

GEOPHYSICAL INVESTIGATION OF THE IMPACT OF SOLID WASTE DUMP ON SUBSURFACE SOIL AND GROUNDWATER IN ENEKA, RIVERS STATE NIGERIA

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ABSTRACT

The geophysical electrical method was used to investigate how the refuse dump in Eneka (Rivers State, Nigeria) affects the subsurface soil and groundwater within its environs. The research was carried out applying Wenner and Schlumberger array configurations of electrical resistivity techniques to image the subsurface resistivity within the area using ABEM SAS 300 Terrameter. A total of ten locations were investigated and the measured data across the profiles were processed using RES2DINV and ArcGIS 10.4 computer iterative software. The resulting inverse resistivity model isolated three resistivity zones (anomalously low, intermediate and high resistivity). The anomalously low resistivity zone was interpreted as contaminant leachate plumes and landfill gases from the dump area was observed to have travelled to depths of 14 m below the surface and over 30 m distance eastwards from the dump site, showing the tendency of farm land and crops pollution. However, the aquifer layer in the area estimated at the depth of 40 m may not have been contaminated. The spatial trend of almost all the resistivity values measured at equidistance reveals low value for lines 3 and 4 (which are farther away from the dump site) at the beginning and high value at the end and vice versa for lines 1 and 2. At the rate at which the leachate has infiltrated the subsurface the aquifer within the area is likely to be contaminated in the future if adequate measures are not taken.

Keywords: Dump site; Electrical resistivity; Eneka; Groundwater; Leachate plume.

1 INTRODUCTION

Activities of man on Earth give rise to residual materials that may not be of immediate use. Such materials may be recycled, reclaimed, or re-used; otherwise they constitute waste (pollutants) that will ultimately be released to the environment in mobile form or in situ [1]. These pollutants pose common environmental problems that have created the need to find suitable methods for monitoring the extent of such environmental damage [2].

Areas near landfills or dump sites are prone to groundwater and soil contamination because of the presence of leachate originating from the source to the natural environment. The fumes/odour emanating from solid waste can also lead to skin and blood infections, eye and respiratory infections, as well as chronic diseases such as cancers [3]. Economic activities are also affected as people will not like to locate their companies, businesses and houses in toxic areas/environment. Land and water borne diseases and infections may also occur near such dump sites.

The use of geophysics for engineering and groundwater contamination studies has increased in recent time with rapid advances in computer software and associated numerical modeling solutions. The geoelectrical imaging method has been widely used in environmental and geotechnical investigations to detect the surface effects produced by the flow of electric current inside the earth [4]. The vertical electrical sounding (VES) technique has been used in a wide range of geophysical investigations such as mineral exploration, archeological investigation, engineering studies, geothermal exploration, permafrost mapping and geological mapping [5–8]. Soil which is an essential resource for the existence of plant life, food production and industrial materials can easily be affected by contamination from surface pollution, waste disposal or toxic industrial wastes [9].

In this study, vertical electrical sounding (VES) and two-dimensional (2-D) geoelectric methods were used to delineate the aquifer depth and level of contamination on the subsurface soil and groundwater from landfill mixed with both hazardous and non-hazardous materials from industries, homes and offices. This was achieved by measuring the electrical resistance of the subsurface, evaluate the depth and direction of flow of the leachate resulting from the waste materials and hence delineate the possibility of contamination of near surface formation and aquifer, based on interpreted resistivity models.

Several works have been documented on the use of various geophysical electrical techniques in probing the effect of leachate plume at landfill sites on soil and groundwater [10–13]. Roseqvist in [14], carried out 2-D resistivity imaging aimed at mapping possible leachate plumes at two landfill sites in South Africa. The inverse model section reveals the extent of the leachate plumes in the landfills, with resistivity value of less than $10\Omega\cdot\text{m}$. Research in [15] mapped contaminated plumes at municipal solid waste disposal sites in Malaysia using geoelectric imaging technique. The result of the interpretation defined the contaminated leachate plumes as electrically conductive anomalies of relatively low resistivity values less than $10\Omega\cdot\text{m}$. Also, Ehirim et al. in [16] carried out 2-D resistivity imaging to determine the impact of municipal solid waste landfill in Port Harcourt Municipality. Two distinctive zones were mapped, the zones of anomalously low and high resistive structures. The low resistive structures were interpreted as rock materials contaminated with leachate plumes that are predominantly methane, ammonium, hydrogen sulphide and carbon dioxide.

2 GEOLOGY OF THE STUDY AREA

Eneka town is located within the North-Central axis of Rivers State, Nigeria between latitudes $4^{\circ}53'N$ through $4^{\circ}54'N$, and longitudes $7^{\circ}0'E$ through $7^{\circ}2'E$ (Fig. 1). The region is characterized by low lying plain with mean elevation 13 meters below mean sea level. Eneka lies within the tropical belt, characterized by abundant rainfall almost all year round, with the exception of the months of December through February. An annual rainfall of about 240 cm, relative humidity of over 90 % and mean annual temperature of 27°C is common in the area [8]. The rainy/wet season occurs between April and October with heavy rainfall and relatively constant humidity. Thick mangrove forest, raffia palms and light rainforest are the major types of vegetation.

The study area is a typical Niger Delta sedimentary environment with three stratigraphic units, namely, the Benin, Agbada and Akata Formations in order of increasing age [17]. The formations consist of permeable sands, alternations of shale, sandstones and siltstone; and thick shale sequence at the base. The area is known for high aquifer potential, with the groundwater flowing in the NW-SE direction, in line with the Niger Delta trend.

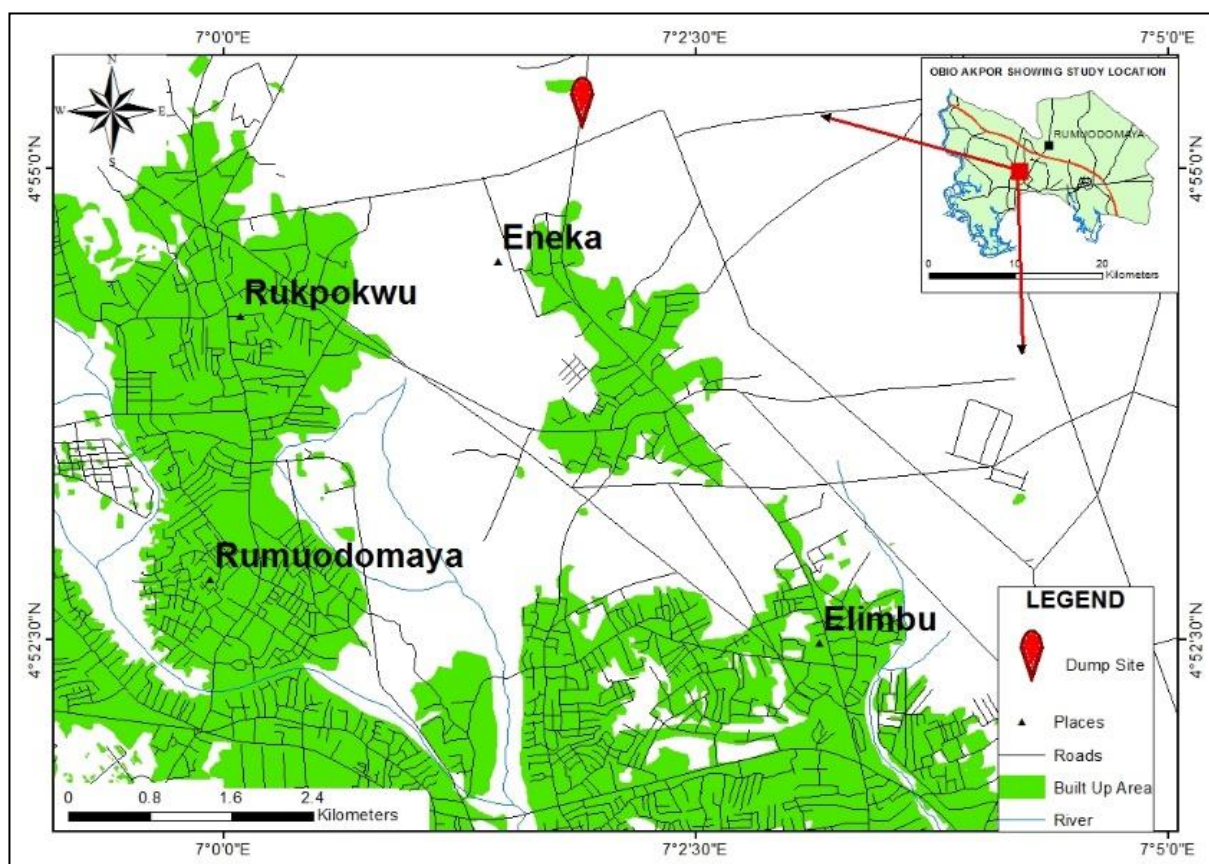


Figure 1. Map of the study area

3 MATERIALS AND METHODS

The geophysical investigation involved two electrical resistivity techniques: Vertical Electrical Sounding (VES) using the Schlumberger configuration and 2-D electrical imaging using Wenner array. The VES technique uses the principle of static electrical array that is pulled across the ground surface for continuous coverage of the resistance of the subsurface, utilizing resistivity meter, ABEM Terrameter SAS 300. A total of six stations were occupied along the traverse with a maximum current separation of 300 m and potential electrode separation of 15 m. The reels of cables were laid along the traverse with the current and potential electrodes distances measured with measuring tapes. The potential electrodes MN were placed very close to the sounding point such that MN is about five times less than the current electrodes, AB. Potential electrode separation (MN/2) is measured at 0.5 m interval and at each fixed point, current was injected into the ground and the resulting potential drops between the electrodes were measured by the meter, which automatically calculates the resistance that was displayed on the screen. The current electrodes were then moved to next marked point for another shooting while the potential electrodes remained fixed at the point, but moved only when the reading becomes very small. The acquired data were processed using resistivity inversion (RES2DINV) computer iterative software and presented as sounding curves, which are plots of apparent resistivity values against current electrode separation (AB/2). Quantitative interpretation of the sounding curves gave interpreted results as geoelectric parameters (that is, layer resistivity and layer thickness).

In the 2-D resistivity imaging, four horizontal profile stations were occupied, utilizing a multi-electrode system with equal minimum spacing 'a' between successive electrodes (Fig. 2). The multi core cable was laid on the ground in a straight line along the traverses with interval spacing ranges of 5 m to 30 m at each sounding station. The electrodes were connected to a Central switching system (Terrameter) and currents were injected into the ground via the current electrodes (C1 and C2) located at the exterior of the potential electrodes (P1 and P2). The potential difference between the potential electrodes were measured and the resistance of the ground was calculated

automatically by the meter. After taking the first reading at station 1, the cables and electrodes were moved in a leap-frog manner to the next position for the second reading. This process continued until all measurement points along the traverse were covered. Two hundred and ninety-two data points were acquired and subsequently processed using the RES2DINV and geographic information system (ArcGIS 10.4) software.

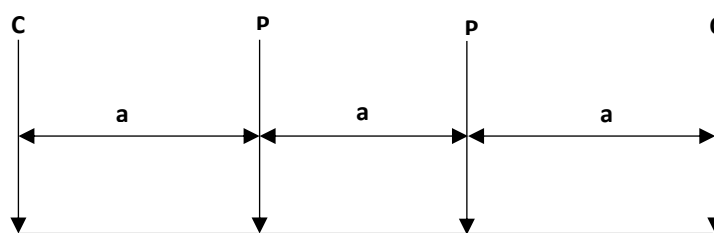


Figure 2. Wenner array configuration

4 RESULTS

The RES2DINV program displayed the result of 2D imaging field data as inverse pseudo-section that gives the resistivity of the subsurface layers as a function of vertical depth (Figures 3 to 6). Three distinct zones were identified from the model section as zones of low, intermediate and high resistivity.

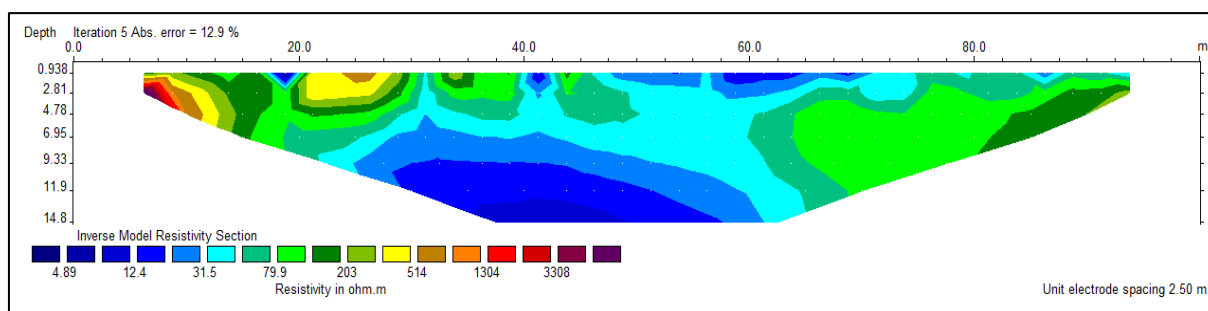


Figure 3. 2-D resistivity pseudo section of Profile 1

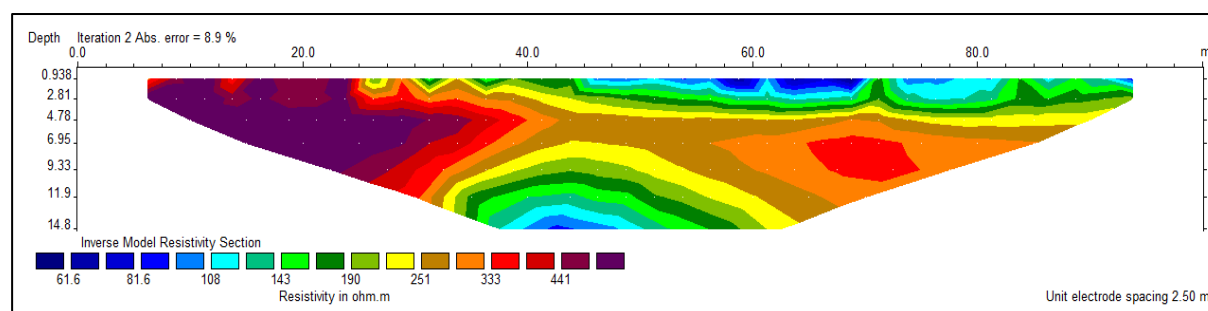


Figure 4. 2-D resistivity pseudo section of Profile 2

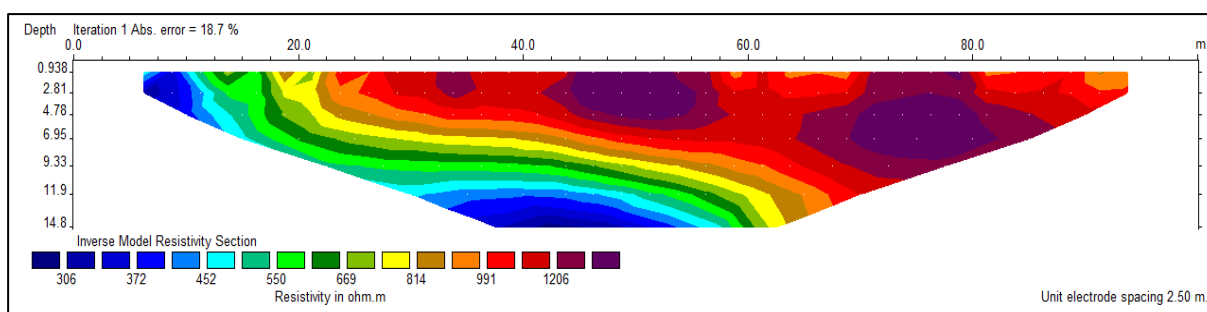


Figure 5. 2-D resistivity pseudo section of Profile 3

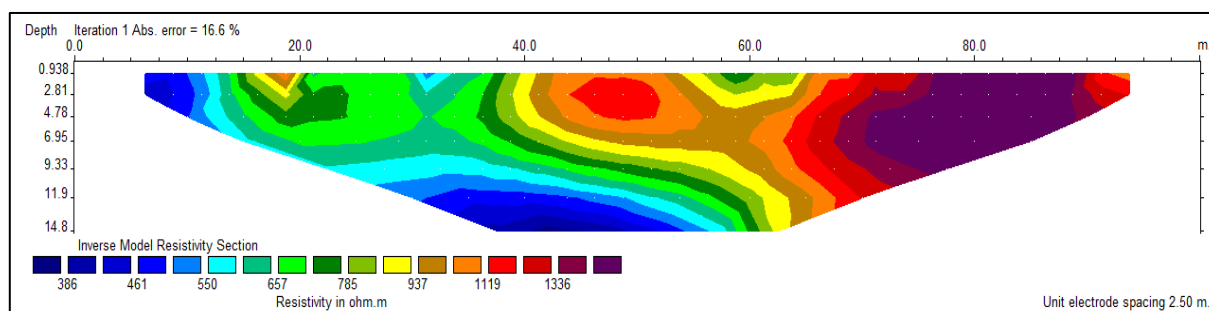


Figure 6. 2-D resistivity pseudo section of Profile 4

Profile 1

The inverse model Pseudo section has resistivity values lower than $4.89 \Omega\text{-m}$ and greater than $3308 \Omega\text{-m}$. The contaminated low resistivity zone (deep to light blue) with resistivity value that is lower than $4.89 \Omega\text{-m}$ was isolated at the lower section of the profile at surface points 35.5 m to 52.0 m and depths range of 12.5 m to 14.8 m. This zone is overlain by more resistive layers with values range of $30.6 \Omega\text{-m}$ to $500.5 \Omega\text{-m}$ (light green to yellow). The high resistivity zone (yellow to purple) values are from $514 \Omega\text{-m}$ to over $3380 \Omega\text{-m}$ at three different shallow surface points. The highest resistive section (purple) was isolated within the depths of 2.52 m and 3.58 m, at 4.26 m to 7.52 m surface points.

Profile 2

The resistivity of the uncontaminated zone ranges between $441 \Omega\text{-m}$ and $251 \Omega\text{-m}$ (purple to orange), spanning through most top section of the profile. The highest resistivity is located at the western part of the profile at a depths range of 0.938 m to 10.0 m and surface points of 5.02 m to 35.0 m. The zones of low resistivity (deep to light blue) were isolated at the upper and lower parts of the profile section with values range of less than 61.6 to $81.6 \Omega\text{-m}$. The depth of the upper part ranges from 0.938 m to 2.21 m, at surface points of 45.2 m to 70.0 m. The lower part of this section was isolated at depths range of 13.0 m to 14.8 m and surface points of 36.5 m to 50.2 m. The intermediate resistivity zone (light green to yellow) has resistivity values ranging between 108 and $251 \Omega\text{-m}$ and spread from the surface to a depth of about 2.81 m, and at surface point range of 30 m to over 90 m. This interval was also isolated at the center of the profile at surface point 30 m to 60 m and depths range of 6.95 m to about 14.8 m.

Profile 3

The high resistivity zone with values range from $1206\Omega\text{-m}$ to $814\Omega\text{-m}$ (purple to orange) spanned through the top permeable soil formation to the bottom of the investigated depth (14.8m), between 28.0 m and 90 m surface points. It covers most parts of the profile. This zone overlies the less resistive zone (light green to yellow) at surface points 6.0 m to 60.0 m and depths range of 0.938 m to 14.0 m. The resistivity range for this zone is 814 to $452\Omega\text{-m}$. The low resistivity zone (deep to light blue) with value range of $306\Omega\text{-m}$ to $452\Omega\text{-m}$ were isolated at depths range of 0.938 m to 4.78 m, at surface points range of 6.0 m to 9.0 m; and also at a depth range of 13.0 m to 14.8 m and surface points of 35.0 m to 50.0 m.

Profile 4

This profile exhibits almost the same characteristics as Profile 3. The contaminated low resistivity zone (deep to light blue) has a resistivity range of 386 to $461\Omega\text{-m}$, at surface points 5.0 m to 8.0 m and depths range of 13.0 m to 14.8 m. The zone overlies a higher resistivity zone (light blue to yellow) having value of 560 to $785\Omega\text{-m}$ and spanning from 0.938 to 14.8 m at surface points range of 6.0 to 58 m. The anomalous resistivity zone (purple to orange) has resistivity in excess of 1336 to $937\Omega\text{-m}$ at depths range of 0.938 to 14.8 m and surface points 40 to 90 m.

Aquifer Depth Determination

The geoelectric curve for each sounding point were processed using RES2DINV automatic analysis software. The representative curve result is presented in Figure 7 and the computer modeled analysis is shown in Table 1. The computer-modelled results are summarized in Table 2.

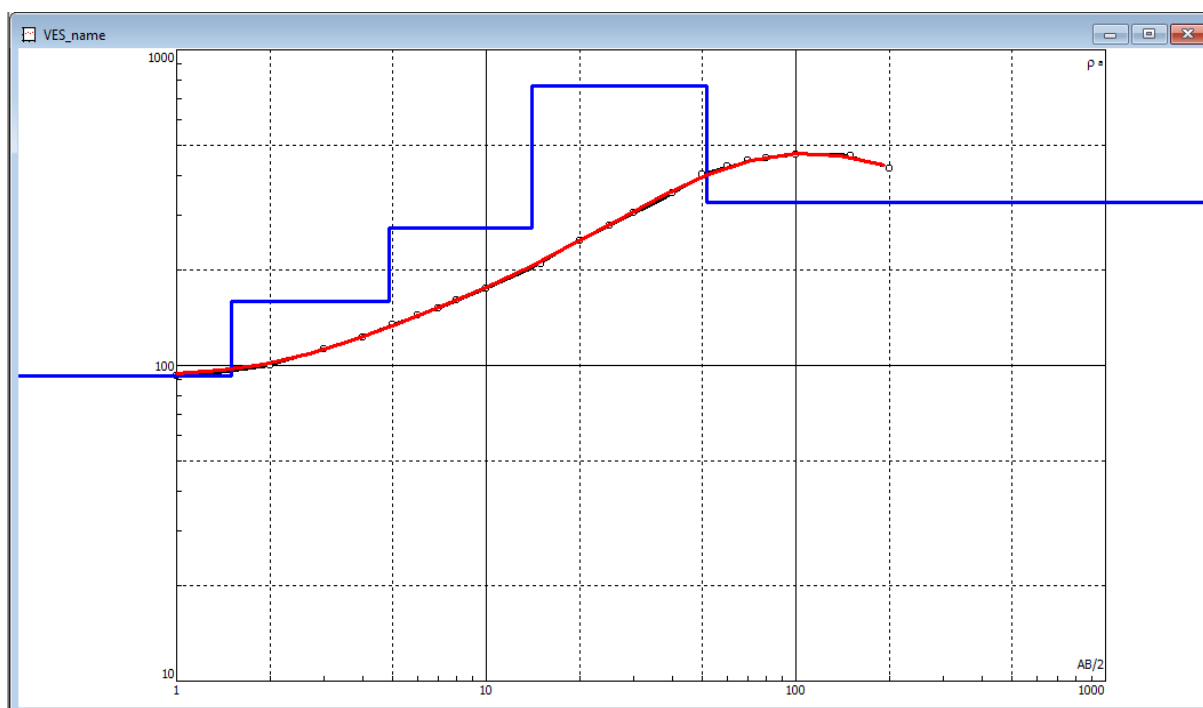


Figure 7. Model curve of VES 1

Table 1. Interpreted computer model for VES 1

App Resistivity	Thickness (m)	Depth (m)
Ohms-m	(m)	(m)
92.5	1.5	1.5
160	3.35	4.85
273	9.19	14.04
768	37.5	51.54
329		

The first layer has a resistivity of $92.5\Omega\text{-m}$ and is described as the topsoil with a thickness of 1.5 m. This layer consists of soft, brownish, lateritic sandy clay and silt clay. Layer two has a resistivity of $160\Omega\text{-m}$ and appears at a depth of 4.85 m. It is described as medium to dense, poorly graded lateritic sand. The underlying layer with a resistivity of $273\Omega\text{-m}$ has a total thickness of 9.19 m is a medium to dense light brown, poorly-graded sands. The fourth layer is a medium to coarse well-sorted sands (aquifer layer) with resistivity of $768\Omega\text{-m}$ and thickness of 37.5m. The depth of the fifth layer with resistivity of $329\Omega\text{-m}$ was not determined.

Table 2. Summary of the results of computer modelling of all the sounding station

VES station no.	Layer Resistivity (Ohm-m)					Layer Thickness (m)					Depth (m)				
	P ₁	P ₂	P ₃	P ₄	P ₅	t ₁	t ₂	t ₃	t ₄	t ₅	h ₁	h ₂	h ₃	h ₄	h ₅
1	162	303	539	1029	785	1.9	4.01	8.56	17.6	-	1.9	5.91	14.5	32.1	-
2	736	589	1859	3428	2612	1.84	1.79	4.85	23.4	-	1.84	3.63	8.48	31.9	-
3	92.5	160	273	768	329	1.5	3.35	9.19	37.5	-	1.5	4.86	14	51.5	-
4	90.76	947.6	924.20	2452.00	490	0.60	1.83	2.43	37.40	-	0.60	2.43	486	42.26	-

5 DISCUSSION

The impact of municipal solid waste landfill on groundwater and soil was investigated using 2-D resistivity imaging technique. The result of the model section reveals that the surrounding soil and groundwater around the landfill may not have been contaminated to depth beyond 14 m, which is below the productive aquifer depth of about 40 m and above in the study area.

The 2-D resistivity imaging mapped three distinctive zones of anomalously low, intermediate and high resistivity. The anomalously low resistivity (deep to light blue) in the profiles were interpreted as high conductive leachate contaminant plumes (as a result of decomposing landfill waste) containing organic and inorganic substances, pathogens and Dissolved solids. The leachate contaminant plume is observed to have seeped from surface to depths exceeding 14 m in the inverse model section. This observed seepage is enhanced by the nature of the permeable sandy layer characteristic of the area. The zones of increasing resistivity (light green to yellow) with resistivity ranging from $79.9\Omega\text{-m}$ to $937\Omega\text{-m}$ in the entire area were also identified as porous and permeable sandy layers of varying grain sizes and moisture content. The zones of anomalously high resistivity (pink to purple) with resistivity greater than $3308\Omega\text{-m}$ in the entire profiles were interpreted as uncontaminated water-filled sands.

The results show that the modelled subsurface is more resistive (uncontaminated) as we move away from the landfill as seen in Profiles 3 and 4 which were taken about 100 m away from the site (Fig. 8), with the resistivity increasing eastwards. This was corroborated by the spatial trend of the equidistance measured resistivity (Figures 9–14) across different lines analyzed with GIS software. Figure 9 shows resistivity profile at 5 meters equidistance across different lines around the dumpsite. It reveals high resistivity near the source for lines 1 and 2, while in line 3, high resistivity was observed in the middle and at the end for lines 3 and 4 respectively. Low resistivity runs

across the middle to the end for lines 1 and 2 and also in the beginning of both lines 3 and 4. Figure 10 shows profiles at 10 meters equidistance across different lines in the study area. It revealed high resistivity at the source for lines 1 and 2, while in line 3, high resistivity is observed in the middle and at the end of the profile. Line 4 recorded high resistivity at the end of the profile only. Low resistivity runs across the middle and end of lines 1 and 2, while there is observed low resistivity at the beginning of lines 3 and 4.

Figure 11 displays resistivity distribution at 15 meters equidistance across different lines around the dumpsite. It revealed high resistivity at the source end for lines 1 and 2, while in lines 3 and 4, high resistivity was observed at the end. Low resistivity runs across the middle to the end for lines 1 and 2 respectively, while lines 3 and 4 observed low resistivity at the beginning. Figure 12 shows profile at 20 meters equidistance across different lines in the study area. It shows high resistivity at the source for lines 1 and 2, while in lines 3 and 4, high resistivity was observed at the middle and the end respectively. Low resistivity runs across the middle and end for lines 1 and 2, while lines 3 and 4 observed low resistivity at the beginning of the profile.

Figure 13 displays the profiles at 25 meters equidistance across different lines near the dumpsite. It shows high resistivity at the source point for line 1 and at the middle for line 2, while in lines 3 and 4, high resistivity was observed at the end. Low resistivity is dominant observed near-middle for line 1 and near-end for line 2, while lines 3 and 4 recorded low resistivity at the beginning of the profile. Figure 14 shows profile recordings at 30-meter equidistance across different lines in the area. This revealed low resistivity at the beginning of all the profiles, high resistivity at the midpoint for lines 1, 3 and 4 and low resistivity was also observed at the middle and end of line 2 and 3, respectively.

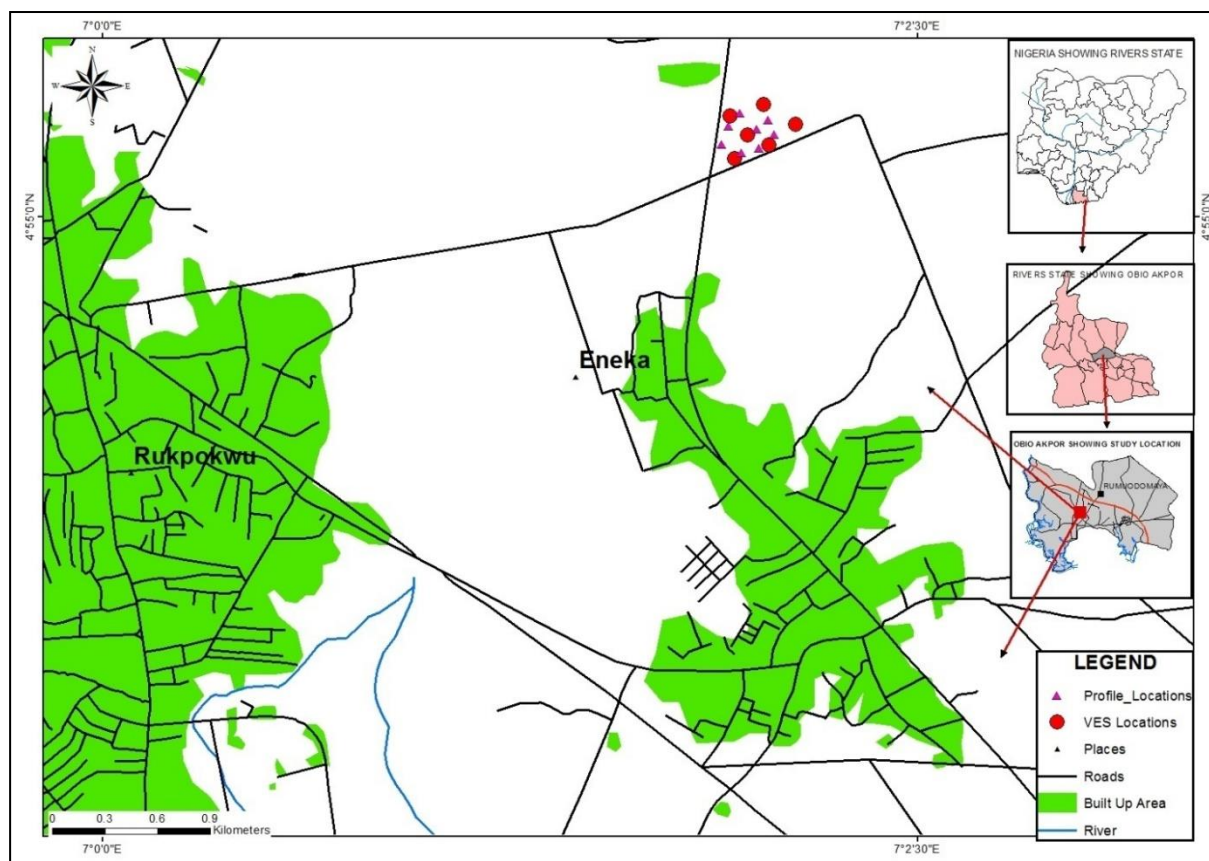


Figure 8. Location of Data points in the Study Area

The VES results reveal that the main aquifer zones occur within the 4th geo-electric layers with a resistivity range of 768 to 2452 Ω -m and depth varying from 31.9 to 51.5 m and layer thickness over 37.5 m. This finding was validated with the aquifer depth determined from works of other authors done very close to the study area [18].

Thus, the aquifer layer within the area may not have been contaminated. However, the location of this dump site in the area will seriously affect the agricultural produce due to the presence of the leachate from the landfill.

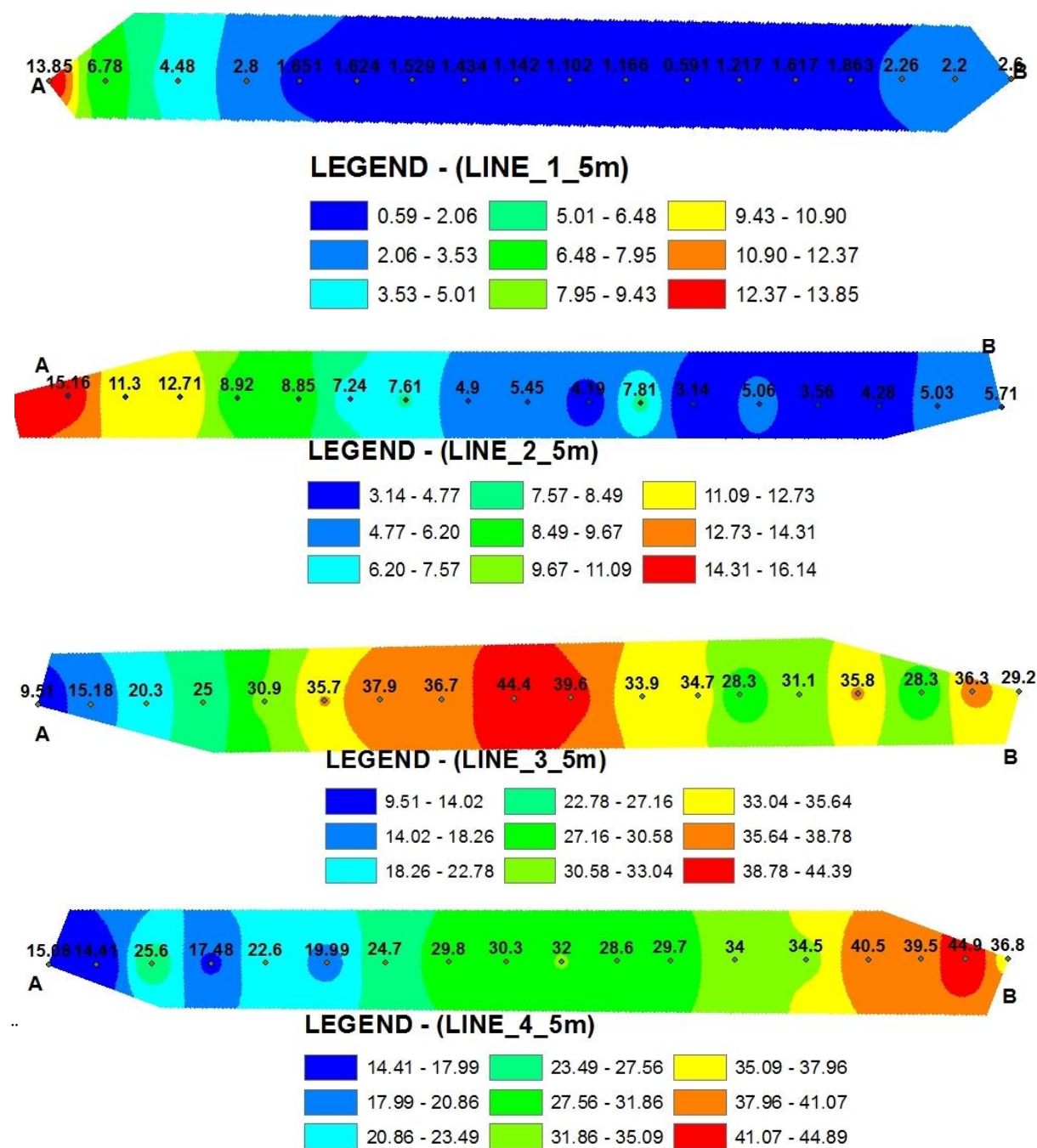


Figure 9. The spatial trend in 5m equidistance measured resistivity between and within observed lines

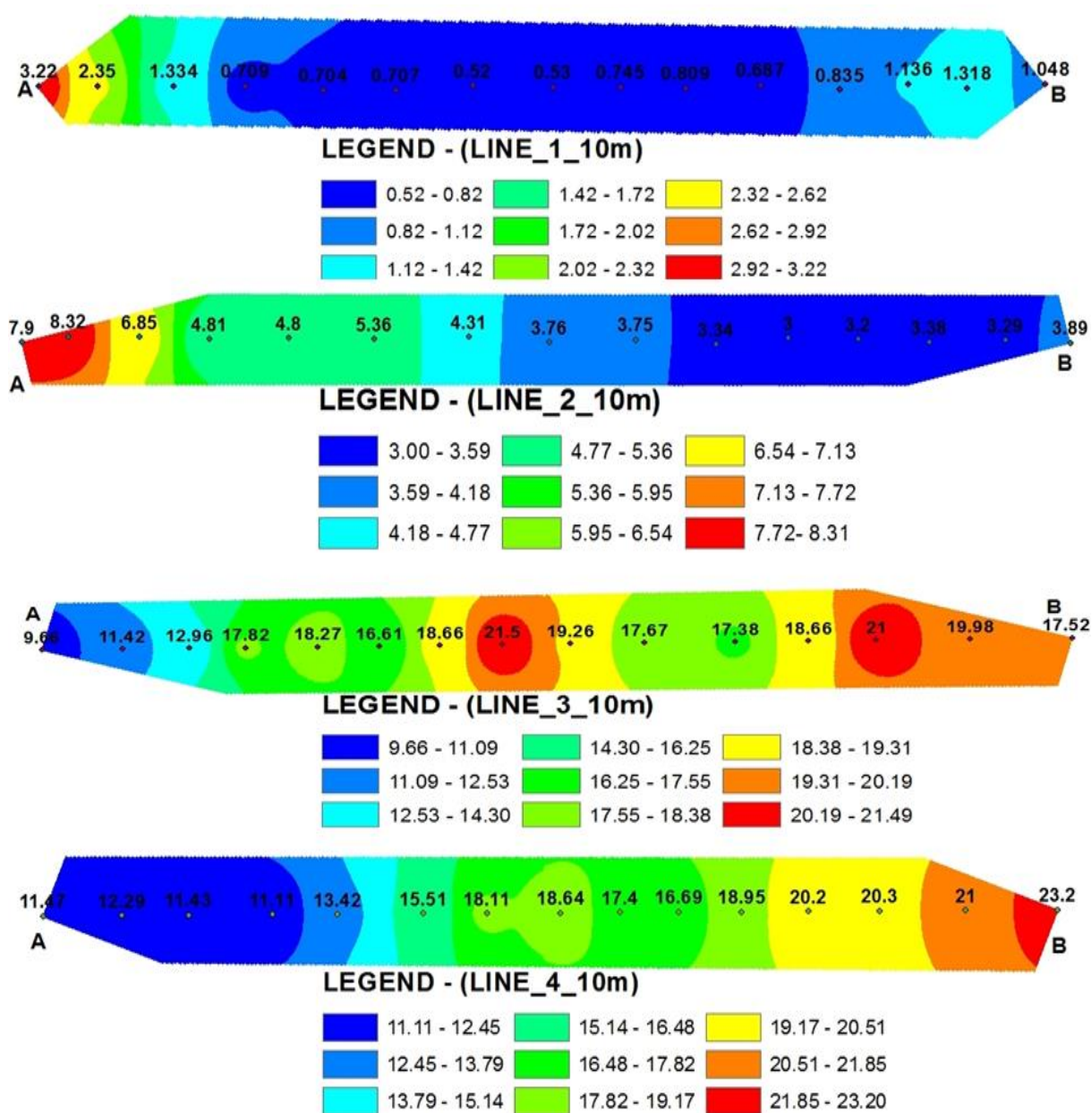


Figure 10. The spatial trend in 10m equidistance measured resistivity between and within observed lines

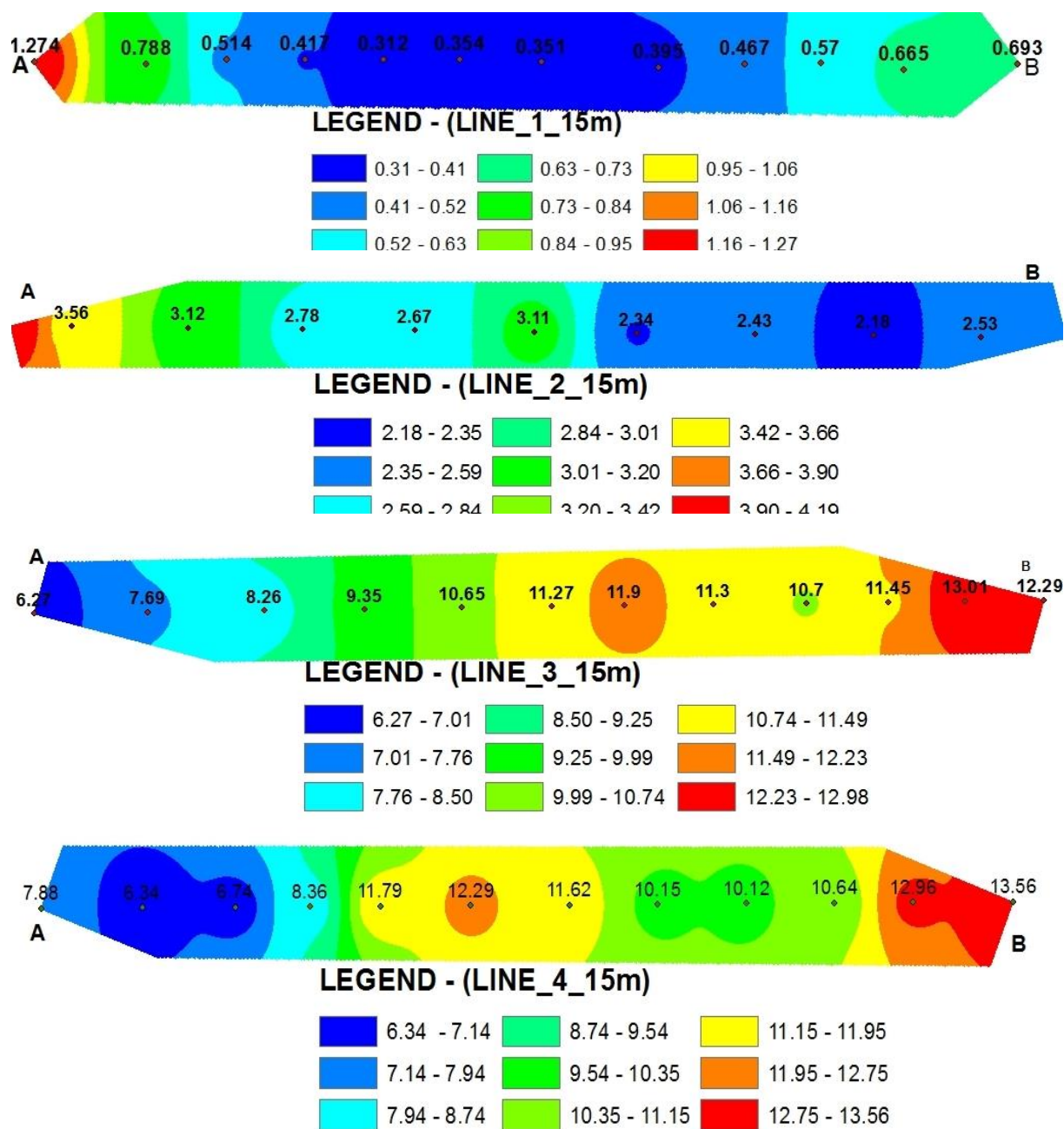


Figure 11. The spatial trend in 15m equidistance measured resistivity between and within observed lines

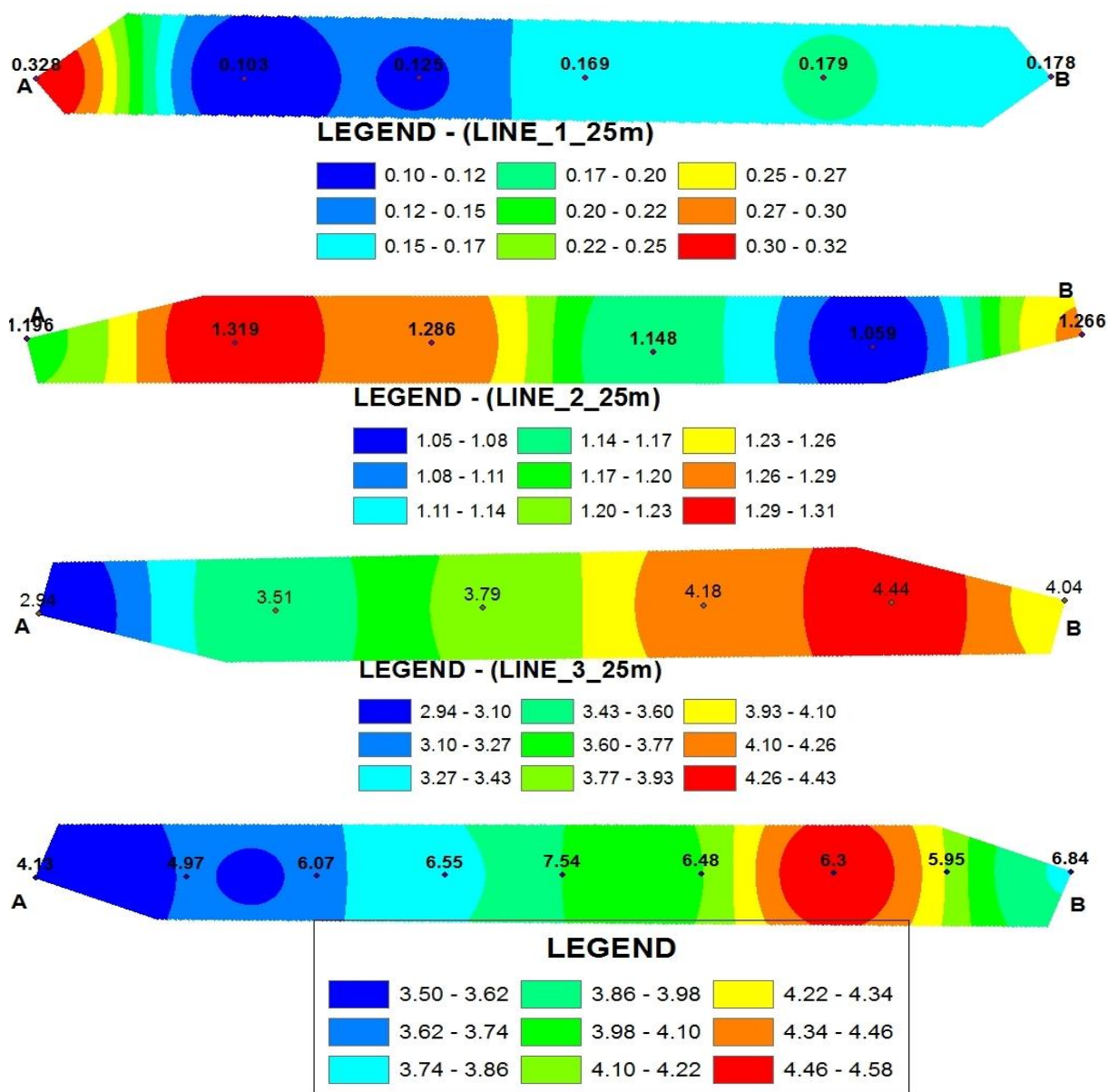


Figure 12. The spatial trend in 20m equidistance measured resistivity between and within observed lines

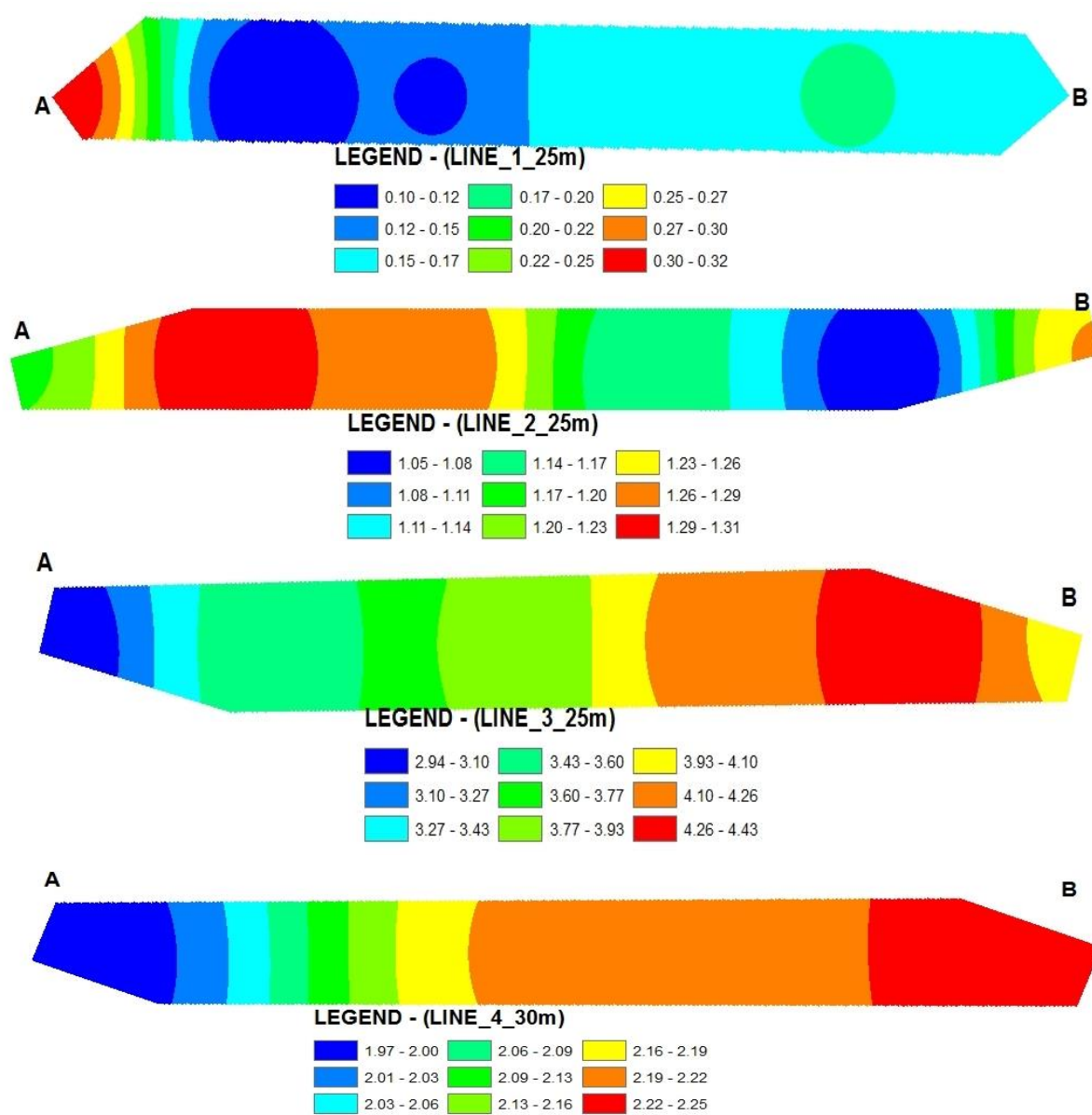


Figure 13. The spatial trend in 25m equidistance measured resistivity between and within observed lines

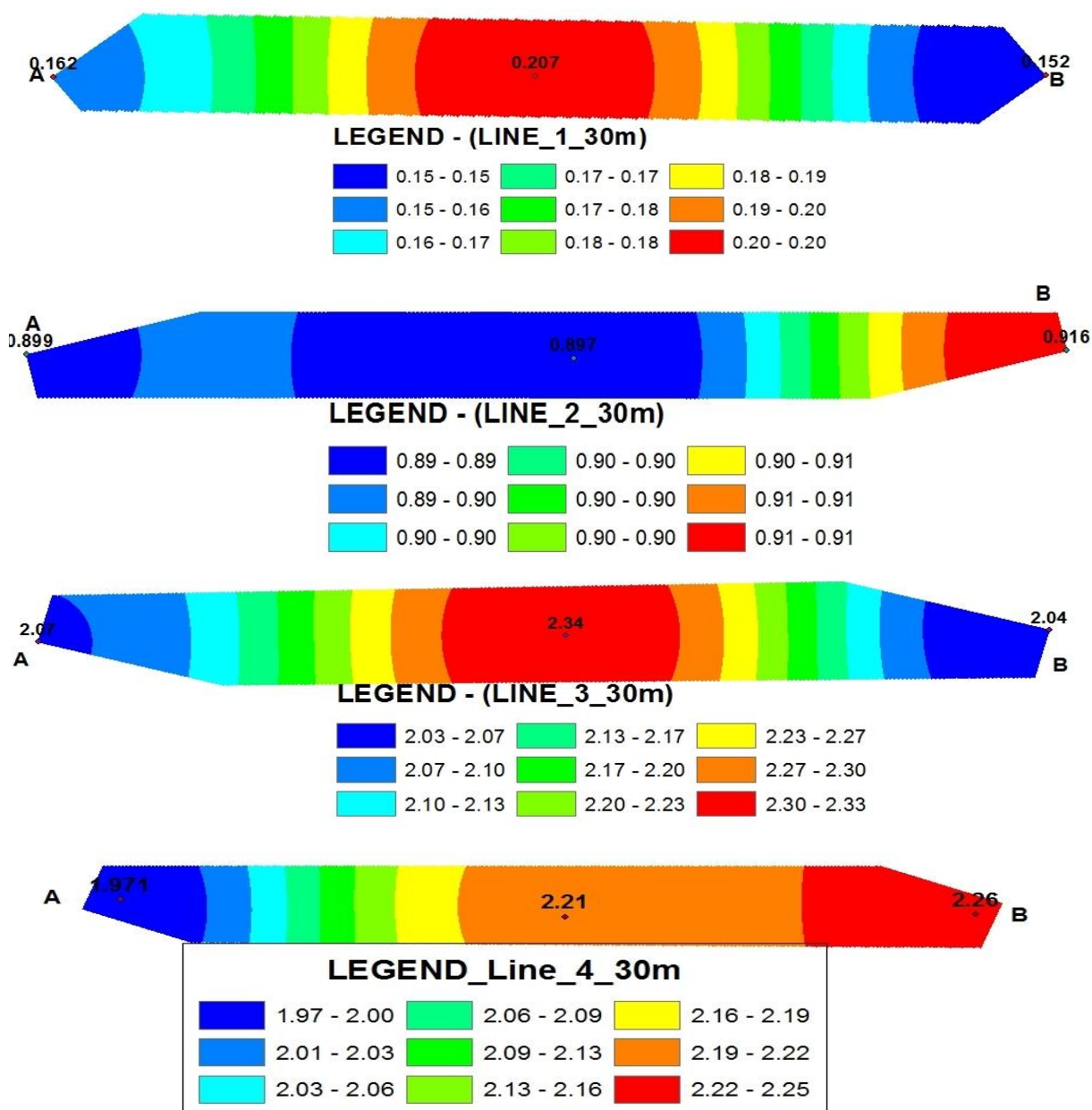


Figure 14. The spatial trend in 30m equidistance measured resistivity between and within observed lines

6 CONCLUSION

The 2-D resistivity imaging model has shown the presence of leachate contaminant in the soil and groundwater around the landfill at depths exceeding 14.0 m, which is however, less than the aquifer depth of the area. Going by the rate at which the leachate has infiltrated the subsurface, there is a possibility of future contamination of the aquifer within the area if adequate measures are not taken.

Three zones were isolated in the study area. These are the zones of anomalously low resistivity structures interpreted as area of high conductive leachate contaminant containing dangerous pathogens and dissolved solids; the zone of increasing resistivity interpreted as a transition zone of porous permeable layer of varying grain sizes, thickness and moisture content with possible small elements of leachate infiltration. The third zone is the zone of anomalously high resistivity which is interpreted as uncontaminated porous layer, probably saturated with water.

The study has therefore demonstrated that 2-D resistivity imaging can be employed to investigate pollutant effects of landfill on the subsurface materials.

REFERENCES

- [1] US EPA. *Municipal solid waste in the United States: 2007 facts and figures*. EPA, 2008.
- [2] BERSTONE, C. and T. DAHLIN. 2-D resistivity of old landfill processes. 2nd European EEGS meeting, Nantes France, Sept. 2–4, 1996, pp. 188–191.
- [3] JERIE, S. Occupational risks associated with solid waste management in the informal sector of Gweru, Zimbabwe. *Journal of Environmental and Public Health*. 2016, Article ID 9024160. DOI: <https://doi.org/10.1155/2016/9024160>
- [4] GRIFFITHS, D.H. and R.D. BARKER. Two-dimensional resistivity imaging and modelling in areas of complex geology. *Journal of Applied Geophysics*. 1993, 29(3–4), pp. 211–226. DOI: [https://doi.org/10.1016/0926-9851\(93\)90005-J](https://doi.org/10.1016/0926-9851(93)90005-J)
- [5] FADELE, S.I., P.O. SULE and B.B.M. DEWU. The use of vertical electrical sounding (VES) for groundwater exploration around Nigerian College of Aviation Technology (NCAT), Zaria, Kaduna State, Nigeria. *Pacific Journal of Science and Technology*. 2013, 14(1), pp. 549–555.
- [6] BOOTH, C.J. and P.J. VOGT. Hydrogeology and historical assessment of a classical sequential land US site, Illinois, USA. *Environmental Geology and Water Sciences*. 1990, 15, pp. 165–178.
- [7] OLAYINKA, A.I. and M.A. OLAYIWOLA. Integrated use of geophysical imaging and hydrochemical methods in delineating limit of polluted surface and groundwater at a landfill site in Ibadan area, Southwest Nigeria. *Journal of Mining and Geology*. 2000, 37(1), pp. 193–198.
- [8] KAYABALI, K., F.A. YUEKSEL and T. VEKEN. Integrated use of hydrochemical and resistivity methods in groundwater contamination caused by recently closed solid waste site. *Environmental Geology*. 1998, 36(3), pp. 227–234.
- [9] BARKER, R.D. The Application of electrical tomography in groundwater contamination studies. In: 58th Annual Conference and technical exhibition extended abstract. EAGE, 1996, pp. 82.
- [10] CHRISTOPHER, L.B. and S.A. JONES. Subsurface evaluation of the Wes parking lot and land filling 3 Areas of Air force plant 4, Forth Worth, Texas, using 2-D direct current resistivity profiling. *US Geological survey*. 1999, pp. 1–11.
- [11] IBE, K.M. and J.C. NJOKU. Migration of contaminants in groundwater at a landfill site in Owerri, South East Nigeria. *Journal of Environmental hydrology*. 1999, 7(8), pp. 1–9.
- [12] UDOM, G.J. and E.O. ESU. A preliminary assessment of the impact of solid wastes on soil and groundwater in parts of Port Harcourt city and its environs, Rivers State Nigeria. *Global Journal of Environmental Science*. 2004, 4(1), pp. 234–239.
- [13] UGWU, S.A., H.O. NWANKWOALA and S.N. WORLU. Effects of waste dumps on groundwater using geophysical methods. *Journal of Applied Science & Environmental Management*. 2016, 13(1), pp. 35–49.
- [14] ROSEQVIST, P.O. Geology of South African Basement Complex. *Journal of Mining and Geology*. 2003, 1, pp. 110–121.
- [15] SAMSUDIN, A.R., B.E.A. RAHIM, W.Z.W. YAACOB and U. HAMZAH. Mapping contamination plumes at municipal solid wastes disposal sites using geoelectric imaging technique: case studies in Malaysia. *Journal of Spatial Hydrology*. 2006, 6(2), pp. 13–22.
- [16] EHIRIM, C.N., J.O. EBENIRO and D.A. OGWU. A geophysical and hydrophysiochemical impact of a solid waste landfill in Port Harcourt municipality, Nigeria. *Pacific Journal of Science Technology*. 2009, 10, pp. 596–603.
- [17] SHORT, K.C. and A.J. STAUBLE. Outline of the geology of the Niger Delta. *AAPG Bulletin*. 1967, 51, pp. 761–769.
- [18] EHIRIM, C.N. and C.N. NWANKWO. Evaluation of aquifer characteristics and groundwater quality using geoelectric method in Choba, Port Harcourt. *Archives of Applied Science Research*. 2010, 2(2), pp. 396–403.