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Characterization and Monitoring of Leachate Plume migration in Active Dumpsite within Basement Complex of Southwest Nigeria using Integrated Geophysical Methods

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ABSTRACT

Infiltration of leachate plume from dumpsite into nearby shallow aquifer units poses a considerable threat to groundwater quality and human health. This study employed integrated geophysical methods (Very low frequency-electromagnetic (VLF-EM) and 2D electrical resistivity tomography (ERT) techniques) to map the conductive lineament structures, extent of leachate plume accretion and migration for likely pollution of nearby shallow groundwater sources. The VLF-EM and 2D ERT surveys were carried out with the aid of ABEM WADI VLF-EM meter and Campus Tigre model terrameter, respectively. Nine VLF-EM traverses of lengths varying between 120 and 250 m and nine 2D ERT traverses (with lengths ranging between 80 and 120 m) utilizing Wenner array arrangement and electrode separation distance varying from 5 to 25 m were mapped in the dumpsite. Control traverses of VLF-EM and 2D ERT surveys were also carried out at roughly 400 m away from the dumpsite. VLF-EM and 2D ERT data were processed and interpreted utilizing Fraser and Karous Hjelt filters as well as RES2DINV code, respectively. The integrated results of Fraser graphs and Karous Hjelt pseudo sections of VLF-EM data revealed west - leaning leachate plumes/conductive lineaments of several depths that cut transversely the dumpsite. However, 2D inverse resistivity sections showed leachate plume of < 10 Ωm that has migrated up to a depth of about 6.5 m at the west side of the dumpsite. The study recognized more of regions of accumulated leachate plume to depths that could have permeate the shallow aquifer units on the western part of the dumpsite.

Keywords:
Dumpsite,
Leachate plume,
2D ERT,
VLF-EM,
Subsurface structure,
Shallow aquifer.

INTRODUCTION

Municipal solid wastes belong to a class of unwanted manufactured goods and/or edible crops and foods that have been used for definite purposes (Wei et al., 2017; Islami et al., 2020). These waste products have their origins from anthropogenic activities and rises as population of human beings increases (Islami et al., 2020; Ganiyu et al., 2016). Increase in amount of municipal solid wastes (MSWs) generated in most of the developing countries is as a result of several factors such as rise in population growth, rural-urban migration, limited available land for safe waste disposal purpose and insufficient provision of well-equipped disposal system that encourages waste to wealth initiative (Orhorhoro & Oghoghorie, 2019; Igelle et al., 2024). The rise in MSWs generation has considerably affected populace and the environment in general (Islam et al., 2020). These waste products (majorly domestic and industrial ones) are collected through various modes and then sent to government approved municipal waste disposal sites. However, there are presence of illegal dumping sites for several kinds of waste materials ranging from MSWs to e -waste in some parts of the country. The kind and amount of solid waste generated in a particular city or country depend on several factors like literacy level, industrialization, consumption pattern, urban development and awareness of residents (Islami et al., 2020; Ojo et al., 2021). The waste products on dumpsite, not only contaminate the dumpsite soil but also leads to various appealing and public health issues (Ojo et al., 2021; Badmus et al., 2022). Various kind of MSWs scattered on open landfill undergo decomposition all the time and generates appreciable amount of leachate apart from several decaying products like dumpsite gas and potentially toxic elements that could migrate away the dumpsite and infiltrates nearby shallow aquifer unit, thereby altering adversely its inherent quality and that of the environment (Islami et al., 2020; Abdel-Shafy et al., 2024). Leachate, conductive liquid formed from decomposed waste materials and major source of trace organic contaminants, has been reported to have higher lower electrical resistivity value (Ganiyu et al., 2016; Islami et al., 2022; Igelle et al., 2024).This means that presence of leachate in permeable subsurface ;structures can improve electrical conductivity of lithological structure from fair to extremely elevated (Raji & Adeoye, 2017). It should be noted that leachate hardly ever stays at the point of release, but are rather migrated horizontally and vertically through the permeable soil matrix/lithology by four major transport processes of diffusion, advection, dispersion and sorption (Memarianfard & Poshtegal, 2015; Mosthaf et al., 2024). Leachate contamination of groundwater system is due to infiltration of pollutants into shallow groundwater sources, thereby compromising the quality of major source of drinking water for local residents (Islami et al., 2020; Igelle et al., 2024). Therefore, siting of municipal solid waste dumpsite within high density residential area with shallow hand dug wells places the underground water resources at high risk.

Geophysical techniques have been used successfully to study various environmental problems as the outcomes of the geophysical methods can be achieved in a comparatively short period, and can be repeated again over the same site at different time interludes (Islami et al., 2020; Igelle et al., 2024). The geophysical technique, particularly electrical resistivity and/or electromagnetic have been broadly utilized either as a stand alone or in integrated form for various environmental issues such as determination of groundwater prospective zones, subsurface characterization for foundation purpose, detection of buried materials, detection of leachate plume movement and groundwater pollution, detection of saline water intrusion along structural discontinuities, etc. (Karlik & Kaya, 2001; Falade et al., 2019; Jamal & Singh, 2018,; Torrese & Pilla, 2021; Alao et al., 2024; Adeniji et al., 2024; Audu et al., 2025). This study involves 2D ERT and VLF-EM techniques due to their capacity in detecting conductive liquids and/or subsurface bodies which represent the main geophysical target of this research study. VLF-EM offers expeditious detection of conductive bodies and lineament/fracture zones within the study site whereas 2D ERT provides both horizontal and vertical distribution of leachate plume (Torrese &Pilla, 2021; Igelle et al., 2024) This makes electrical resistivity imaging technique as reliable tool for mapping the extent of contaminant plume around the dumpsite.

In order to develop an appropriate water management plan in the community nearer the active dumpsite, it is a crucial task to detect the location and extent of contaminant plumes in the vicinity of such waste disposal sites. In such circumstances, integrated approach of geophysical methods provides an important tool in the evaluation and characterization of contaminants (leachate) generated by waste disposal site (Osazuwa and Abdullahi, 2008; Ganiyu et al., 2016; Osinowo et al., 2020). The use of electrical resistivity technique to evaluate the impact of leachate plume on nearby groundwater was well reported (Ugor et al., 2021; Ndifereke 2022; Odong et al., 2024). VLF-EM technique is principally used to detect subsurface conductive materials, fracture zones and faults that might act preferentially as the conduits for the leachate plume movement (Al-Tarazi et al., 2008; Abdullahi et al., 2016; Raji & Adeoye, 2017). By employing 2D ERT and VLF-EM, this study provides a detailed evaluation of the accumulation zone, extent of leachate plume migration and mapping of polluted regions of aquifer units surrounding the dumpsite within a basement complex area.

Several researchers have used resistivity and/or electromagnetic geophysical methods for dumpsite investigation (Sunmonu et al, 2012; Raji & Adeoye, 2017; Osinowo et al., 2020; Okunowo et al., 2020). The purpose of this study is to assess the extent of migration of subsurface plumes originating from decomposed MSWs in Lapite dumpsite. To do so will entail integration of electrical resistivity tomography and very low frequency electromagnetic techniques. To the best of authors' knowledge, there is dearth of study involving delineation of leachate plume migration in Lapite dumpsite with an integrated geophysical methods. The insights gained from the integrated method can assist in selection of the best policy interventions and environmental management strategies to mitigate shallow groundwater contamination. Although, Akintola et al. (2019) employed integrated method comprising few traverses of VLF-EM and 61 VES sounding points, their aim was to assess the suitability of the dumpsite for MSWs disposal by evaluating the hydrogeophysical characteristics of the underlying rocks. Therefore, this study not only presents a maiden approach to investigate the extent of environmental pollution due to migration of leachate plumes within the study area, but also corroborates the benefit of utilizing integrated geophysical methods.

The aim of this research is to map leachate plume contamination in the soil dumpsite and underlying rock units around the MSWs disposal site in order to know its impact on nearby shallow groundwater sources. The objectives of the study include the use of integrated method of 2D ERT and VLF-EM for the detection of leachate plume accumulation regions, identification of leachate geometry and detection of possible groundwater pollution within the vicinity of the dumpsite.

MATERIALS AND METHODS

Site Description and Geological Setting

The study site is Lapite municipal solid waste disposal site located within Ibadan metropolis and lies between Latitude 7.5682^{0}N and 7.57032^{0}N as well as Longitude 03.91160^{0}E to 3.9146^{0}E. The dumpsite was commissioned in 1998 and active up to now. It is sited over 20 acres of land beside old Oyo highway, within Akinyele Local Government area of Oyo State, Nigeria (Popoola & Fakunle, 2016; Akintola et al., 2019). The dumpsite is managed and conserved by government board- Oyo State Waste Management Agency (OSWMA). According to 2016 data of distribution of MSWs generated per annum in Ibadan city as released by OSWMA, Lapite dumpsite received almost 31% of the total generated solid wastes in Ibadan (Ipeaiyeda & Falusi, 2018). Ibadan metropolis was reported to have an average annual precipitation of 1270 mm, average yearly evapotranspiration equals1467 mm coupled with average yearly maximum recorded temperature of 32 to 33^{0}C (Akintola, 1986; Ganiyu, 2025). A detailed explanation of the kind of wastes, heap size and waste segregation in Lapite dumpsite has been previously reported by Ganiyu et al., 2015; Akintola et al. (2019) and Smart et al. (2024). The geological setting of Ibadan city is of Precambrian basement complex of Southern Nigeria. The main lithologies are migmatite, undifferenciated gneiss, quartzite and augen gneisses whereas the insignificant rock kinds are pegmatite, quartz, amphibolites, diorites and xenoliths (Elueze 2000; Bolarinwa, 2017). The predominant rock type underlies the Lapite MSW disposal site is migmatite (Figure 1).

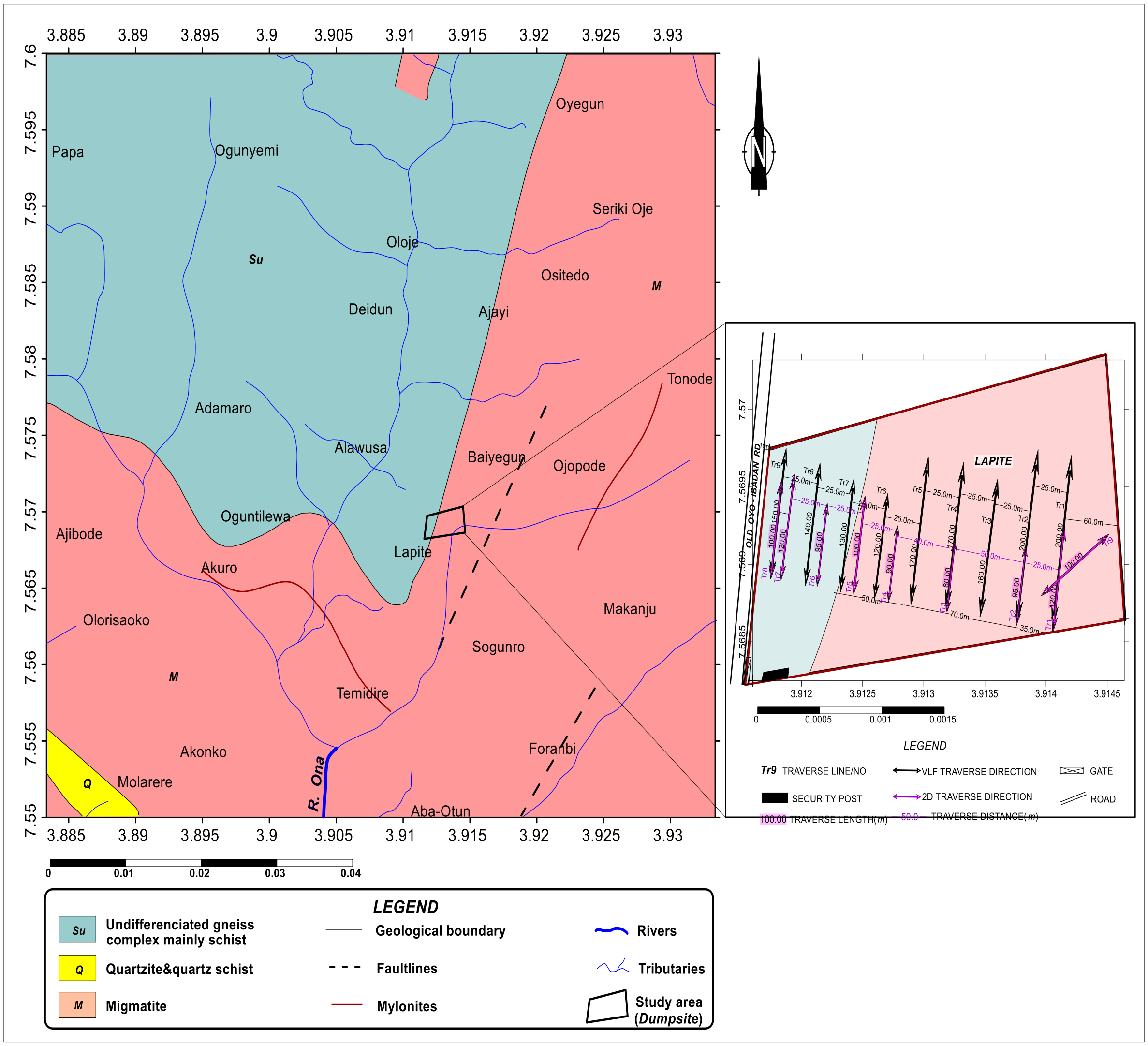


Figure 1: Topographical map of the study site and data acquisition for VLF and 2D ERT surveys

Geophysical techniques

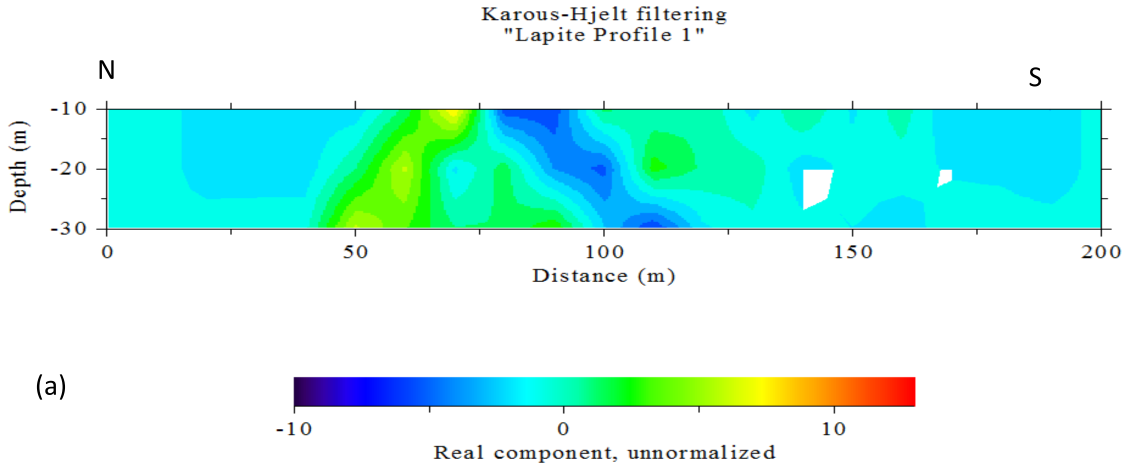
The VLF-EM technique was the first geophysical method carried out on the dumpsite in February 2018 as a reconnaissance survey to detect potential linear conductive subsurface features like faults, fracture zones and leachate accumulation zones. This is followed by a detailed 2D ERT for mapping the extent of leachate plume movement. The Very low frequency electromagnetic technique is a kind of passive electromagnetic method that uses signals of military worldwide network transmitters within the range of 15 – 30 KHz frequency (Raji & Adeoye, 2017; Adagunodo et al., 2023; Adeniji et al., 2024). The theory and principle that govern the operation of VLF-EM method are well described in the literature (Osinowo & Olayinka, 2012; Torrese & Pilla, 2021; Alao et al., 2024). For this study, VLF-EM data were measured using the ABEM WADI VLF meter laterally on each traverse with a spacing interval of 10 m using a signal strength of 18.2 KHz. A total of nine matching VLF-EM traverses with interspace equals 25 m and stretch spanning from 120 to 250 m were established within the open dumpsite. The orientation of VLF-EM traverse was in such a way that all the VLF-EM traverses trend in the North to South direction of the dumpsite. The obtained VLF-EM response data were processed and interpreted using Fraser and Karous Hjelt filtering methods (Fraser, 1969; Karous & Hjelt, 1983). Through the use of KHFFILT software, the filtering procedures enable the computation of pseudosection of the relative current density that forms the real (i.e. in-phase) data as well as extraction of undesirable fluctuations (Fraser, 1969; Adagunodo et al., 2023; Alao et al., 2024). Furthermore, the KHFFILT software was also utilized to transform observed VLF anomalies from raw data to current density distribution plot, fraser filtered data as well as where the backward crossovers modified to negative readings and genuine crossovers changed to positive peak values (Adagunodo et al., 2023; Alao et al., 2024).

In a similar vein, field apparent electrical resistivity readings were obtained across nine (9) 2D ERT traverses within the dumpsite. The apparent resistivity were measured with the aid of terrameter (Campus Tigre 4 - channel model) utilizing Wenner array configuration. Wenner array was adopted for the 2D ERT survey because it offers high anomaly effect as well as high signal to noise ratio (Donohue *et al*., 2012; Ganiyu et al., 2021). The electrode separation distance for each traverse varied from a = 5 to a= 25 m with a regular position spacing of 5 m. All the 2D ERT traverses excluding traverse 9 orient in the north-south bearing of the dumpsite. Control traverse for VLF-EM and 2D ERT was established outside the dumpsite (at 300 m away from the dumpsite). For the apparent resistivity readings, the terameter was set for four cycle stacking and the standard error of measurements of < 1% (Ganiyu et al., 2021). At each measurement, the terameter displayed both the field resistance value as well as root mean square error of the measurement. The field resistance data were later utilized to calculate apparent resistivity (ρ_a) data for all the established traverses. The 2D inverse resistivity models of the subsurface was obtained from the input 2D ERT resistivity data using RES2DINV software (Loke 2008). RES2DINV is a kind of inversion program that automatically determines the 2D and 3D resistivity models of the subsurface materials from the input field resistivity data using smoothness constrained least square technique (Sasaki, 1992; Devendran *et al*., 2003; Ganiyu et al., 2021). Data acquisition map showing the orientations of VLF-EM and 2D ERT traverse lines is presented in Fig. 1.

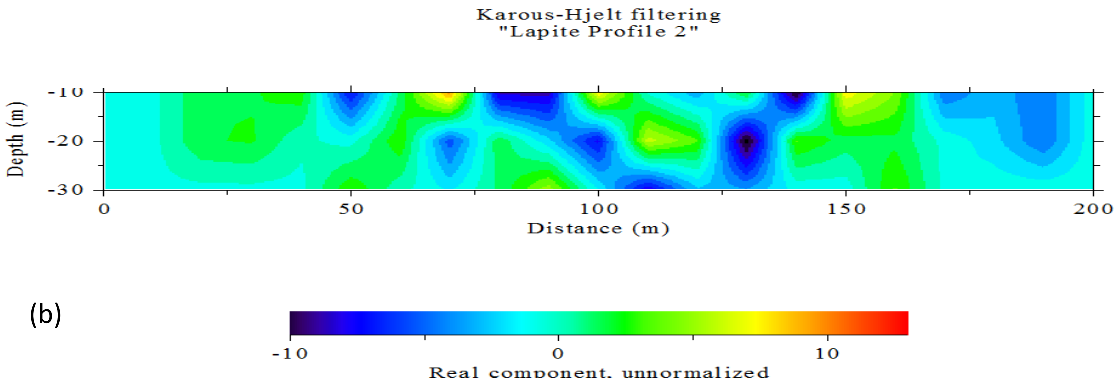
RESULTS AND DISCUSSION

Explanation of VLF-EM readings

The interpretation of VLF-EM readings were done based on the fraser graphs for the spotting of linear conductive materials as well as leachate accretion regions while current density distribution plots revealed the wide and dip of the resistivity anomaly in addition to spatial distribution of leachate plume accumulation zones (Wulandari et al., 2018). The current density distribution plot of VLF traverse 1 indicates positively high at station point 48 m at the base of the plot as well as 75 m at the topmost part of the traverse, suggesting existence of conductive features/lineaments (Fig. 2a). The current density plot of VLF-EM traverse 2 revealed various positions with comparatively great current density readings, suggesting conspicuous existence of permeable subsurface structures and/or leachate plume buildup zones with varied extension depths (Osinowo & Olayinka, 2012; Alao et al., 2024). There is presence of other conductive region at 150 -168 m towards the end of the traverse (Fig.2b).



(a)

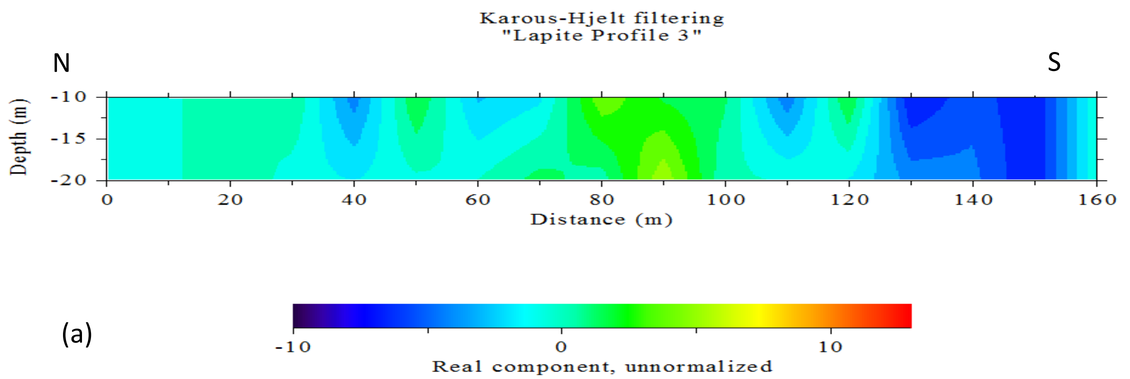


(b)

Figure 2a-b: 2D Current density plots for traverses 1 and 2

The current density distribution of VLF-EM traverse 3 showed marginally high positive current density value, suggesting leachate holding region/ linear conductive layer from 78 m at the top of the current density plot to 98 m near the end of the traverse (Fig. 3a). Signatures of presence of slightly conductive materials allowing the accumulation of leachate was also observed at lateral positions 18 to 25 m and 55 to 105 m across the VLF traverse 4 (as shown in Fig. 3b). The representative current density plot of VLF-EM traverse 4 showed faintly conductive regions at lateral position 18 to 30 m at estimated thickness of 25 m as well as additional linear fracture/fault structure extending from 65 m at the top to roughly 88 at the base of the traverse (as shown in Fig. 3b).

The current density plot (Fig. 4a) revealed that leachate plume/conductive subsurface structures have higher current density value greater than 10 at lateral position 12 to 40 m at approximately 27 m thickness. However, the current density plot of traverse 6 showed that slightly conductive section (with current density value ranging between 0 and 10) was visible between distance 89 and 115 m towards the end of VLF-EM traverse 6 (as shown in Fig. 4b).



(a)

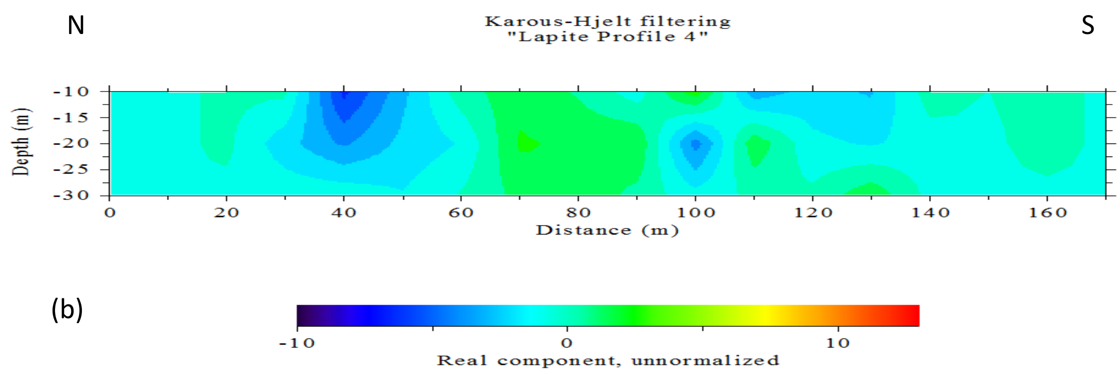
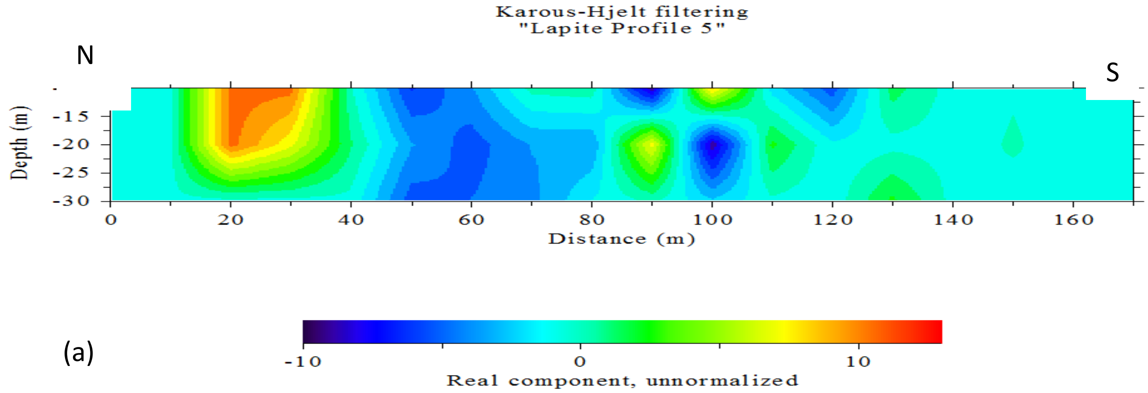


Figure 3a-b: 2D Current density plots for traverses 3 and 4



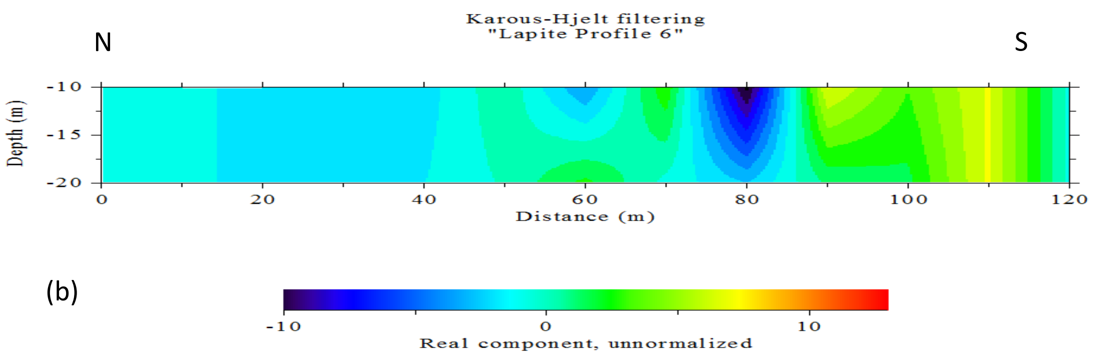


Figure 4a-b: 2D Current density plots for traverses 5 and 6

The current density plot of traverse 7 depicts slightly conductive formation at lateral distance 82 - 96 m of the traverse with approximate depth of 20 m, possibly indicating existence of leachate accumulation section (Fig. 5a). Figure 5b shows that the current density plot of VLF traverse 8 showed weakly conductive anomalies at variable thickness from station points 38 to 42 m and 70 - 82 m along the traverse. From the current density distribution plot of VLF traverse 9, a comparably low positive response manifesting as slightly resistive to slightly conductive bodies were observed at lateral distance 47 to 70 m and 105 to 118 m along the traverse 9 (Fig. 6a).

The current density plot of VLF control traverse delineated two distinct regions pertaining to the current density distribution. The first one is the highly conductivity body between traverse distance 97 and 103 m with current density value greater than 10. This could be clay units, saturated weathered profiles and possibly buried optic fibers pipe under the ground surface (Fig. 6(b)). The second is the highly resistive zone with a current density value < 10. This was noticed at lateral distance 125 - 150 m alongside the VLF-EM traverse. It was observed that signatures for conductive anomalies have been condensed to natural background values at lateral position 152 m of the VLF- EM control traverse, indicating the absence of leachate on this traverse (Fig. 6b).

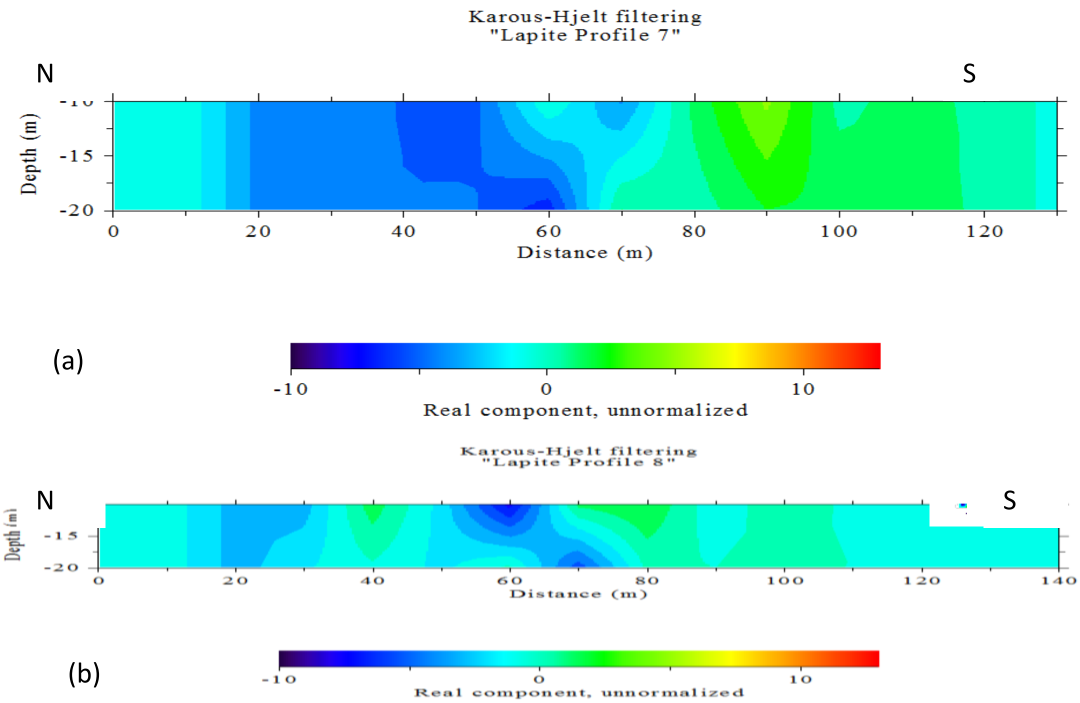


Figure 5a-b: 2D Current density plots for traverses 7 and 8

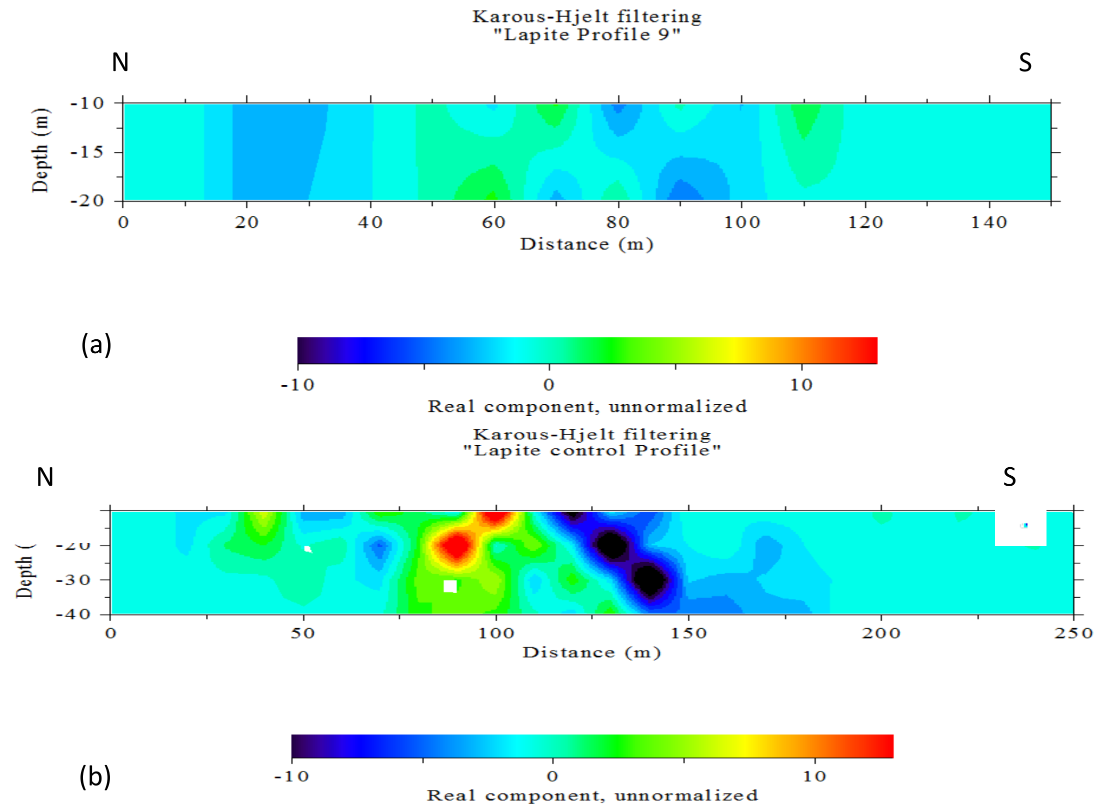
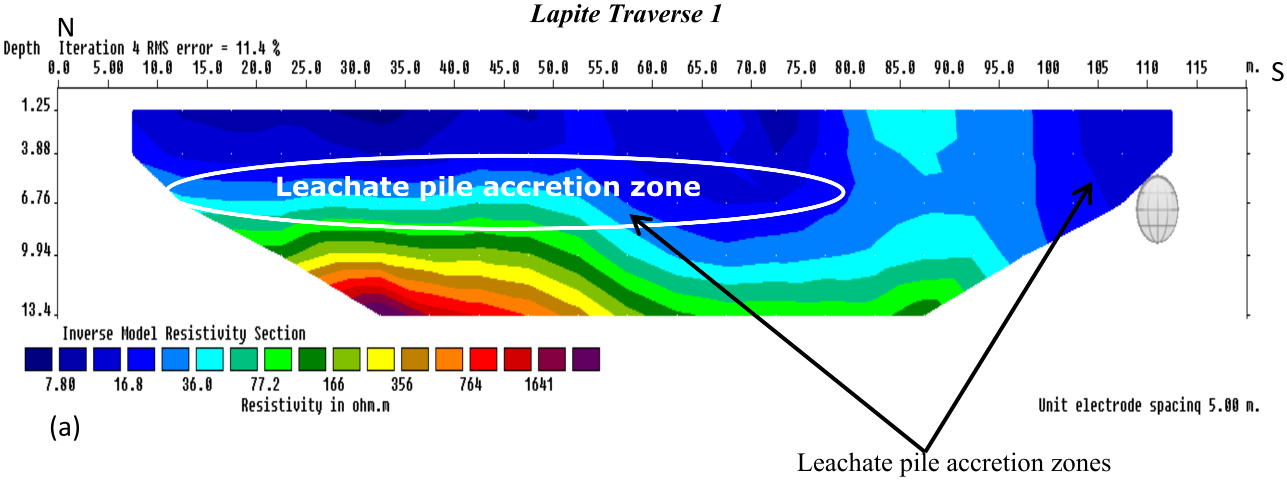


Figure 6a-b: 2D current density plots for traverses 9 and control

The current density distribution plots of laid VLF traverses portray the leachate and permeable conductive lineament as highly conductive zones with current density value ranging between 5 and 10. Generally, the results from the current distribution plots for VLF-EM traverses showed strong existence of conductive anomalies and leachate accumulation sections at the west side of the Lapite dumpsite. This observation concurs with earlier report of Popoola and Fakunle (2016) on the same dumpsite. The west-oriented flow of the leachate plume is also buttressed by reported information by Akintola et al. (2021) that the northwest side of the study dumpsite has lower altitude compared to the remaining axes of Lapite dumpsite. Furthermore Oluokun et al. (2017) reported higher permeability coefficients of the soils at the downslope section of the dumpsite (west side) than those at the upslope part of the Lapite dumpsite.

Explanation of ERT model sections

2D inverted model sections of traverses within and outside the dumpsite are presented in Figures 7a-j. Figure 7a shows the model section for 2D ERT traverse 1. According to this inverted model section, three distinct zones of low resistivity anomalies (< 10 Ωm) were observed at lateral distance 7 to 50 m, 55 to 75 m and 98 to 112 m along the traverse. This is an indication of leachate pile accretion zone. The distance from 78 to 98 m along traverse1 had resistivity readings ranging between 23 and 85 Ωm, corresponding to clay units or saturated weathered profiles (Osinowo &Olayinka, 2012). Figure 7b displays the inverse model pseudo section for ERT traverse 2 wherein low resistivity values (14-23 Ωm), indicating highly conductive materials (possibly clay units) was observed from the beginning of the traverse up to lateral distance 50 m of 2D ERT traverse 2. However, an evidence of leachate plume accumulation (with resistivity values less than 10 Ωm) was noticed from the surface up to 4 m depth at lateral position 50 - 88 m towards the south tail of the traverse. At the base thickness of the section, a comparatively highly resistivity regions, mostly of resistivity greater than 200 Ωm, corresponding to weathered basement were observed. The resistivity depth model of 2D ERT traverse 3 as depicted in Figure 7c showed relatively low resistivity saturated sandy units/ not biodegradable MSWs variegated with latosol (35 -118 Ωm) was noticed at lateral position 7 to 28 m of the traverse. Furthermore, at lateral distance 10 - 25 m of the traverse and at estimated thickness of 4 to 9 m, there is an indication of highly conductive zone which perhaps clay units. The south tail of traverse 3 depicts a distinct pluton at comparatively shallow thickness (6 - 10 m).



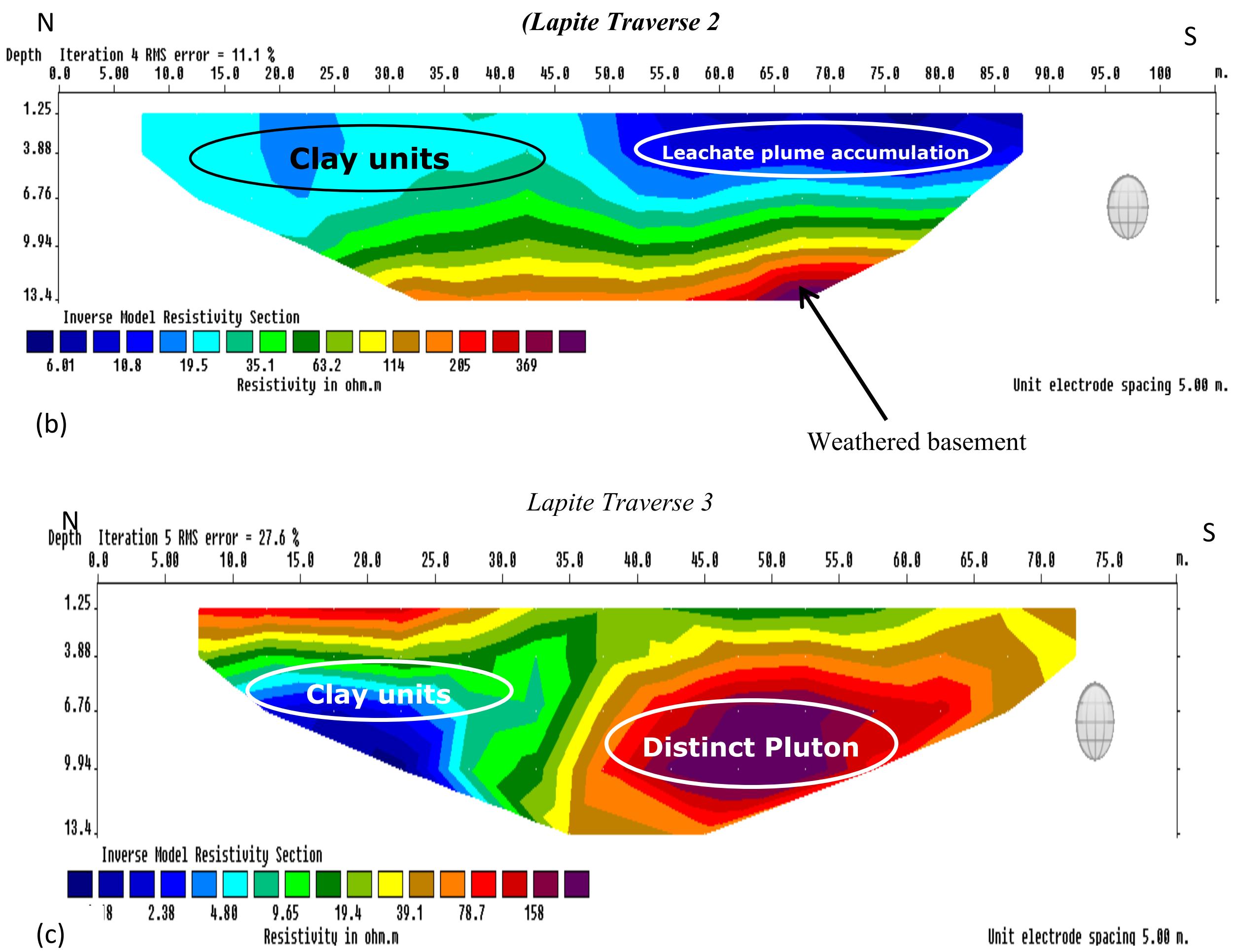


Figure 7: (a-c) 2D ERT model sections for traverses 1, 2 and 3

The inverse model sections for ERT traverses 4, 5, and 6 were depicted in Figures 7d – 7f. There is continuous spread of low resistive zone (< 8 Ωm) starting from the beginning of traverse 4 up till a lateral position 75 m suggesting existence of leachate pile. This leachate accretion zone is restricted to the topmost zone alongside ERT traverse 4. The resistivity distribution on this traverse rises with increase in depth. Furthermore, the crystalline basement region depicts almost even subsurface geomorphology, an indication of even extent of lithology weathering. The 2D inverse model section of ERT traverse 5 showed slight indication of leachate plume existence at lateral distance 7 to 20 m of the traverse (Fig.7e). Another very low resistivity anomaly region (< 11 Ωm) was also observed at lateral distance of 38 to 52 m along the traverse. The 2D model section of traverse 5 further showed that clay cap cover is steady at lateral distances of 22 to 38 m as well as 53 to 100 m near the south end of the traverse. However, at lateral distance of 7 -20 m across the traverse, there was existence of leachate plume zone from the surface up to 3.75 m thick. Figure 7f displays the 2D inverted model section for traverse 6. This model section revealed that the beginning of the traverse up to 35 m was characterized by highly conductive region (less than 8 Ωm) at a thickness of 4 m, suggesting leachate plume accumulation zone. In addition, an occurrence of pocket of very low resistive zone (<10 Ωm) was observed at lateral distance 44 to 58 m across the traverse. As displayed in Figure 7f, it is uncomplicated for the leachate to travel from the point of formation towards the weathered basement on this traverse.

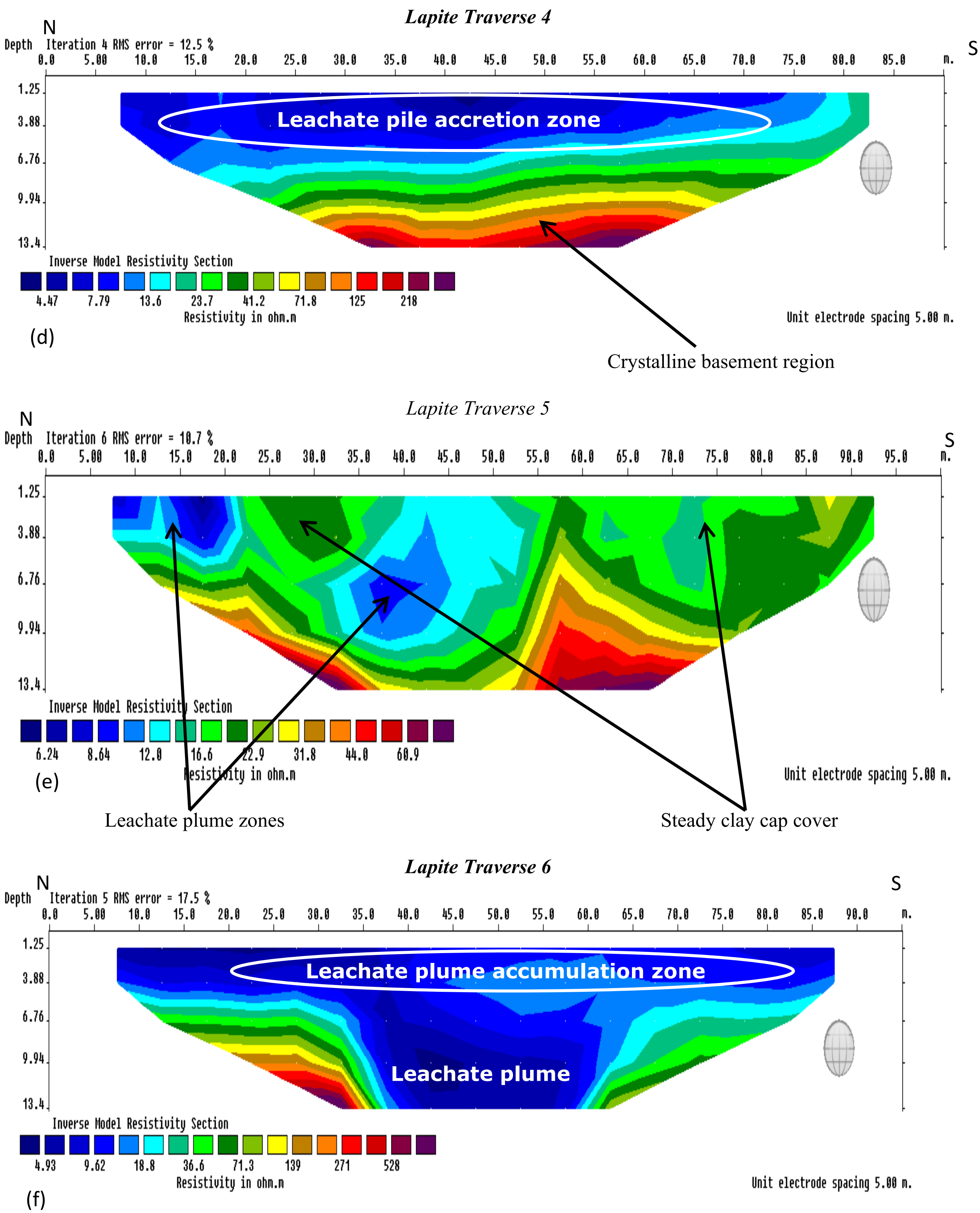
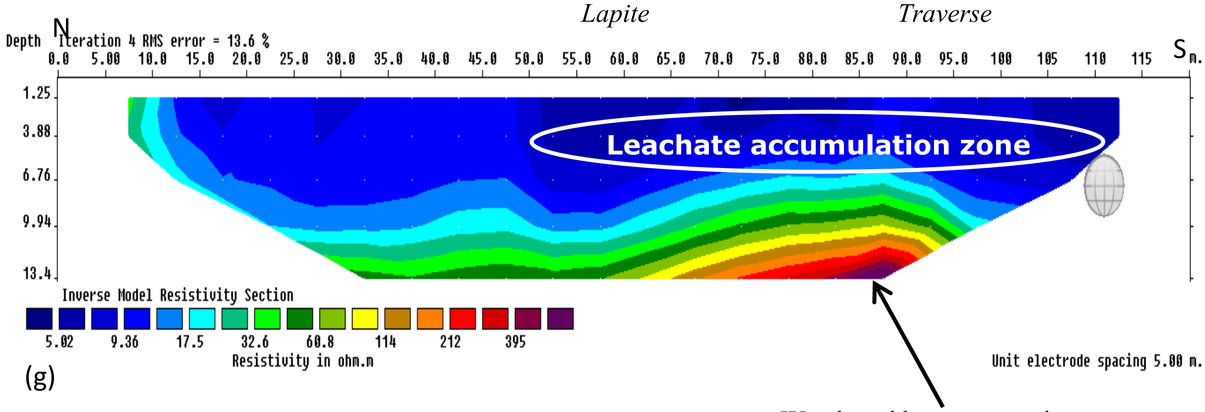


Figure 7: (d-f) 2D ERT model sections for traverses 4, 5, and 6

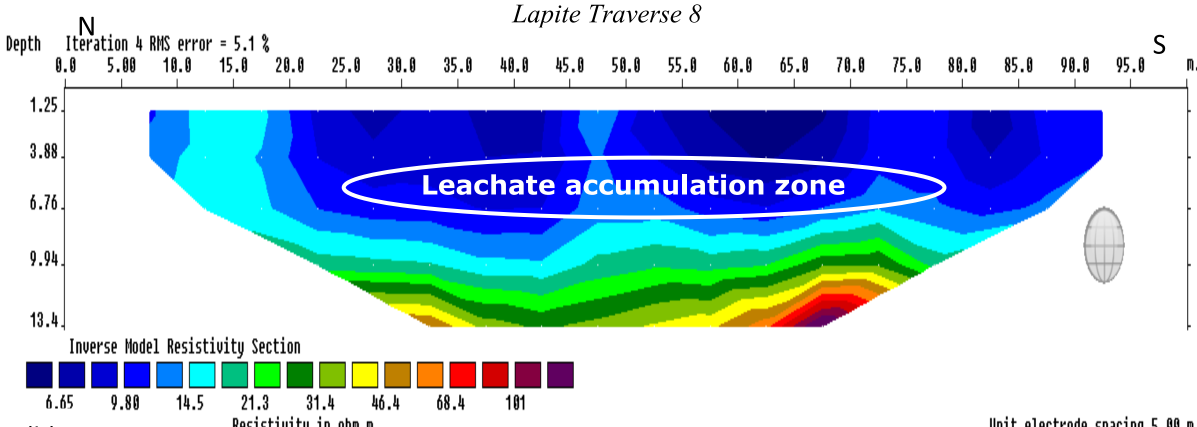
The inverse 2D resistivity sections of traverses 7, 8, 9 and control are presented in Figures 7g - j. From Figure 7g, the 2D inverse resistivity section of traverse 7 revealed low resistivity signature (<10 Ωm), suggesting leachate plume, occurring at lateral distance between 50 and 112 m. A relatively higher resistivity zone (85-141 Ωm), corresponding to weathered basement rock was observed at depth of 10 to 12 m towards the southern part of the traverse. The inverse model section of traverse 8 showed highly conductive signatures (resistivity readings less than 8 Ωm) that protrude from the surface to 6 m thickness (Fg. 7h). This was observed at lateral distance of 20 to 92 m as well as towards the southern end of the traverse. Figure 7i revealed 2D inverse resistivity section of traverse 9, oriented in the East-West of the dumpsite. At lateral distance 20 - 45 m of the traverse, there is a presence of conductive zone /leachate accumulation zone (less than 20 Ωm) that extends from the surface up to a depth of 9 m (Fig. 7i). Another low resistivity anomaly region (< 15 Ωm) also occurs at lateral position 55 - 96 m, in the direction of west tail of the traverse at depth of 9 m. This is an evidence of greater depth of penetration of leachate plume pile at the western side of the dumpsite. The inverse resistivity section for ERT control as shown in Figure 7j revealed a rather diversified and composite subsurface structures wherein higher resistivity signatures zones (above 300 Ωm) were observed at lateral positions 90 to 115 m and 160 to 175 m along the traverse. Furthermore, several isolated highly resistive regions at varying depths were also noticed at lateral positions 10-25 m, 35-45 m, 60-75m, 90 -140 m and 155-175 m, respectively. This confirms no existence of leachate plume on the control traverse which was laid parallel to old Oyo express road. An isolated low resistive region (less than 20 Ωm), corresponding to clay rich unit was observed at lateral distance 130 to 139 m at approximate thickness varying from 4 - 8 m.

Lapite Traverse 7



(g)

Lapite Traverse 8



(h)

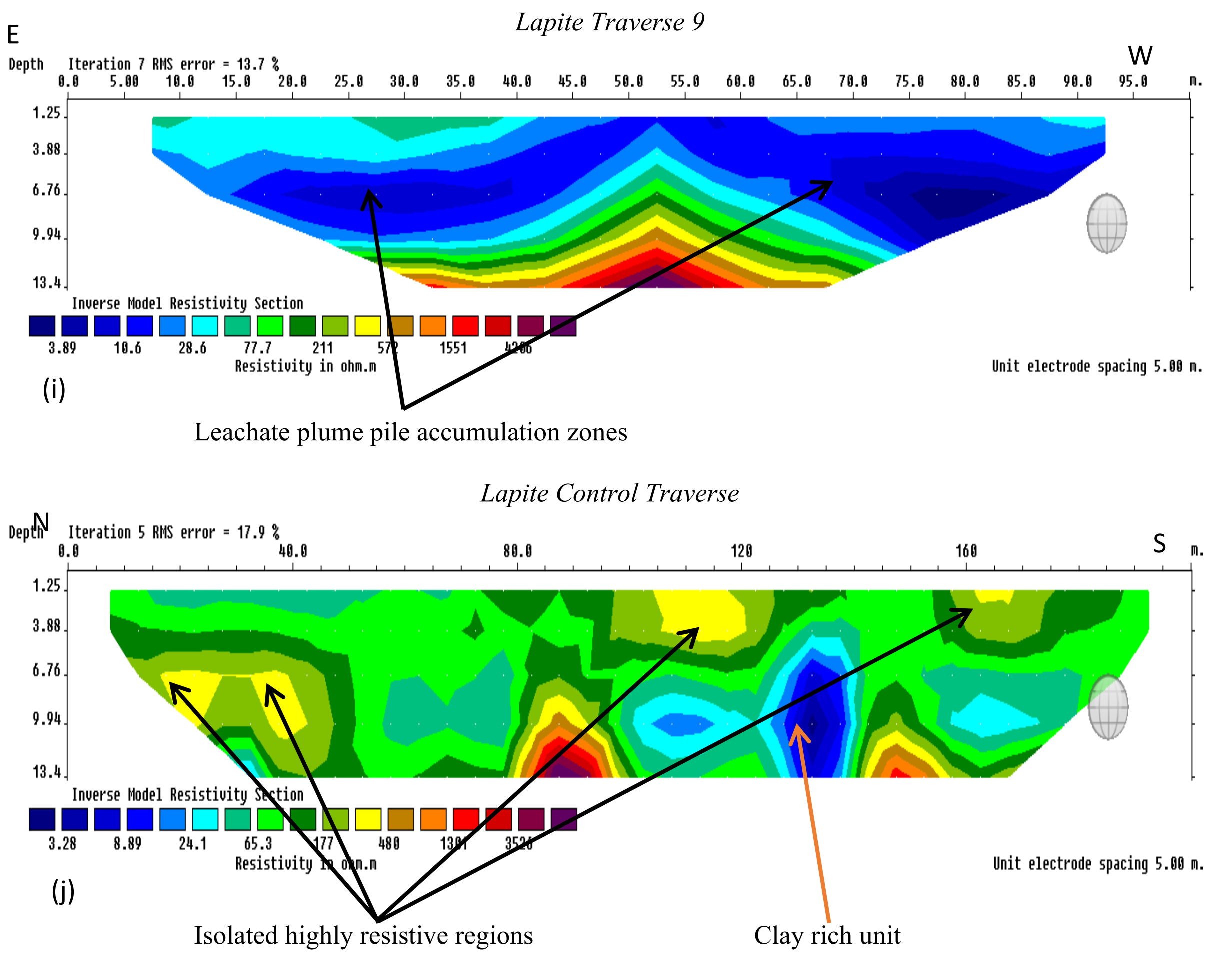


Figure 7: (g-j) 2D ERT model sections for traverses 7, 8, 9, and control

CONCLUSION

The integration of VLF-EM and 2D ERT techniques were employed to investigate the extent of leachate plume accumulation and migration in Lapite dumpsite, southwest Nigeria. The current density distribution plots of VLF-EM traverses indicate conductive lineaments and/or leachate plumes at various depths in addition to greater possibility of the leachate plume having the highest extension depth towards western part of the dumpsite. In terms of 2D ERT, lateral and perpendicular size of leachate piles were mapped as response signatures of the changing electrical conductivity anomalies in the open active MSWs disposal site. The near and direct relationship noticed from the outcomes of VLF-EM and 2D ERT geophysical techniques over the dumpsite established the reliability of the present study. There is potential pollution of aquifer units within the west side of the open dumpsite in the future as a result of movement thickness of the leachate. The leachate could permeate aquifer system sited on the west end of the Lapite dumpsite.

REFERENCES

Abdel –Shafy, H.I., Ibrahim, A.M., Al-Sulaiman, A.M., Okasha, R.A. (2024): Landfill leachate: sources, nature, organic composition, and treatment: An environmental overview. Ain Shams Engineering Journal, 15 (1): 102293.

Abdullahi, N.K., Jegede, S.I., Ango, A. (2016): Qualitative and Quantitative interpretation of the filtered real component of VLF-EM data: Case study of solid waste dumpsite of Precambrian Basement Complex Rocks. American Journal of Engineering Research, 5 (10): 37-46.

Adagunodo, T.A., Ojoawo, A.T., Anie, N.O., Edukugho, P.O. (2023): Application of frequency selection and geoelectrical sounding methods for mapping of leachate pathways in an active dumpsite. SN Applied Sciences, 5:352. https://doi.org/10.1007/s42452-023-0557-8.

Adeniji, A.A., Ajani, O.O., Adagunodo, T.A., Ojo, O.F. (2024): Application of VLF-EM response and geoelectrical sounding in groundwater investigation around an active dumpsite. IOP Conf Series:Earth & Environmental Sci, 1342: 012021. DOI: 10.1088/1755-1315/1/012021.

Akintola, O.O., Adeyemi, G.O., Ariyo, S.O., Bodede, I.A. (2019): Integrated geophysical methods in the characterization of subsurface conditions of Lapite dumpsite in Ibadan, Southwestern Nigeria. FULafia Journal of Science & Technology, 5 (2):88-94.

Alao, J.O., Lawal, M.K., Dewu, B.B.M., Raimi, J. (2024): The effectiveness of Very Low Frequency electromagnetic (VLF-EM) method in detecting buried targets at a controlled site. Discover Applied Sciences, 6(29). https://doi.org/10.1007/s42452-024-05650-6.

Audu, J., Ike, E., Yerima, J.B., Oniku, A.S. (2025): Geophysical investigation of road pavement failure along the Mubi Bypass road, Jambutu, Jimeta, Yola, Adamawa State. Nigerian Journal of Physics, 34(2):28-43. https://doi.org/10.6229/njp.v34i2.2025.369.

Badmus, G.O., Ogungbemi, O.S., Enuiyin, O.V., Adeyeye, J.A., Ogunyemi, A.T. (2022): Delineation of leachate plume migration and appraisal of heavy metals in groundwater around Emirin dumpsite, Ado-Ekiti, Nigeria. Scientific African, 17:e01308. https://doi.org/10.1016/j.sciaf.2022.e01308.

Bolarinwa, A. (2017): Seasonal variation of groundwater chemistry in the Basement and Sedimentary rocks of Ibadan and Lagos Areas, southwestern Nigeria. Earth Science Research, 7 (1):55. https://doi.org/10.5539/esr.v7n1p55.

Devendran, A., Rosli, S., Zuhar, Z.T. and Mohammed, N. (2003): Mapping quarterly sediments using shallow seismic survey USM, seminar on geo-physics: 48-53.

Donohue, S., Long, M., O'Connor, P., Eide-Helle, T., Pffathuber, A.A. and Romoen, M (2012): Geophysical mapping of quick clay: a case study from Smørgrav, Norway. *Near Surface Geophysics*, 10 (3): 207-219.

Elueze, A.A. (2000): Compositional appraisal and pedtrotectonic significance of the Inch banded ferruginous rock in the Ilesha Schist belt, SW Nigeria. J. of Min. Geology 36(1) 9-18.

Falade, A.O., Amigun, J.O., Kafisanwo, O.O. (2019): Application of Electrical Resistivity and Very Low Frequency Electromagnetic induction methods in Groundwater investigation in Ilara-Mokin, Akure, Southwestern Nigeria. Environ &Earth Sci Res J, 6 (3): 125-135.

Fraser DC (1969): Contouring of VLF-EM data. Geophysics, 34:958-967.

Ganiyu, S.A., Badmus, B.S., Oladunjoye, M.A., Aizebeokhai, A.P., Olurin, O.T. (2015): Delineation of leachate plume migration using electrical resistivity imaging on Lapite dumpsite in Ibadan, Southwestern Nigeria. Geosciences, 5 (2): 70-80. https://doi.org/10.5923/j.geo.20150502.03.

Ganiyu, S.A., Badmus, B.S., Oladunjoye, M.A., Ozebo, V.C., Idowu, O.A., Olurin, O.T. 2016. Assessment of groundwater contamination around active dumpsite in Ibadan, Southwest Nigeria using integrated electrical resistivity and hydrochemical methods. *Environ Earth Sci*, 75:643. https://doi.org/10.1007/s12665-016-5463-2.

Ganiyu, S.A., Oladunjoye, M.A., Olobadola, M.O., Aizebeokhai, A.P., Badmus, B.S. (2021): Investigation of incessant road failure in parts of Abeokuta, Southwestern Nigeria using integrated geoelectric methods and soil analysis. Environ Earth Sci, 80:133. https://doi.org/10.1007/s12665-021-09446-4.

Igelle, I.E., Uttah, C., Akim, O., Ekwok, I.C. et al. (2024): Analyzing the extent of leachate from a major dumpsite within the cretaceous sediments of Ikom-Mamfe Embayment, Southeast Nigeria. Carpathian Journal of Earth & Environmental Sciences, 19 (2):328-344. https://doi.org/10.26471/cjees/2024/019/303.

Ipeaiyeda, A.R., Falusi, B.A. (2018): Monitoring of SO_2, NO_x and NH_3 emission from burnimg of solid wastes at Awotan and Lapite Dumpsites, Ibadan, Nigeria. S Afr J Chem, 71:166-173. https://doi.org/10.17159/0379-4350/2018/v71a22,

Islami, N., Irianti, M., Fakhruddin, F., Azhar, A., Nor, M. (2020): Application of geoelectrical resistivity method for the assessment of shallow aquifer quality in landfill areas. Environ Monit Assess, 192:606. https://doi.org/10.1007/s10661-020-08564-z.

Karlik, G, Kaya, A. and Oguz, F.F. (2001): Investigation of groundwater contamination using Electric and electromagnetic methods at an open waste-disposal site. A case study from Isparta, Turkey. Environ. Geol. 40(6): 725-731.

Karous, M., Hjelt, S.E (1983): Linear filtering of VLF dip angle measurements. Geophys prospect. 31:782-794.

Loke, M.H. (2008): RES2DINV- Rapid 2D resistivity and IP inversion using the least square method. Geo-electrical ranging 2D and 3-D GEOTOMO software, Malaysia 145pp. https://www.aarhusgeosoftware.dk/res2dinv.

Memarianfard, M., Poshtegal, M.K. (2015): Leachate transport through Advection-Diffusion and linear Sorption in saturated land. Water Resources, 42 (2): 247-259. https://doi.org/10.1134/S0097807815020086.

Mosthaf, K., Rosenberg, L., Broholm, M.M., Fjordboge, A.S. et al. (2024): Quantification of contaminant mass discharge from point sources in aquitard/aquifer systems based on vertical concentration profiles and 3D modelling. Journal of Contaminant Hydrology, 260:104281. https://doi.org/10.1016/j.jconhyd.2023.104281.

Udosen, N.I. (2022): Geoelectrical modelling of leachate contamination at a major waste disposal site in south-eastern Nigeria. Modelling Earth Systems & Environment, 8: 847-856. https://doi.org/10.1007/s40808-021-01120-9.

Odong, P.O., Ebong, E.D., Awak, E.A., Ojong, R.A., Umera, R.B. (2024): Integrated geophysical and hydrochemical characterization of groundwater vulnerability conditions in part of Ikom-Mamfe Embayment, southeastern Nigeria. Sustainable Water Resources Management, 10 (3): 120.

Ojo, A.O., Olurin, O.T., Ganiyu, S.A., Badmus, B.S., Idowu, O.A. (2022): Electrical Imaging characterization of a dumpsite on an abandoned Quarry site in Abeokuta, Southwest, Nigeria. Scientific African, 17: e01330. https://doi.org/10.1016/j.sciaf.2022.e01330.

Okunowo, O.O., Adeogun, O.Y., Ishola, K.S., Alli, S. (2020): Delineation of leachate at a dumpsite using geo-electrical resistivity method: a case study of Abule Egba, Lagos, Nigeria. SN Applied Sciences, 2:2183. https://doi.org/10.1007/s42452-020-03573-6.

Oluokun, G.O., Agbede, O.A., Adeyemi, G.A., Akinniyi, B.D. (2017): Impact of leachate on permeability characteristics of soil around Lapite dumpsite in Ibadan, Southwestern Nigeria. Int J Res Engr &Appl Sci, 7 (4): 1-10.

Osazuwa, I.B and Abdullahi, N.K. (2008): 2D Electrical Resistivity and Induced Polarization investigation at an open solid waste dumpsite. Case study from Kaduna, North Central Nigeria. Journal of Environmental Hydrology. 16(2a): 1-11.

Osinowo, O.O., Olayinka, A.I. (2012): Very low frequency electromagnetic (VLF-EM) and electrical resistivity (ER) investigation for groundwater potential evaluation in a complex geological terrain around the Ijebu- Ode transition zone, southwestern, Nigeria. Journal of Geophysics & Engineering, 9(4):374-396. https://doi.org/10.1088/1742-2132/9/4/374.

Osinowo, O.O., Agbaje, M.A., Ariyo, S.O. (2020): Integrated geophysical investigation techniques for mapping cassava effluent leachate contamination plume at a dumpsite in Ilero, southwestern Nigeria. Scientific African, 8: e00374. https://doi.org/10.1016/j.sciaf.2020.e00374.

Popoola, O.I., Fakunle, M.A. (2016): Determination of maximum horizontal distance (XHMD) travelled by landfill leachate from Lapite Dumpsite in Ibadan, southwestern Nigeria. Analele Universitatii de Vest din Timisoara, 59:18-29. https://doi.org/10.1515/awutp-2016-0004.

Raji, W.O., Adeoye, T.O. (2017): Geophysical mapping of contaminant leachate around a reclaimed open dumpsite. Journal of King Saud University-Science, 29:348-359. http://dx.doi.org/10.1016/j.jksus.2016.09.005

RES2DINV manual (2006): Electrical Imaging of 2D data. Geolomo software, Penang, Malaysia.

Sasaki, Y. (1992): Resolution of resistivity tomography inferred from numerical simulation. Geophysical prospecting, 40: 453-464.

Smart, M.O., Okumodi, B.O., Ibiyeye, D.E., Roberts, A.E., Olunloyo, O.O. et al. (2024): Concentration and ecological risk assessment of PTEs in soils around Lapite Dump site, Akinyele Local Government Area, Ibadan, Nigeria. J Appl Sci Environ Manage, 28(1):19-25.

Sunmonu, L.A, Olafisoye, E.R., Adagunodo, T.A, Ojoawo, I.A. and Oladejo, O.P (2012): Integrated Geophysical survey in a Refuse dumpsite of Aarada, Ogbomoso, Southwestern Nigeria. IOSR Journal of Applied Physics vol 2(5): pp11-20.

Torrese, P., Pilla, G. (2021): 1D-4D electrical and electromagnetic methods revealing fault-controlled aquifer geometry and saline water uprising. Journal of Hydrology, 600:126568. https://doi.org/10.1016/j.jhydrol.2021.126568.

Wei, Y., Li, J., Shi, D., Liu, G., Zhao, Y.Shimaoka, T. (2017): Environmental challenges impending the composting of biodegradable municipal solid waste: A critical review. Resources, Conservation and Recycling, 122:51-65. https://doi.org/10.1016/j.resconrec.2017.01.024.

Wulandari, A., Anggari, E.A., Dwiasih, N., Suyanto, I. (2018): Estimation of existence geothermal manifestation using very low frequency (VLF) method in the Pagerkandag Vulcanic, Dieng, Central Java. IOP Conf Series: Earth & Environmental Sciences, 132:012023. https://doi.org/10.1088/1755-1315/132/1/012023.