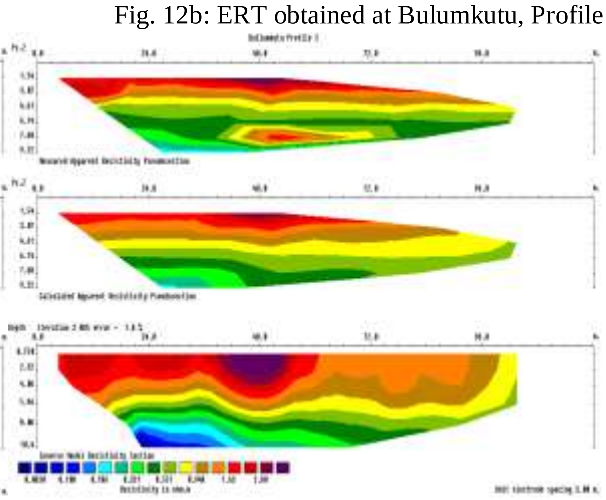
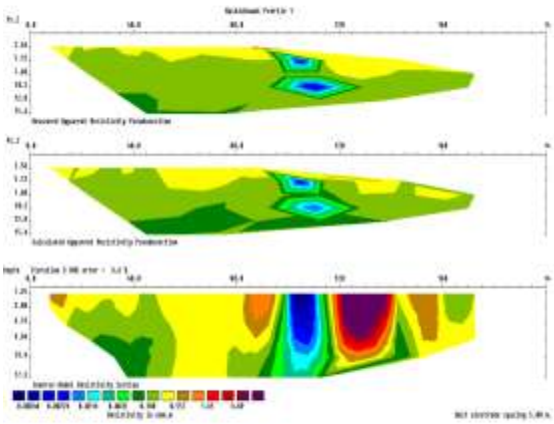


Fig. 13b: ERT obtained at Kumshe profile 2



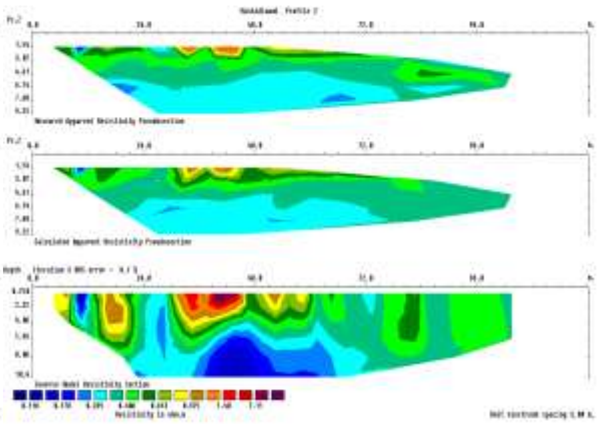
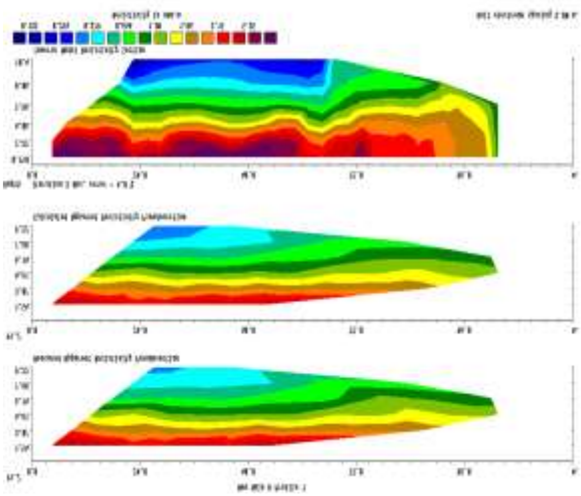


Fig. 14a: ERT obtained at Mashidimami, profile 1 Fig. 14b: ERT obtained at Mashidimami, profile 2



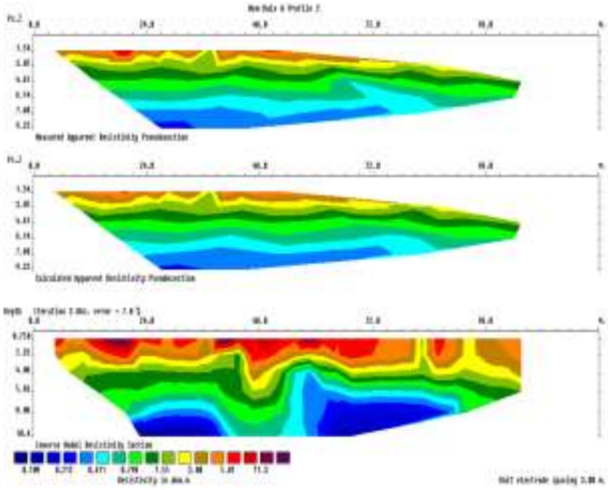


Fig. 15a: ERT obtained Behind Hostel, Unimaid, profile 1 Fig. 15b: ERT obtained Behind Hostel, Unimaid, profile 2

Discussion

Eight profiles were taken for this study as stated above, 2- profiles on each dumpsite. The inversion result for each profile (figures 8a,8b-15a,15b) shows the images of the pseudosections (geoelectrical sections) obtained from the processed data. The result show three distinct sections for each profile. The first image is a plot of the measured (observed) apparent resistivity pseudosection. The second image is the calculated apparent resistivity pseudosection and the third image is the true model obtained after a definite number of iterations of the inversion programme. All the profiles indicate that, good fit between the measured and calculated apparent resistivity data were achieved. The apparent resistivity is plotted against pseudo-depth (in metre). All the profiles indicatessix series of colors dark blue, light blue, green, yellow, red and dark purple. While the (Dark blue-light blue) indicate lower resistivity with possible contamination and decomposed of leachate and decaying materials within the formation, (Green to yellow) coloration indicate moderate resistivity zone having no possible contamination which is likely composed of sand with little amount of clay and (Reddish-purple) coloration indicate the zone higher resistivity usually at the top of the profile composed of dry sand. Almost all the profiles have pockets of contaminants on the first layer that moves through moderate resistivity which is interpreted as sand and silt with small amount of clay that have high porosity and permeability which allow the downward movement of the contaminants as clearly shown in profile (8a,9a,10a,12a,12b,14a,14b). Some of the profile show a clear preferential flow path (Contaminant flow path) which allow the movement of the contaminants from the top layer to the bottom layer as a result of the porosity and permeability of the ground as shown in profile (8a,8b,9a,9b,10a,10b,11b,12a,12b,13a,13b,14a,14b) above, while some of the profiles only have the presence of the contaminants at the bottom layer with no pocket of contaminants at the top layer and clear preferential flow path this happens as result high porosity and permeability of the ground that allow the complete migration of the contaminants to the bottom layer as shown in profile (11a,15a,15b). The interpretation shows that the contaminants are present within the unsaturated zone and there are structures that will allow the continuous downward movement of these contaminants into the subsurface and might eventually find their way with time into the groundwater.

IV. Conclusion

Three distinctive zones of varying resistivity contrast was delineated beneath the studied dumpsites using resistivity imaging survey viz; the zone of low resistivity known as the zone of impact delineated as composed of leachate and decaying waste materials. The second zone of moderate resistivity composed of sand and clay materials while the third zone of high resistivity composed of dry sand. The second and the third zones are of no impact because no trace of contaminant was seen on them. The conductivity value of the subsurface materials is believed to facilitate the movement of the leachate near and below the surface. The movement of leachate constitutes a threat to the surface and groundwater system and especially surface water in some areas having a shallow aquifer and therefore, sinking boreholes around the dumpsite is dangerous. The biological and chemical constituents of these pollutants are unknown. This however, calls for more detailed integrated studies involving geochemistry, drilling of monitory boreholes, and chemical analysis of water samples. These will actually ascertain the nature of these pollutants around the dumpsite.

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