Application of Electrical Resistivity Method in the Assessment of the Suitability of a Proposed Filling Station for Burial of Metallic Utilities, Akure, Southwestern Nigeria.

Ojo, Bosede Taiwo[1], Bawallah, Musa Adesola[1], Ajayi Damilola Samuel[1]. Afolabi, Daniel Oluwafunmilade[1]
Department of Applied Geophysics, Federal University of technology, Akure

Corresponding Author's Email: danielafolabi31@gmail.com

Abstract

Geophysics has been employed as a tool for site location of a proposed petrol station in Akure metropolis. The electrical resistivity method involving vertical electrical sounding (VES) of AB/2 = 100 m was engaged for this study. The technique deployed allowed for delineation of layer stratifications, identification and overburden thickness for a good understanding of the suitability of the site for the burial of metallic utilities. The resistivity map and the thickness map of the intermediate horizon produced from the VES data which is the interest of the study indicate that the area is underlain with resistive materials with resistivity values in the range of 185–291 Ωm and thickness in the range of 4.2–8.2 m. These primary geoelectric parameters indicate the competence of the subsurface for the burial of metallic utilities. Furthermore, the longitudinal conductance map with values in the range of 0.043–0.073 Ω^{-1} and transverse resistance map with values in the range of 2727–16474 Ω indicate that the area is underlain by resistive materials that would not pose a threat of corrosion to the buried metallic tanks and pipes. Therefore, the study recommends that the study area is ideal for the burial of metallic tanks and pipes. However, the central area is considered very favorable due to the extensive overburden thickness in the zone.

Keywords: Electrical resistivity, Metallic tanks and pipes, Corrosivity, Longitudinal conductance, Transverse resistance.

Application de la méthode de résistivité électrique à l'évaluation de l'adéquation d'une station-service proposée pour l'enfouissement d'utilitaires métalliques, Akure, sud-ouest du Nigéria.

Résumé

La géophysique a été utilisée comme outil pour localiser le site d'une station-service proposée dans la métropole d'Akure. La méthode de résistivité électrique impliquant un sondage électrique vertical (SEV) de AB/2 = 100 m a été utilisée pour cette étude. La technique déployée a permis de délimiter les stratifications des couches, l'identification et l'épaisseur des morts-terrains pour une bonne compréhension de l'adéquation du site à l'enfouissement d'utilités métalliques. La carte de résistivité et la carte d'épaisseur de l'horizon intermédiaire produites à partir des données SEV qui constituent l'intérêt de l'étude indiquent que la zone repose sur des matériaux résistifs avec des valeurs de résistivité comprises entre 185 et 291 Ωm et une épaisseur comprise entre 4,2. –8,2 m. Ces paramètres *géoélectriques primaires indiquent la compétence du sous-sol pour l'enfouissement des utilités métalliques. De plus, la carte de conductance longitudinale avec des valeurs comprises entre 0,043 et 0,073 Ω^{-1} et la carte de résistance transversale avec des valeurs comprises entre 2 727 et 16 474 Ω indiquent que la zone repose sur des matériaux résistifs qui ne constitueraient pas une menace de corrosion pour les réservoirs et canalisations métalliques enterrés. Par conséquent, l'étude recommande que la zone d'étude soit idéale pour l'enfouissement de réservoirs et de canalisations métalliques. Cependant, la zone centrale est considérée comme très favorable en raison de l'épaisseur importante des morts-terrains dans la zone.*

Mots-clés : Résistivité électrique, Réservoirs et canalisations métalliques, Corrosivité, Conductance longitudinale, Résistance transversale.

Introduction

Environmental pollution from leakages of petroleum products has been on the increase in recent times due to leakage from buried metallic utilities such as pipes and tanks (Nwankwo and Emujakporue, 2012; Akinlalu *et al.,* 2016). Corroded metallic utilities have been found to be the major cause of organic pollution and contamination in urban areas, causing infiltration of organic pollutants such as petroleum products into adjoining aquifer units (Yokus, 2022). Corrosion of these metallic utilities on the other hand, has been attributed to the placement and burial of the metallic utilities in subsurface materials that are conductive because of being saturated with water, leading to the ionic exchange and corrosive action on the metallic utilities (Ntarlagiannis *et al.,* 2015).

Geophysics has been found to be of very many useful applications in the service of mankind. Some of these areas include but are not limited to the followings: mineral and groundwater exploration, civil engineering and foundation studies, environmental studies as well as structural evaluations for a better understanding of the dynamics of geology (Sherma, 1997). Due to the ability of geophysical techniques to map and delineate subsurface materials, it has been engaged extensively in the planning and design of depots involving organic and petroleum products storage (Akinlalu *et al.,* 2016; Yokus, 2022) to curtail the environmental pollution that may arise from corroded buried metallic utilities. The use of electrical resistivity method has been found the most appropriate in assessing the suitability of a site for the burial of metallic utilities (Ntarlagiannis *et al.,* 2015). This is due to its ability in identifying subsurface formations, including depth of occurrence and extent (Abiola *et al.,* 2009; Adelusi *et al.,* 2013). Furthermore, a conductive zone is known to be corrosive and the parameter of measurement of the electrical resistivity method (apparent resistivity) is the inverse of conductivity, and therefore can be used as a direct tool in determining the suitability of a site for burial of metallic utilities.

In this present study, geophysics has been engaged as a tool to determine the suitability or otherwise of the present study site to identify a suitable place(s) for burial of tanks and pipes in a proposed petrol station in the area. To be able to achieve this, geophysical technique involving the electrical resistivity method was adopted to give an informed decision on the suitability of the site for burial of metallic utilities.

Site Description and Geology of the Study Area

The study area is located within Akure metropolis, bounded by latitude 7°14'30"N and 7°16'0"N and longitude 5°6'30"E and 5°10'0"E (Figure 1). It is accessible via the Itaoniyan road through the Akure Army Barrack base. It has two peaks of rainfall in April and August with a mean annual rainfall between 1000 and 1500 mm and a mean annual temperature of 27°C (Iloeje, 1981). The topography of the study area is slightly uniform with a mean elevation of 342 m above sea level (Aluko, 2008). The geology of the study area is typical of the southwest basement complex of Nigeria, where the geology is characterized by eight petrological units of the basement complex of southwestern Nigeria involving Migmatite–Gneiss, Quartzite, Charnockite, Biotite–Gneiss, Pelitic–Schist, Granit–Gneiss, Porphyritic Granite and Amphibolite (Rahaman, 1989; Owoyemi, 1986; Odeyemi *et al.,* 1999; Aluko, 2008; Adebiyi *et al.,* 2018). This also includes superficial deposit of clay and quartzite (Olubusola *et al.,* 2018). In addition, the association of the fine–grained Charnockite and porphyritic Biotite–Hornblende Granite suggests a common age (Omotoyinbo, 1994).

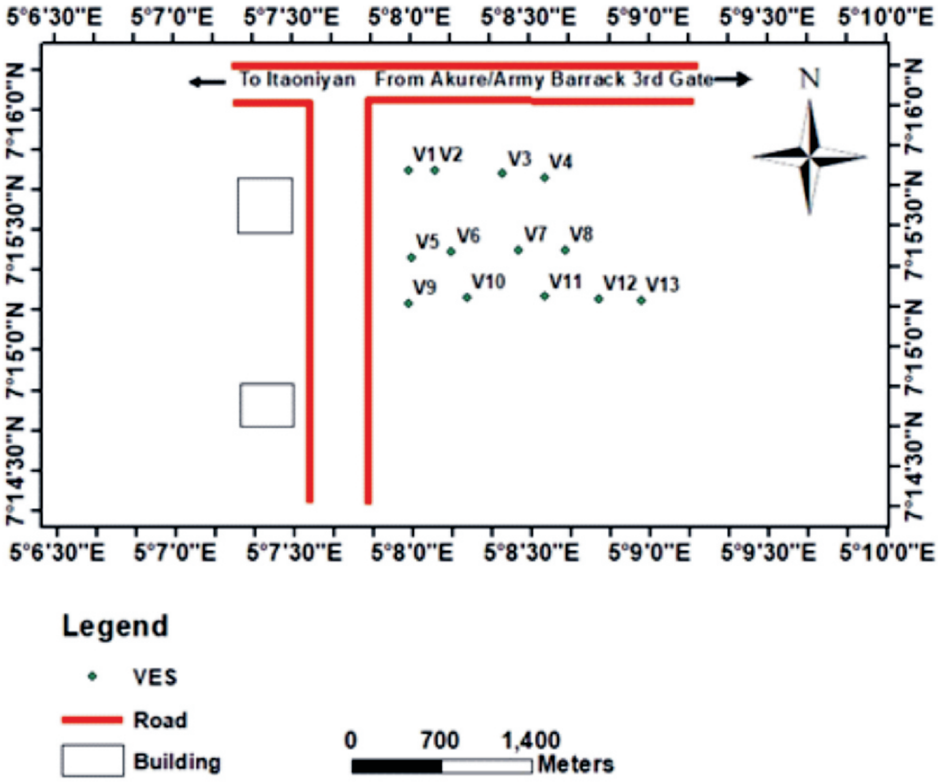

Figure 1: Location Map of the Study Area

However, the local geology of the study area reflects the geology of the southwestern part of Akure metropolis. This is predominantly characterized by Migmatite–Gneiss covering the entire part of the study area. This lithologic unit extends beyond the study area. There are also occurrences of Quartzite in the northern, eastern, and western parts of the study area (Figure 2).

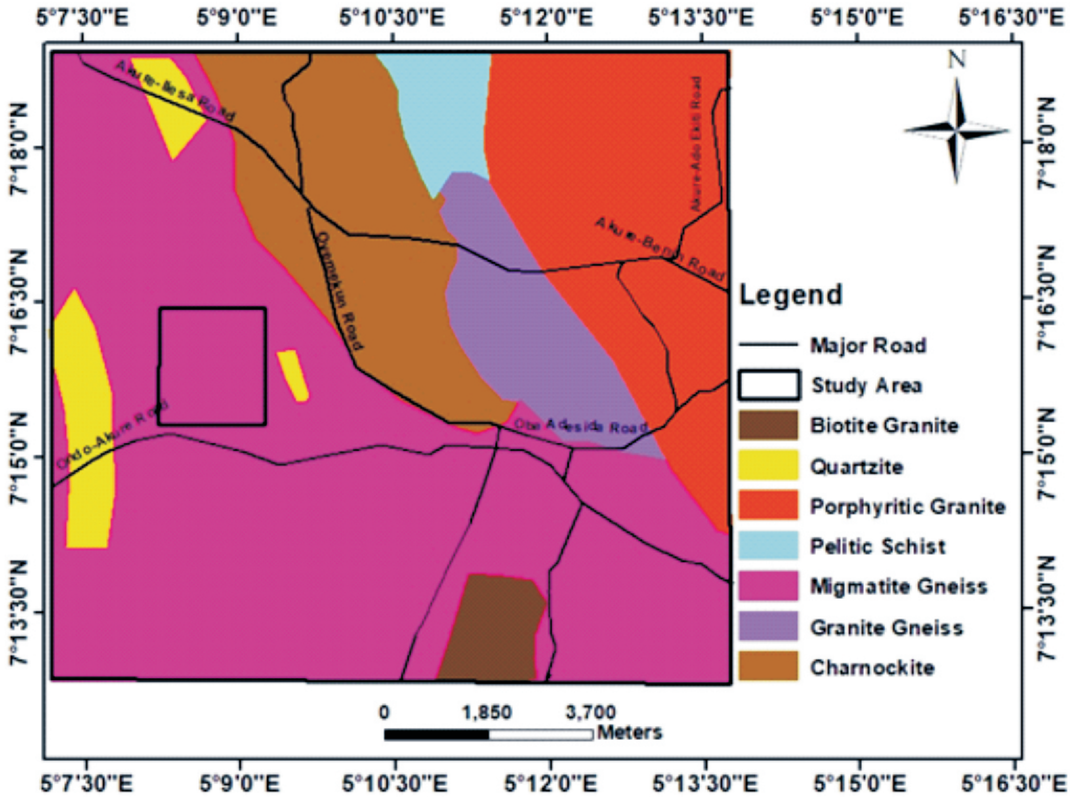

Figure 2: Geological Map of the Study Area

Methodology

The geo-electrical resistivity survey method was adopted for this study. The geo–electric resistivity data vertical electrical sounding (VES). Three traverses were oriented approximately in the E–W direction. A total of thirteen VES data were occupied on the three traverses with AB/2 ranging between 1 and 100 m (Figure 1). The VES field data were processed by plotting the apparent resistivity values against electrode spread on a bi–log paper. The result was thereafter compared with model curves by iterating the geoelectric parameters obtained on the WinResist software until the perfect fit is obtained. The interpretation of the VES data was done qualitatively and quantitatively. The geoelectric parameters (layer resistivity and thickness) obtained from the iterated data were used to calculate the Dar–Zarrouk parameters such as longitudinal conductance and transverse resistance to give better insight in regard to the suitability of the study area for burial of tanks and pipes (Telford *et al.,* 1991; Reynolds, 1998; Milsom, 2003).

Geoelectric Parameters

Geoelectric parameters such as resistivity and thickness were derived from the VES data. The resistivity values of the subsurface can be used to determine the suitability of a site for burial of metallic objects. This is because there is a direct relationship between conductivity and corrosivity. Relatively low resistivity values in the range of 20–120 Ωm are considered conductive and are indicative of clayey formation or highly saturated formation (Sherma, 1997; Akinlalu *et al.,* 2016; Adesola *et al.,* 2021). This, therefore, means that buried metallic utilities in areas of relatively low resistivity values in the range identified above are susceptible to corrosion, which will in turn, have negative impact on the environment. This is mainly because toxic and harmful substances stored in the corroded tanks and pipes can leak into adjoining aquifers, thereby causing contamination and pollution of the groundwater system in the area. The corrosivity index with respect to resistivity values using Sherma (1997) classification is presented in table 1.

Table 1: Relationship between resistivity and corrosivity (Sherma, 1997).

Resistivity (Ωm)	Corrosivity Index
1–100	Extremely High
100 – 130	High
130 – 150	Moderate
150 - 200	Low
= 200	Very Low

The thickness of a layer is important in assessing the suitability of a site for burial of metallic utilities such as tanks and pipes. The depth of burial of most tanks for petroleum and other combustible liquids ranges between 5 ft (1.524 m) and 7 ft (2.134 m) (STI, 2011). This implies that a resistive layer having thickness more than 7ft (2.134) is appropriate for burial of metallic utilities such as pipes and tanks for underground storage of petroleum products.

Dar–Zarrouk Parameters

The Dar–Zarrouk parameters employed for this study are the longitudinal conductance and transverse resistance. They are regarded as the second order geoelectric parameters because they are essentially derived from the first order geoelectric parameters (layer resistivity and thickness) (Telford *et al.,* 1990 Bawallah *et al.,* 2018).

The longitudinal conductance (S) is the sum of all thickness/resistivity ratios of n–1 layer which overlie a semi–infinite substratum of resistivity ρ (eq. 1).

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \dots + \frac{h_{n-1}}{\rho_{n-1}} \qquad 1$$

It is used to assess the clay content and degree of saturation of subsurface lithology, thereby serving as an aid in determining the susceptibility of an area to corrosivity (Sherma, 1997; Oladapo *et al.,* 2004; Abiola *et al.,* 2009; Akinlalu *et al.,* 2016; Bawallah *et al.,* 2018; Akinlalu *et al.,* 2021). The longitudinal index and its relationship as regards saturation and in turn corrosivity based on the classification of Foster *et al.* (2002) is given in table 2.

Table 2: Relationship between longitudinal conductance values and degree of saturation (Foster *et al.,* 2002).

Longitudinal Conductance Values (Ω^{-1})	Degree of Saturation
0–0.045	Very Low
0.045–0.09	Low
0.09–0.2	Moderate
0.2–0.4	High
0.4–0.8	Very High
0.8–2	Extremely High

The transverse resistance, T is defined as the sum of the layer thickness and resistivity as expressed in eq. 2.

$$T = \int_{i=1}^{n} h_i p_i = h_1 p_1 + h_2 p_2 + h_3 p_3 + \cdots + h_n p_n \qquad 2$$

The transverse resistance is important in assessing the degree of saturation of the subsurface lithology. It is essentially the inverse of longitudinal conductance and can be used in assessing the suitability of a site for the burial of metallic utilities. Transverse resistance values often in the range of 2000 Ω and greater are considered to contain resistive materials, thus would not corrode metallic utilities when buried within them.

Shallow Horizon Maps

Figure 3 shows the resistivity of the topsoil/shallow horizon map. It is characterized by four geologic settings associated with Sandy Clay with layer resistivity between 101–130 Ωm, found to be dominant in the northern with patches of occurrence in the centre and southern parts of the study area. Resistivity values in the range of 130–1500 Ωm, indicative of Clayey Sand materials is found to be dominant in the central part of the study area and extend to the southern part of the study area. Also, resistivity values in the range of 150–170 Ωm, indicative of Sandy materials are observed to have major occurrences in the eastern and western parts of the study area. Patches of highly weathered materials with resistivity values in the range of 170–194 Ωm and weathered materials with resistivity values in the range of 194–228 Ωm are observed to have minor occurrences in the northwestern, western, and southeastern parts of the study area. The General assessment of the resistivity map of the shallow horizon indicates there is minimal moisture content within the topsoil that would pose a threat to buried metallic pipes and tanks. However, regions around the central part of the study area should be avoided because of the constitution of clayey materials within the materials in the area that could cause corrosion of the buried metallic pipes and tanks in the long run.

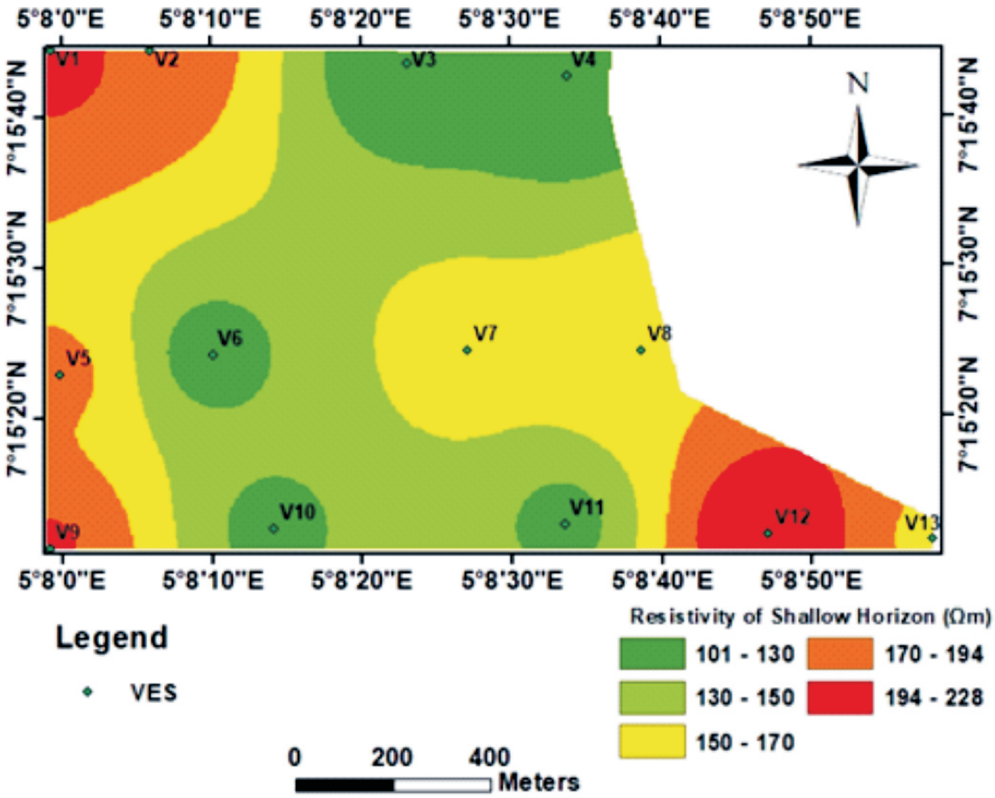

Figure 3: Resistivity Map of the Shallow Horizon

Figure 4 shows the thickness map of the shallow horizon/topsoil. The thickness of the shallow horizon ranges between 0.8 and 2.8 m. The map shows that the central part of the study area is very thin in the range of 0.8 and 1.48 m while the southern, eastern, and western parts with some parts of the north flank of the study area are relatively thick in the range of 1.48 and 2.80 m. Based on the resistivity map of the shallow horizon, the central part is not suitable for long term burial of metallic tanks and pipes. In addition, based on the classification of STI (2011), areas of relatively high thickness in the range of 1.48 and 2.80 m around the western, eastern, northern, and southern parts of the study area are suitable for burial of metallic pipes and tanks considering the relatively high resistivity values present in the areas.

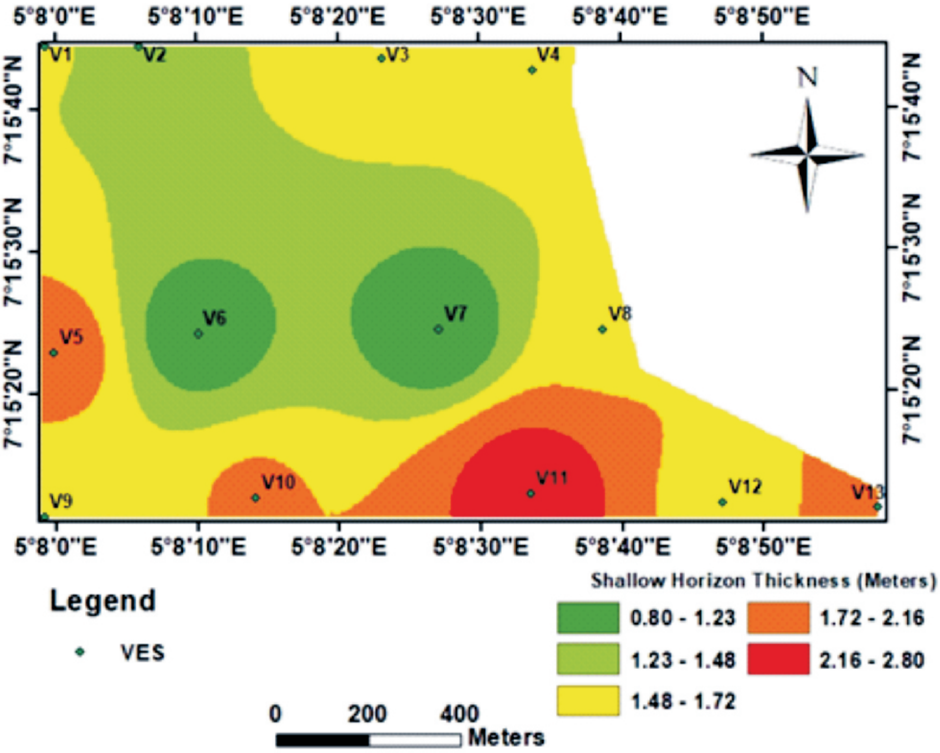

Figure 4: Thickness Map of Shallow Horizon

Intermediate Horizon Maps

Figure 5 shows the resistivity map of the intermediate horizon with resistivity values in the range of 185–291 Ωm. This horizon is of major interest in this study because most depths of burial of buried utilities are within this horizon. Resistivity values in the range of 185–225 Ωm, indicative of Sandy materials have patches of occurrences in the northern, central, and southern parts of the study area. Resistivity values in the range of 225–242 Ωm indicative of Sandy/highly weathered geologic materials are observed to occupy majority of the study area, with dominance in the central, extending to the northern and southern parts of the study area. On the other hand, relatively high resistivity values in the range of 242–291 Ωm, indicative of resistive materials associated with bedrock occurring at shallow depth is found to occur around the southeastern and southwestern parts of the study area.

The intermediate horizon is of primary importance in terms of structural evaluation and delineation of the subsurface for the location and sitting of underground reservoirs and tanks for fuel storage and distribution. Therefore, considering the resistivity of the intermediate horizon, indicates the intermediate horizon is competent for the burial of metallic tanks and pipes due to the absence of conductive materials that could cause corrosion of the pipes or tanks. Furthermore, considering the uniformity and spread of the formation in the central part of the study area, the central part of the study area has all the essential features and geologic settings that may be favorably disposed to the interest of this study.

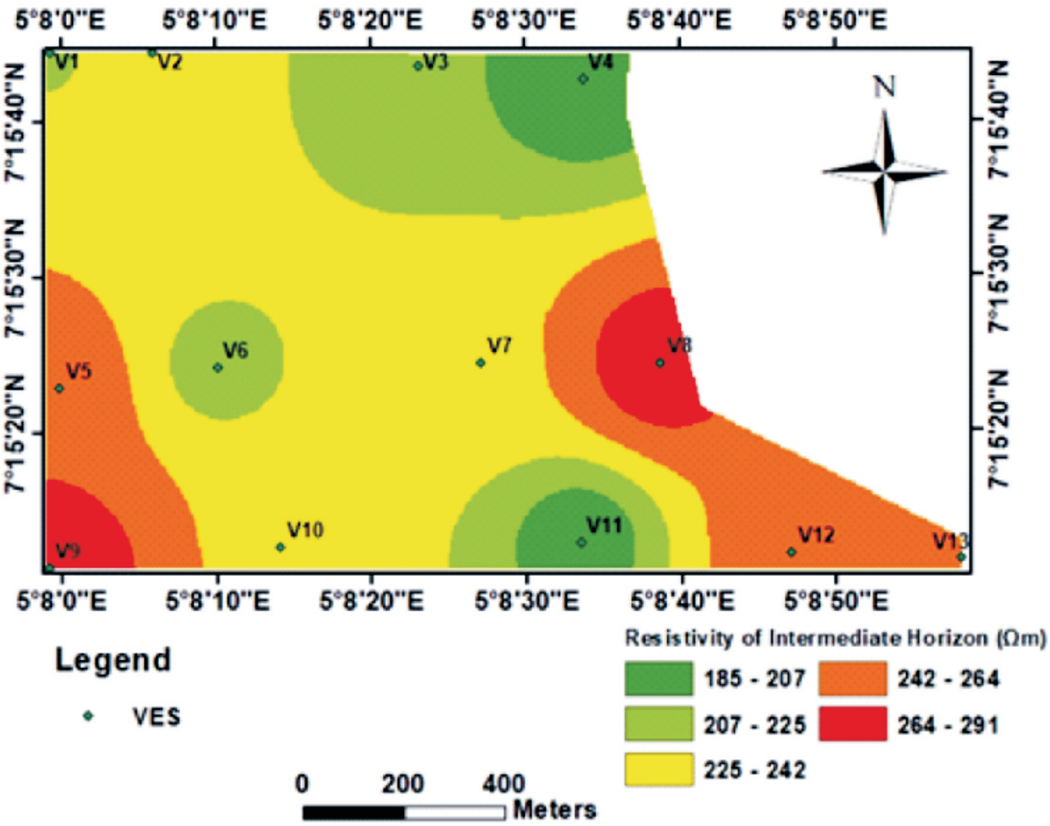

Figure 5: Resistivity Map of the Intermediate Horizon.

Figure 6 shows the thickness map of the intermediate horizon with thickness values ranging between 4.2–8.2 m. Relatively thin thickness values in the range of 4.2–5.71 m is observed to have occurrences in the northern part of the study area, with patches in the southern part of the study area. Moderate thickness values in the range of 5.71–6.21 m is observed to have major occurrences in the central part including the southern and northwestern parts of the study area. On the other hand, very high thickness values in the range of 6.21–8.2 m are observed to have occurrences in the eastern part of the study area, including patches in the northwestern and southwestern parts of the study area. Based on the uniformity observed in the central part of the study area in terms of the resistivity values and since the maximum depth of burial of metallic pipes and tanks for petroleum related products is about 2.134, areas around the central part of the study area are ideal for the burial of the metallic pipes and tanks without fear of corrosion.

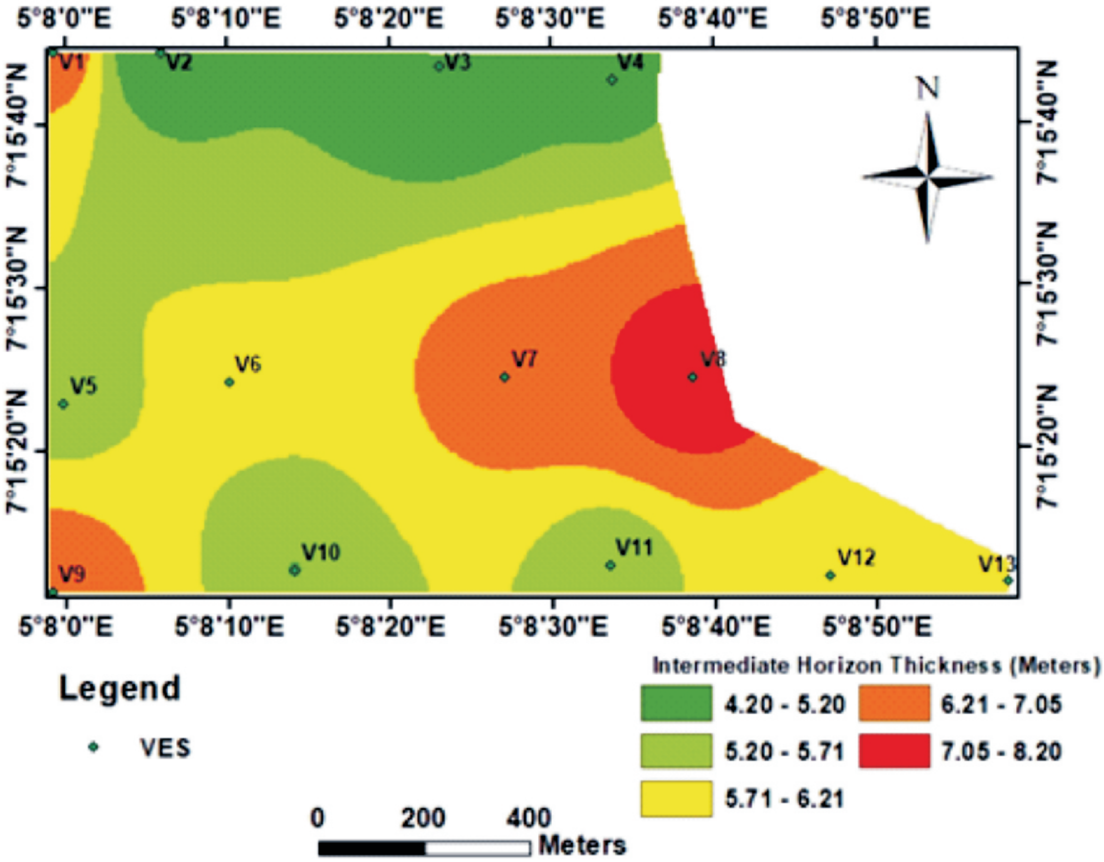

Figure 6: Thickness Map of the Intermediate Horizon

Overburden Thickness Map

Figure 7 shows the overburden thickness map of the study area with thickness values in the range of 5.8–9.8 m. The overburden thickness of the study area indicates that everywhere is suitable for the burial of metallic pipes and tanks because the maximum depth of burial of tanks and pipes for petroleum related products is about 2.134 m. However, the presence of the clayey and conductive materials especially in the northern and southern parts of the shallow horizon of the study area may constitute a long term threat to the longevity of the buried metallic utilities. Therefore, considering the uniformity of the relatively high resistivity values and the thickness of the central part of the study area, the central part of the study area especially around V7 and V8 is ideal for the burial of metallic tanks and pipes.

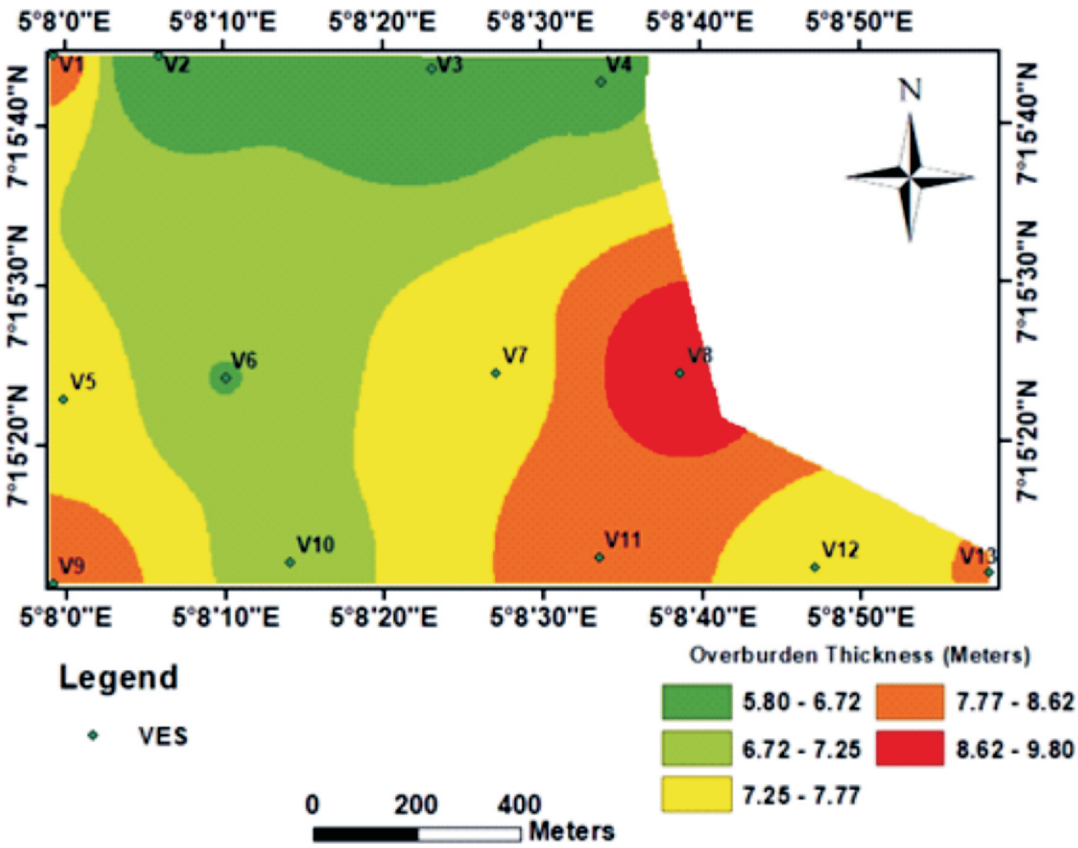

Figure 7: Overburden Thickness Map

Longitudinal Conductance Map

Figure 8 shows the longitudinal conductance map of the study area with values in the range of 0.043 – 0.073 Ω^{-1}. Longitudinal conductance indicates the clayey and moisture content of subsurface materials; it therefore plays a role in the assessment of the suitability of a site for burial of metallic tanks and pipes. Based on the classification of Foster *et al.* (2002), majority of the area has low degree of water saturation, indicating the suitability of the study area for the burial of metallic tanks and pipes. However, the extent of the thickness of the central part of the study area would make it ideal for the burial of metallic pipes and tanks.

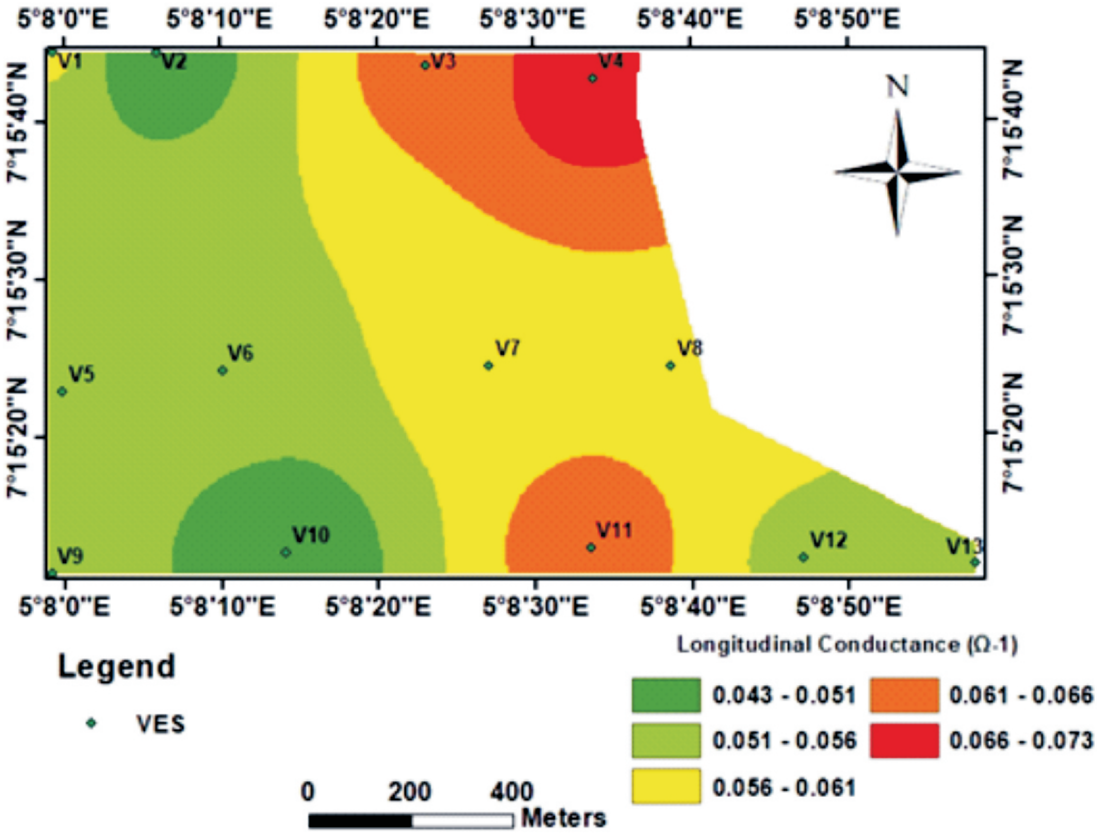

Figure 8: Longitudinal Conductance Map of the Study Area

Transverse Resistance Map

Figure 9 shows the transverse resistance map of the study area with values in the range of 2727–16474 Ω. The values obtained for the transverse resistance indicate that the subsurface materials are characteristically composed of resistive materials. This shows that there is generally a lack of conductive materials that would cause a threat of corrosion to buried metallic utilities. Therefore, that the study area is suitable for the burial of metallic tanks and pipes for petroleum related products storage.

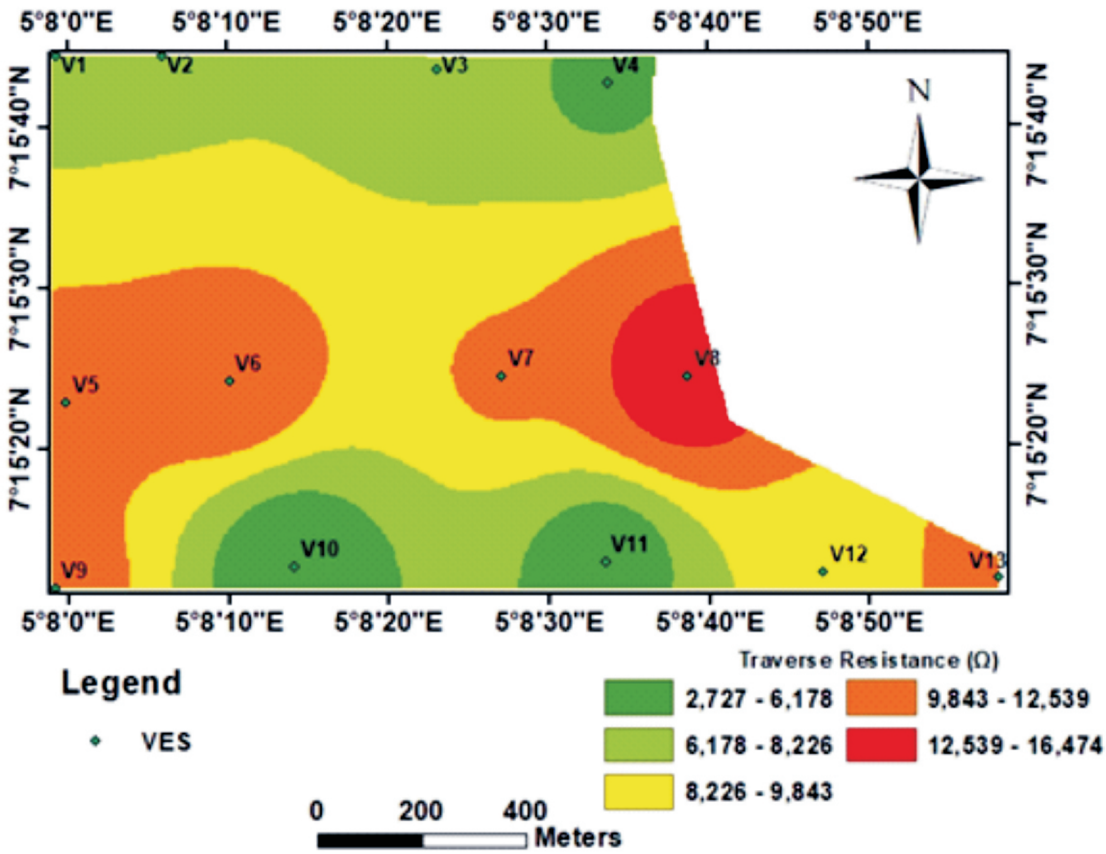

Figure 9: Transverse Resistance Map of the Study Area

Conclusion

In this study, the use of electrical resistivity method was employed to determine the suitability of a proposed petroleum related products filling station for the burial of storage metallic tanks and pipes. Analysis of the resistivity and thickness maps of the shallow horizon and Intermediate horizon, including the overburden thickness, longitudinal conductance and transverse resistance maps of the study area shows that the study area is suitable for the burial of metallic tanks and pipes. The study showed that the area is composed almost entirely of resistive materials in the near subsurface owing to the very low longitudinal conductance values in the range of 0.043–0.073 Ω^{-1} and high transverse resistance values in the range of 2727–16474 Ω. The thickness of the intermediate horizon coupled with the thickness of the overburden in the range of 4.3–8.4 m makes the central part of the study area an ideal location for the burial of the metallic tanks and pipes for petroleum related products storage while taking into consideration proper planning and controls in setting up the station's facilities.

This study has been able to show the suitability of the electrical resistivity method in assessing the suitability of a site for buried metallic utilities. Therefore, this method can be applied for further studies including the planning and design of a filling station.

References

Abiola, O., Enikanselu, P. A., and Oladapo, M. I. (2009). Groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, southwestern Nigeria. *International Journal of Physical Sciences, 4*(3), 120–132.

Adebiyi, A. D., Ilugbo, S. O., Bamidele, O. E., and Egunjobi, T. (2018). Assessment of aquifer vulnerability using multi-criteria decision analysis around Akure industrial estate, Akure, southwestern Nigeria. *Journal of Engineering Research and Reports,* 1-13.

Adelusi, A. O. Akinlalu A. A and Adebayo S. S. (2013). Geophysical and Hydrochemistry Methods for Mapping Groundwater Contamination around Aule area, Akure, Southwestern Nigeria. *International Journal of Water Resources and Environmental Engineering.* Vol. 5(7), pp. 442-451.

Adesola, B. M., Abdul–Nafiu, A.K., Adewale, A. A., Olubusola, I. S., Omowonuola, A. K., Omang, B. O., Akinola, O. A., Gregory, O. O. and Issac, A. (2021). Groundwater sustainability and the divergence of rock types in a typical crystalline basement complex region, southwestern Nigeria. *Turkish Journal of Geosciences* 2(1), 1–11. https://doi.org/10.48053/turkgeo.777217.

Akinlalu A. A., Adegbuyiro A. and Obore, A. A. (2016). Application of Electrical Resistivity Method in Designing a Structural Model for a Proposed Filling Station Site, Akure, Southwestern Nigeria. *Global Journal of Science Frontier Research (A): Physics and Space Science*, 16 (6): 21-34.

Akinlalu, A. A., Mogaji, K. A. and Adebodun, T. S. (2021). Assessment of aquifer vulnerability using a developed "GODL" method (modified GOD model) in a schist belt environ, southwestern Nigeria. *Journal of Environmental Monitoring and Assessment* 193:199. https://doi.org/10.1007/s10661-021-08960-z.

Aluko, A. B. (2008). Geology of Akure Area Southwestern Nigeria. Unpublished B. Tech. Thesis, Federal University of Technology, Akure, 70pp.

Bawallah, M. A., Aina, A. O., Ilugbo, S. O., Ozegin, K. O., and Olasunkanmi, K. N. (2018). Evaluation of groundwater yield capacity using Dar-zarrouk parameter of central Kwara State, Southwestern Nigeria. *Asian Journal of Geological Research,* 1-13.

Foster, S., Hirata, R., Gomes, D., Elia, M. D., Paris, M. (2002). Groundwater Quality Protection A guide for water utilities, municipal authorities and environment agencies. The World Bank. ISBN 0–8213–4951–1.

Iloeje, N. P. (1981). A new geography of Nigeria (New Revised Edition). Longman Group: London, UK. 32–45.

Milsom, J. (2003). Field Geophysics; The Geological Field Guide Series, 3rd ed. John Wiley & Sons Ltd. West Sussex. 249 pp.

Ntarlagiannis, D., Robinson, J., Kirmizakis, P., Soupios, P and Slater L. D. (2015). Electrical geophysical of organic waste contamination. *Near surface geosciences, 21st European meeting of environmental and engineering geophysics, European association of geoscientist and engineers (EAGE).* Pp 186–190.

Nwankwo, C. and Emujakporue, G. (2012). Geophysical method o investigating groundwater and sub–soil contamination – A case study. *American journal of environmental engineering,* Vol.2:3 pp. 49–53.

Odeyemi, I. B., Asiwaju-Bello, Y. A., and Anifowose A. Y. B. (1999). Remote sensing fracture characteristics of the Pan African granite batholiths in the Basement Complex of parts of southwestern Nigeria. *The Journal of Technoscience,* 3, 56-60.

Oladapo, M. I., Mohammed, M. Z., Adeoye, O. O. and Adetola, B. A. (2004). Geo-electrical Investigation of Ondo State Housing Corporation Estate. *Ijapo, Akure, South Western Nigeria, Journal of Mining Geology, 40*(1), 41–48.

Olubusola, I. S., Adebo, B. A., Oladimeji, O. K., and Ayodele, A. (2018). Application of GIS and multicriteria decision analysis to geoelectric parameters for modeling of groundwater potential around Ilesha, Southwestern Nigeria. *European Journal of Academic Essays*, 5(5), 105-123.

Omotoyinbo, O. S. (1994). Geology of Ado-Ekiti, (Unpublished thesis), Ondo State University Of Ado-Ekiti. Pp 84.

Owoyemi, F. B. (1996). A Geologic-Geophysical Investigation of rain-Induced erosional features in Akure metropolis. Unpublished M.Sc. Thesis, Federal University of Technology, Akure. 11–18.

Rahaman, M. A. (1989). Review of the basement geology of southwestern Nigeria: In Geology of Nigeria (Kogbe C.A. Ed.). Elizabeth Publishing. Co. Nigeria. P. 41-58.

Reynolds, J. M. (1998). An Introduction to Applied and Environmental Geophysics. John Wiley and Sons Ltd, West Sussex, 800 pp.

Sherma, P. V. (1997). Environmental and engineering geophysics. Cambridge University Press, Edinburgh building, U.K. 500 pp.

Steel Tank Institute (Division of STI/SPFA), STI R971 (2011). ACT-100U installation instructions for Urethane coated underground steel storage tanks. 20 pp.

Telford, W. M., Geldart, L. P. and Sheriff, R. E. (1990). Applied Geophysics, 2nd ed. Cambridge University Press, Cambridge U.K., p. 770.

Yokus, S. Z. (2022). Using geophysical methods to understand, monitor and assess a hydrocarbon–contaminated area. Unpublished graduate thesis, Rutgers University, Newark, U.S.A. 98 pp.