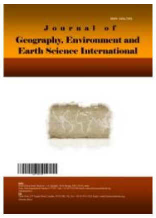

Journal of Geography, Environment and Earth Science International

24(4): 40-50, 2020; Article no.JGEESI.57889
ISSN: 2454-7352

Hydro-geologic, Corrosivity and Geotechnical Implications of Geoelectric Sounding Survey at FUTA Cooperative Housing Estate, Ilaramokin near Akure Southwestern Nigeria

I. A. Adeyemo[1*], V. O. Iwuala[1], T. S. Fadare[1] and E. O. Otayemi[1]

[1]Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author IAA designed the research, participated in the field exercise and proof read the final draft. Author VOI participated in data acquisition exercise and generated the figures and wrote the first draft. Author TSF participated in the data acquisition and interpreted the VES data. Author EOO participated in the data acquisition exercise and carried out literature review. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2020/v24i430217
Editor(s):
(1) Dr. Wen-Cheng Liu, National United University, Taiwan.
Reviewers:
(1) Muralitharan Jothimani, University of Gondar, Ethiopia.
(2) Shivaji Govind Patil, Savitribai Phule Pune University, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57889

Original Research Article

Received 24 March 2020
Accepted 29 May 2020
Published 06 June 2020

ABSTRACT

Aim: Groundwater potential evaluation, corrosivity and geotechnical competence investigations of the subsurface layers were carried at FUTA Cooperative Housing Estate, Ilaramokin near Akure Southwestern Nigeria in order to facilitate proper positioning of facilities within the estate.
Methodology: A total of 14 vertical electrical sounding (VES) data was acquired across the estate using Schlumberger array.
Results: The VES survey results delineated 3 - 5 geoelectric layers across the estate which corresponds to the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock. The groundwater potential map of the estate revealed that the groundwater potential is moderate (GWP of 0.5 - 0.75) to high (GWP of 0.75 - 1.0) in the western and southeastern parts of the estate. The depth slice corrosivity maps (1.0, 2.0 and 3.0 m) of the estate indicated that the corrosivity of the subsurface layers within the estate reduces with

**Corresponding author: E-mail: iaadeyemo@futa.edu.ng;*

depth. The 0.5 m depth slice isoresistivity map of the estate indicates that the central and a segment of the southwestern parts of the estate are characterized with low resistivity (50 - 100 Ωm) indicating incompetence, while the estate flanks (west and east) are considered to be moderately competent (100 - 350 Ωm). Likewise, the 1.0 m depth slice isoresistivity map of the estate reveals that the central and western parts of the estate are characterized with low resistivity (50 - 100 Ωm) suggesting incompetent layer, while the northern, southern and eastern parts of the estate are moderately competent (100 - 350 Ωm).

Conclusion: These results suggested that structural failures can be expected on any engineering structures sited at the central, northern, southern and eastern parts of the estate. Groundwater efforts should be concentrated at the western and southeastern parts of the estate.

Keywords: Investigation; groundwater potential; corrosivity; geotechnical competence; depth surfaces.

1. INTRODUCTION

The study area is FUTA Cooperative Housing Estate, Ilaramokin near Akure, Southwestern Nigeria. The estate was established as part of effort to solve the accommodation challenges facing the growing population of FUTA staff. Interestingly a good number of staff are already residing in the estate and many more staff and non-staff are showing interest. It is therefore important that the estate is well planned by situating necessary facilities in their rightful positions. This will allow residents to derive maximum benefits from such facilities. To achieve this objective some important information on the subsurface geologic condition must be known. These subsurface information includes the geotechnical competence, hydro-geologic and corrosivity conditions of the subsurface layers. Electrical resistivity method has been used extensively to evaluate subsurface groundwater potential in a similar geologic terrain to that of Ilaramokin, southwestern Nigeria [1-10]. Similarly, electrical resistivity method has also been used successfully in investigating subsurface corrosivity [11-17]. Also electrical resistivity method has been successfully used in mapping subsurface competence [18-23]. Electrical resistivity method was adopted for this work because of its wide applications in solving several hydro-geophysical/hydro-geological, engineering and geo-environmental problems.

2. STUDY AREA

The study area is FUTA Cooperative Housing Estate, Ilaramokin near Akure, Southwestern Nigeria. It is situated along Ilaramokin/Igbara-Oke express road. The estate lies within

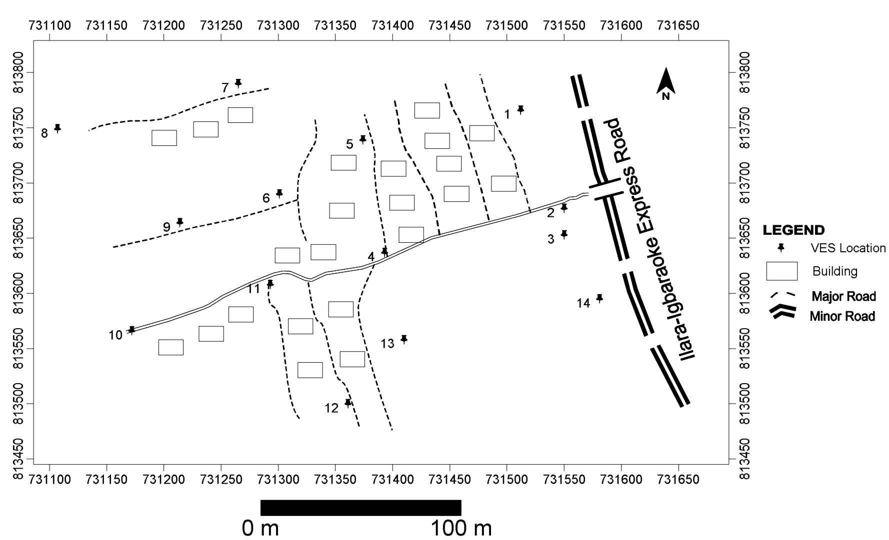

Fig. 1. Base map of FUTA Cooperative Housing Estate, Ilaramokin

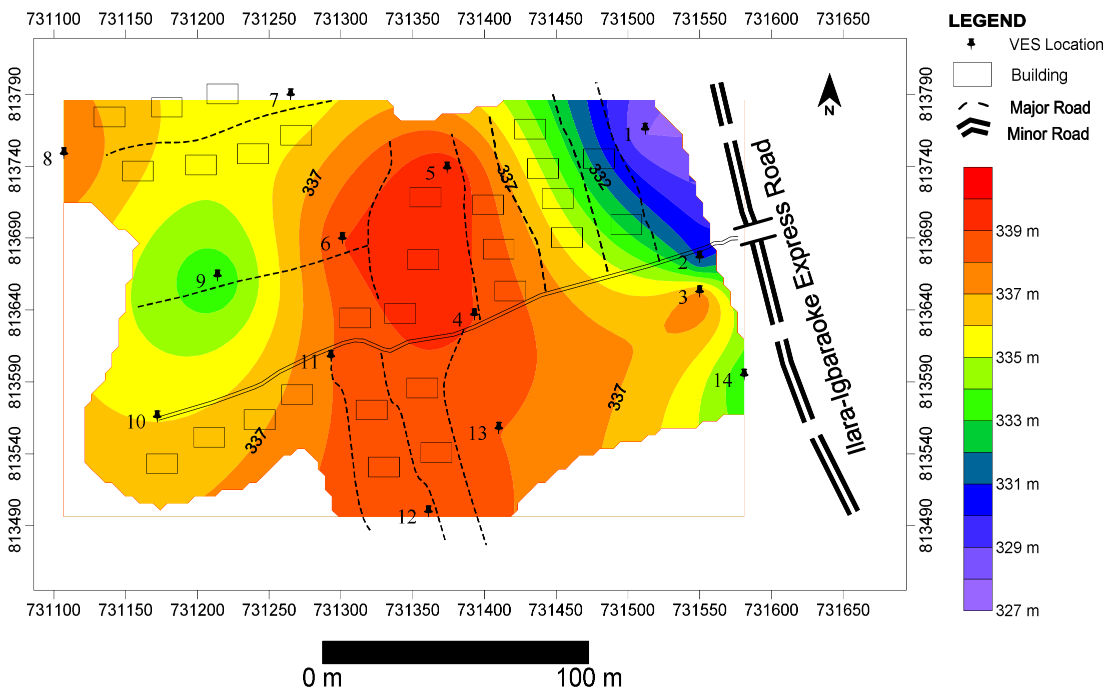

Fig. 2. Topographic Map of FUTA cooperative housing estate, Ilaramokin

the geographic co-ordinates of 731100 - 731650 mE (Easting) and 813450 - 813800 mN (Northing) in the Universal Transverse Mercator coordinates system (UTM) along 31 N using WGS 84 (Fig. 1). The surface elevation ranges from 327 - 341 m above mean sea level and the area generally slopes downward from the centre to the flanks (Fig. 2). The estate lies within the tropical rain forest of southwestern Nigeria and it is characterized by ever green plants and scattered trees. The area is also characterized by uniformly high temperature and well distributed rainfall year round. It has two distinct seasons; wet and dry seasons. The annual rain fall is about 1600 mm, while the average daily temperature is 33°C [17]. The estate is underlain by rocks of migmatite-gneiss-quartzite complex [24] which occurs as low-lying outcrops and discrete bodies in the entire study area.

3. MATERIALS AND METHODS

The Schlumberger array, a variety of vertical electrical sounding (VES) field technique was adopted for this work. A total of 14 VES points were occupied across the estate. The current electrode spread (AB/2) varied from minimum of 1 m to maximum of 65 - 100 m. The Omega resistivity meter was used for this survey, the equipment automatically calculated and displayed the resistance (R). Subsequently the resistance values are multiply with the corresponding geometric factor values to obtained the apparent resistivity (ρ_a) values. The acquired data were plotted on a transparent log-log graph as a plot of apparent resistivity values (ρ_a) against the electrode spacing (AB/2). The VES curves were interpreted both qualitatively and quantitatively. The quantitative interpretation was done using partial curve matching technique [10,22,23] and the resultant geoelectric parameters were further refined using computer iteration algorithm RESIST Version 1.0 [25]. The geoelectric soundings results were presented in table and different iso-resistivity depth slice maps.

4. RESULTS AND DISCUSSION

The vertical electrical sounding (VES) survey results delineated 3 - 5 geoelectric layers across the estate (Table 1). The geoelectric layers corresponds to the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock. The layers' resistivity varies from 86 - 1071 Ωm, 149 - 2217 Ωm, 66 - 879 Ωm, 382 Ωm and 327 - 77764 Ωm in the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock respectively. The layer thickness varies from 0.5 - 2.7 m, 5.2 - 16.8 m, 3.1 - 18.0 m and 13.2 m in the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock. The VES results delineated four different curve types from the estate namely A, H, KH and HKH types (Table 1). The A and KH curve types are the dominant curve types in the area.

4.1 Groundwater Potential Evaluation

To evaluate of the groundwater potential of the subsurface layers in the estate. VES results were presented as maps of aquifer layer resistivity and aquifer layer thickness. The aquifer resistivity depends on the availability of connecting pore spaces in the aquifer layer and presence of conductive fluid such as water within the aquifer layer while the aquifer thickness determines the possible water column and volume of water within the aquifer layer [10]. These two parameters were considered sufficient to evaluate the groundwater potential of the estate since the area is of the same lithology (monolithic).

The aquifer resistivity map (Fig. 3) shows the lateral variation of resistivity within the aquifer layer in the estate. The map indicates that the aquifer layer is more saturated at the western part of the estate and consequently this part of the estate is considered to be of moderate (150 - 250 Ωm) to high (0 - 150 Ωm) groundwater potential based on resistivity values. The aquifer thickness map (Fig. 4) indicates that aquifer thickness in the western part of the estate is thicker and this part of the estate are consequently considered to be of low (5 - 10 m) to moderate (10 - 15 m) groundwater potential. The only exception is VES 7 which is considered to be of high groundwater potential. The two maps were integrated using additive method [10,16,26] to generate groundwater potential (GWP) map of the estate (Fig. 5). Aquifer resistivity was assigned more weight (0.55) than aquifer thickness (0.45) as shown in Table 2 because aquifer resistivity is directly related to those geologic conditions that makes subsurface layer an aquifer (Porosity, permeability, water saturation, degree of weathering and fracturing). The ratings adopted for the two parameters were as presented in Table 3.

The final groundwater potential of the estate was determined using the following relationship;

$$GWP = [(Wt_{Aq\,Res}*Rt_{Aq\,Res}) + (Wt_{AqTh}*Rt_{AqTh})] \quad (1)$$

Where,

Aq = Aquifer
Res = Resistivity
Th = Thickness
Wt = Weight
Rt = Rating

The groundwater potential map (Fig. 5) of the estate agrees with the aquifer resistivity and aquifer thickness maps. The map revealed that the groundwater potential is moderate (GWP of 0.5 - 0.75) to high (GWP of 0.75 - 1.0) in the western and southeastern parts of the estate. The H, HK and HKH curve types which suggest presence of aquifer layers were delineated in these parts of the estate.

Table 1. Vertical electrical sounding results

VES no.	Number of layers	Resistivity (Ohm-m) $\rho_1/\rho_2 ... \rho_{n-1}, \rho_n$	Thickness (m) $h_1, h_2 ...... h_{n-1}, h_n$	Curve type
1	3	403/325/9477	2.7/6.7	H
2	3	140/593/1315	0.9/16.8	A
3	3	117/1664/6604	2.1/6.9	A
4	3	86/1195/1325	1.4/9.8	A
5	3	86/2115/2874	2.0/13.9	A
6	4	86/603/223/1603	0.7/5.5/10.1	KH
7	4	187/966/127/761	1.4/5.8/18	KH
8	5	1071/588/879/382/867	0.5/2/4.5/13.2	HKH
9	3	54/314/327	1/6.2	A
10	4	86/308/66/416	2.1/5.5/13	KH
11	4	119/447/150/476	1/5.2/12	KH
12	4	144/647/184/983	0.8/3.7/8.6	KH
13	3	153/149/7448	0.7/5.2	H
14	5	190/2217/75/77764	1.4/1.5/3.1	KH

Table 2. Parameter weights (Modified after: 10)

S/N	Parameter	Weights
1	Resistivity of the aquifer layer	0.55
2	Thickness of the aquifer layer	0.45

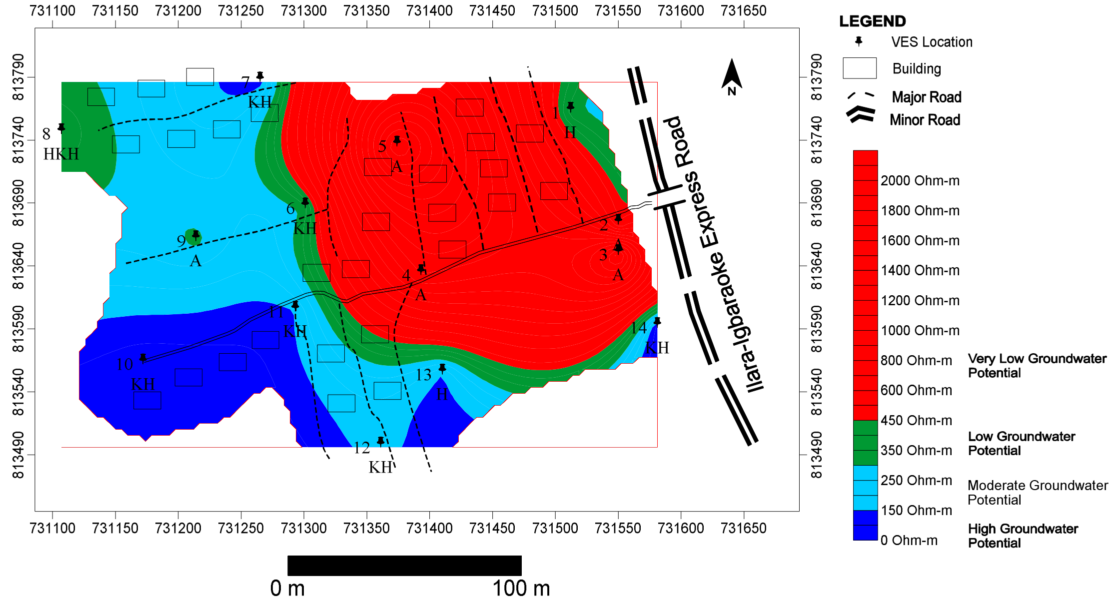

Fig. 3. Aquifer resistivity map of FUTA cooperative housing Estate, Ilaramokin

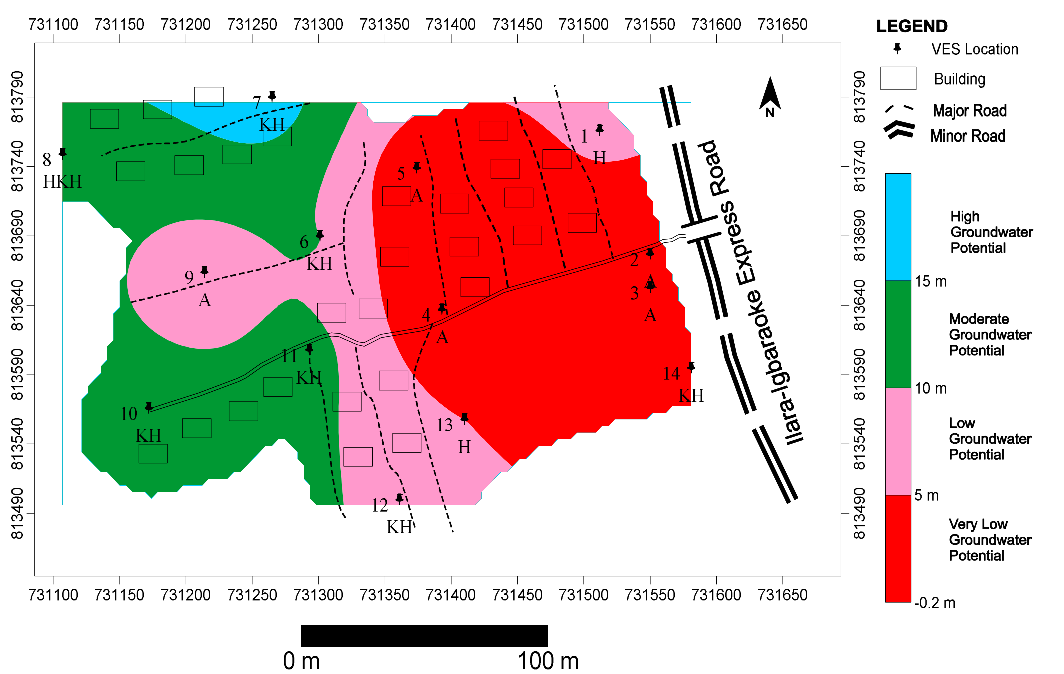

Fig. 4. Aquifer thickness map of FUTA cooperative housing Estate, Ilaramokin

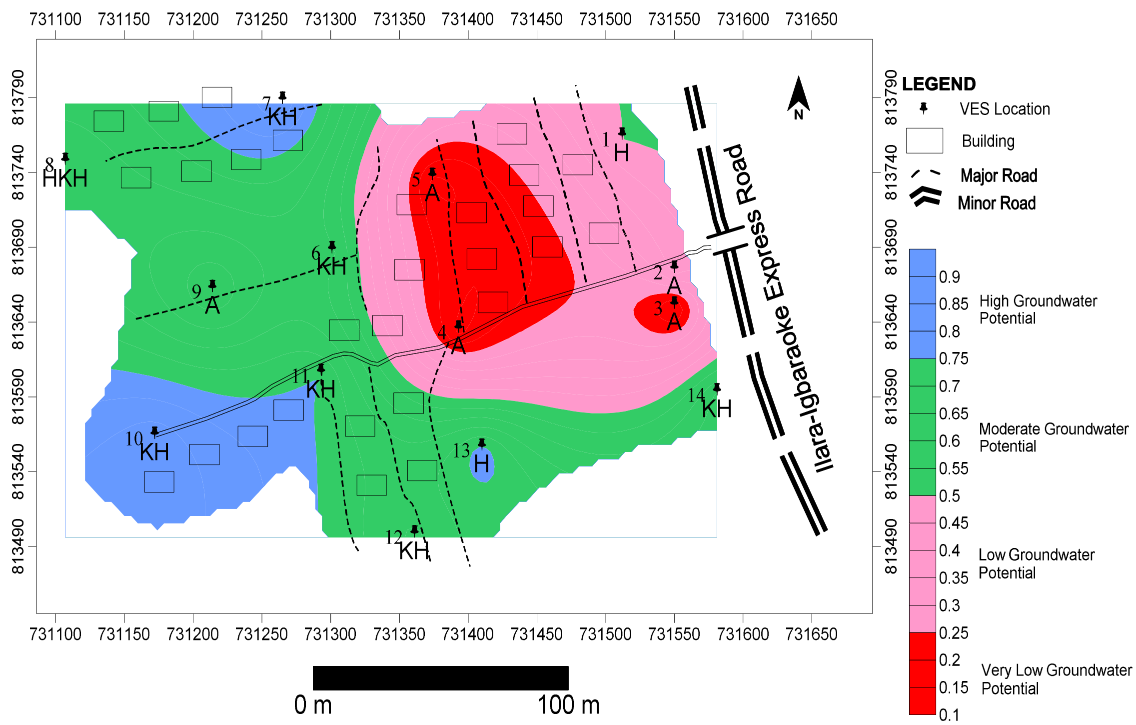

Fig. 5. Groundwater potential of FUTA cooperative housing estate, Ilaramokin

Table 3. Parameter ratings (Modified after: 10)

Parameter	Range	Rating
Aquifer Resistivity	0 - 150 Ωm	1.0
	150 - 300 Ωm	0.75
	300 - 450 Ωm	0.5
	Above 450 Ωm	0.25
Aquifer Layer Thickness	0 - 5 m	0.25
	5 - 10 m	0.5
	10 - 15	0.75
	Above 15 m	1.0

4.2 Subsurface Layers Geotechnical Competence

The VES results were also presented as isoresistivity maps at two depth surfaces (0.5 and 1.0 m). The 0.5 m depth slice isoresistivity map of the estate (Fig. 6) indicates that the central and a section of the southwestern parts of the estate are characterized with low resistivity (50 - 100 Ωm) indicating incompetent layer (Table 4). All most all the buildings in this part of the estate exhibited signs of cracks and openings after plastering which required the application of crack concealers such as plaster of Paris (POP) before applying final paint. The flanks of the estate to the west and east are considered to be moderately competent (100 - 350 Ωm). Similarly, in the 1.0 m depth slice isoresistivity map of the estate (Fig. 7) reveals that the central and western parts of the estate are characterized by low resistivity (50 - 100 Ωm) suggesting incompetent layer, while the northern, southern and eastern parts of the estate are considered moderately competent (100 - 350 Ωm). In view of the foregoing to mitigate against the possible structural failures on buildings precipitated by negative effect of incompetent and moderately incompetent subsurface foundation materials in the estate appropriate foundation designs and standard practice should be adopted.

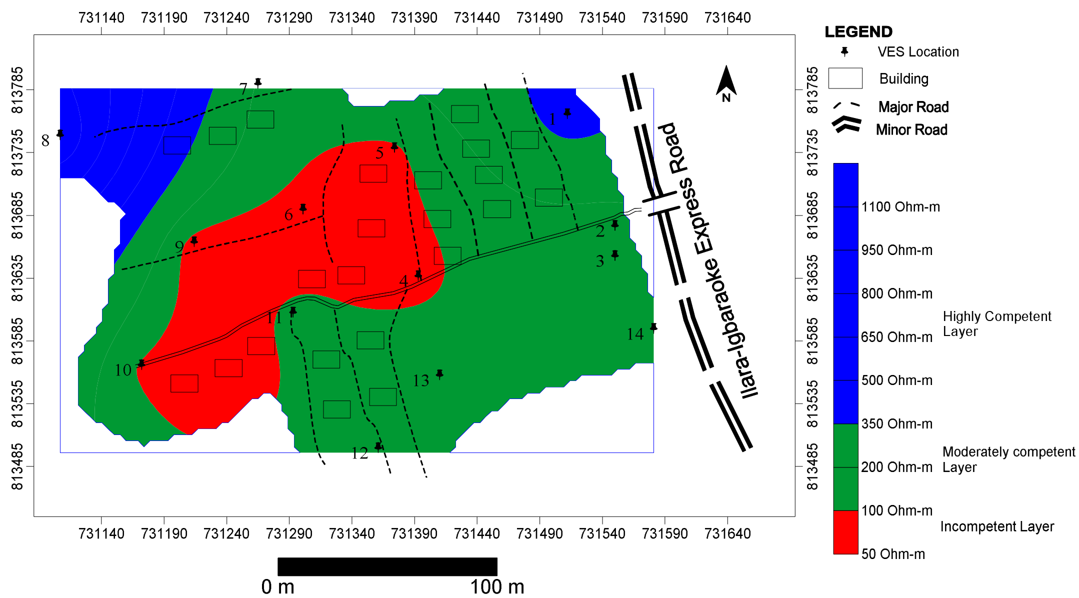

Fig. 6. 0.5 m Depth slice isoresistivity map of FUTA cooperative housing estate, Ilaramokin

Table 4. Rating adopted for geophysical parameter [Sources: 18,19]

	Index range	Class classification
Resistivity of Weathered Layer	< 100	Incompetent
	100-350	Moderately Competent
	> 350	Highly Competent
Resistivity of Bedrock	< 600	Incompetent
	600-750	Moderately Competent
	> 750	Highly Competent

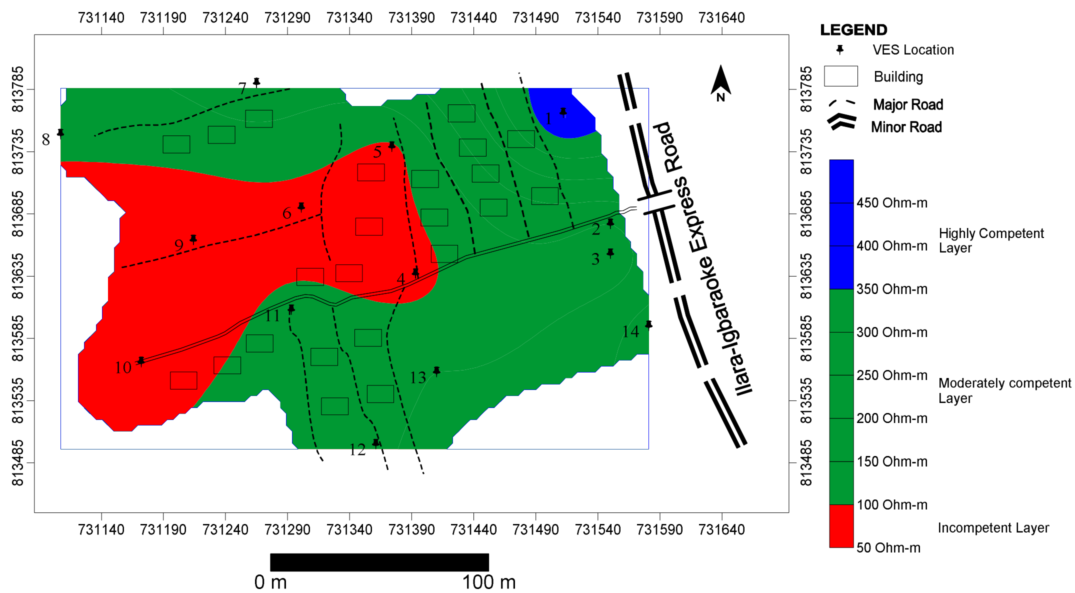

Fig. 7. 1.0 m Depth slice isoresistivity map of FUTA cooperative housing estate, Ilaramokin

4.3 Corrosivity

The iso-resistivity depth slice map at 1 m depth surface (Fig. 8) indicates that the western and central parts of the estate which represents about 70% of the depth surface is strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm), while the northeastern and southeastern flanks of the estate are considered to be moderately corrosive (150 - 250 Ωm) to slightly corrosive (250 - 350 Ωm) and non-corrosive (above 350 Ωm). The isoresistivity depth slice map at 2 m (Fig. 9) shows that the southwestern and northeastern parts of the estate which represents about 30% of this depth surface is strongly corrosive (60 - 150 Ωm), moderately corrosive (150 - 250 Ωm) and slightly corrosive (250 - 350 Ωm), while the larger portion of this depth slice (about 70%) is considered to be non-corrosive (above 350 Ωm). The isoresistivity depth slice map at 3 m (Fig. 10) reveals that about 85% of this depth surface are non-corrosive (above 350 Ωm) while a small portion of southwestern part of the estate are considered to be slightly corrosive (250 - 350 Ωm) comparison of the three depth

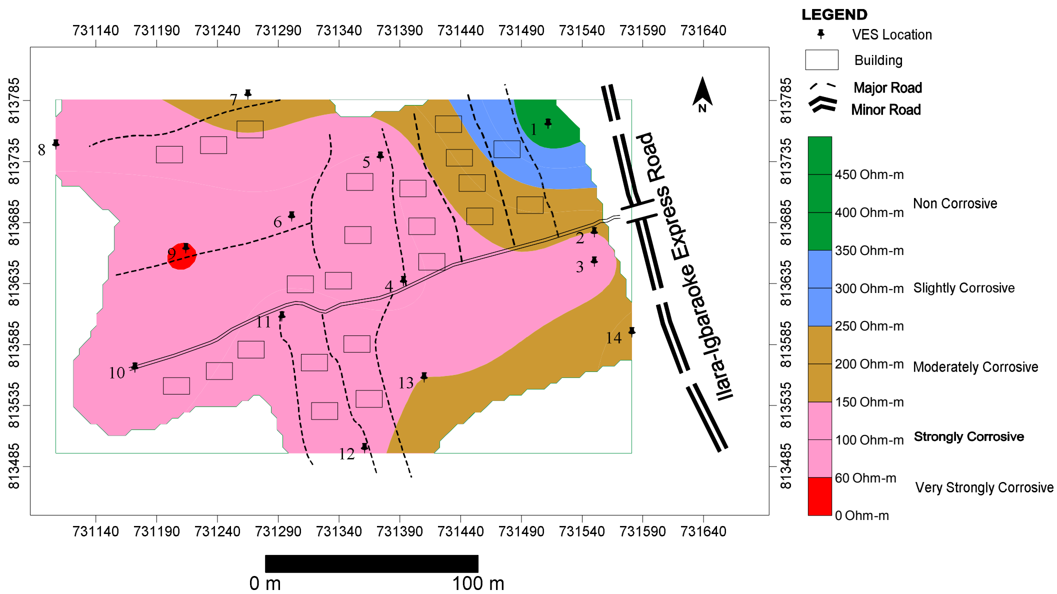

Fig. 8. 1.0 m Depth slice corrosivity map of FUTA cooperative housing estate, Ilaramokin

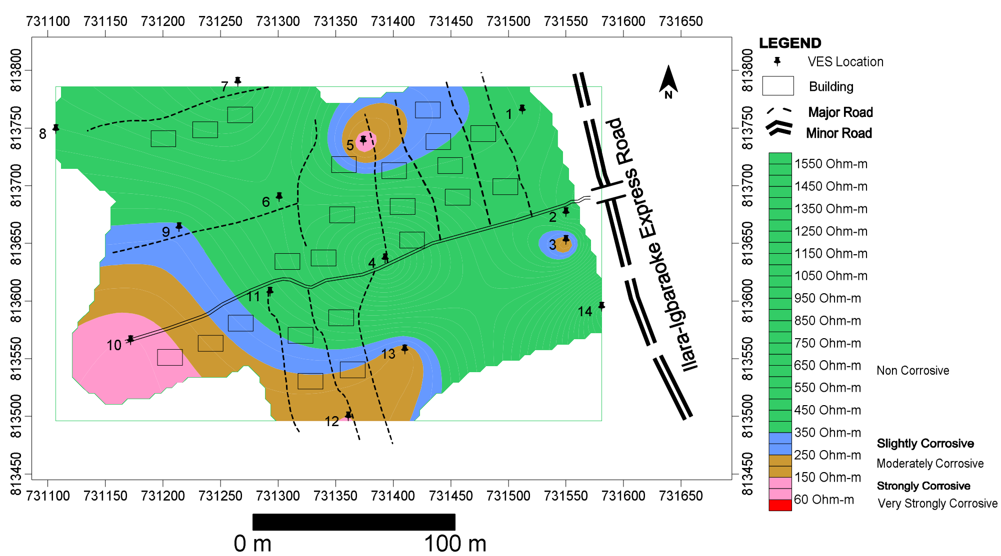

Fig. 9. 2.0 m Depth slice corrosivity map of FUTA cooperative housing estate, Ilaramokin

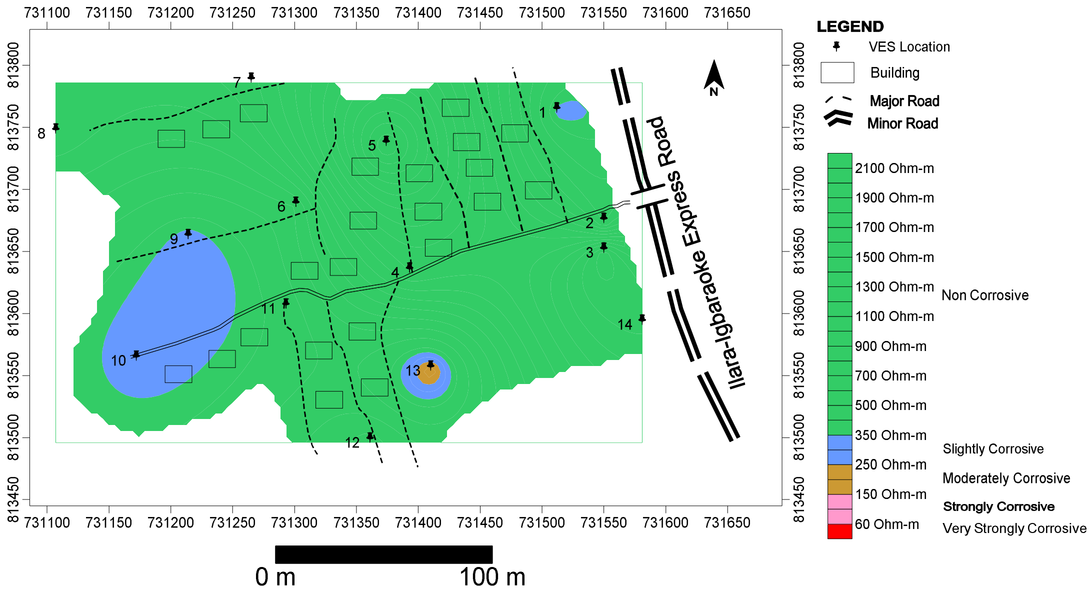

Fig. 10. 3.0 m Depth slice corrosivity map of FUTA cooperative housing estate, Ilaramokin

slice corrosivity maps indicates that the corrosivity of the subsurface layers within the estate reduces with depth. This observation probably suggests that the estate is well drained through surface and shallow subsurface lateral flow from the central to the flanks such that vertical percolation is limited [27]. It therefore safe to suggest that metallic utilities such galvanized pipes and underground storage tanks in the estate should be buried at non-corrosive depth of 3 m to protect them from corrosion and consequently prolong their life span. If metallic utilities must be buried within corrosive zones they must be properly protected using cathodic protection method or by painting with tar.

5. CONCLUSION

Groundwater potential evaluation, corrosivity and geotechnical competence investigations of the subsurface layers were carried at FUTA Cooperative Housing Estate, Ilaramokin near Akure, Southwestern Nigeria. Vertical electrical sounding using Schlumberger array field technique was utilized for this work. A total of 14 VES points was occupied across the estate and the results were presented as table and maps of aquifer layer resistivity and thickness, groundwater potential map, depth slice isoresistivity maps at different surfaces in order to infer subsurface corrosivity and geotechnical competence. The 3 - 5 geoelectric layers geoelectric layers delineated in estate corresponds to the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock. The layers' resistivity varies from 86 - 1071 Ωm, 149 - 2217 Ωm, 66 - 879 Ωm, 382 Ωm and 327 - 77764 Ωm in the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock respectively. The layer thickness varies from 0.5 - 2.7 m, 5.2 - 16.8 m, 3.1 - 18.0 m and 13.2 m in the topsoil, weathered layer, partially weathered basement, partially fractured basement and the presumed fresh bedrock. The groundwater potential map of the estate corroborates the obtained curve types, aquifer resistivity and aquifer thickness maps. The map revealed that the groundwater potential is moderate (GWP of 0.5 - 0.75) to high (GWP of 0.75 - 1.0) in the western and southeastern parts of the estate. Therefore, any groundwater development efforts in the estate should be concentrated at the western and southern parts of the estate. The 0.5 m depth slice isoresistivity map of the estate indicates that the central and a pocket of the southwestern parts of the estate are characterized with low resistivity (50 - 100 Ωm) indicating incompetence, while the estate flanks (west and east) are considered to be moderately competent (100 - 350 Ωm). Similarly, the 1.0 m depth slice isoresistivity map of the estate reveals that the central and western parts of the estate are characterized by low resistivity (50 - 100 Ωm) suggesting incompetent layer, while the northern, southern and eastern parts of the estate are moderately competent (100 - 350 Ωm). These results suggest that structural failures can be expected on any engineering structures constructed at the incompetent and moderately incompetent part of the estate. The three depth slice (1.0, 2.0 and 3.0 m) corrosivity maps indicates that the corrosivity of the subsurface layers within the estate reduces with depth and thus metallic utilities such galvanized pipes and underground storage tanks in the estate should be buried at non-corrosive depth of 3 m.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Amadi AN, Nwawulu CD, Unuevho CI, Ako TA. Evaluation of the groundwater potential of Pompo village, Gidan Kwano, Minna Using Vertical Electrical Resistivity Sounding, British Journal of Applied Science and Technology. 2011;1(3):53-66.
2. Mogaji KA, Omosuyi GO, Olayanju GM. Groundwater system evaluation and protective capacity of overburden material at Ile-Oluji, Southwestern Nigeria Journal of Geology and Mining Research. 2011;3(1): 294-304.
3. Adiat KAN, Nawawi MNM, Abdullah K. Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction toll - A case of predicting potential zones of sustainable groundwater resources, Journal of Hydrology. 2012;440-441(75-89):130-144. DOI: org/10.1016/j.jhydrol.2012.03.028
4. Adiat KAN, Nawawi MNM, Abdullah K. Application of multi-criteria decision analysis to geoelectric and geologic parameters for spatial prediction of groundwater resources and aquifer evaluation, Pure and Applied Geophysics, Springer. 2013;170(3):156-174. DOI: 10.1007/s00024-012-0501-9
5. Akintorinwa OJ, Olowolafe TS. Geoelectric evaluation of groundwater prospect within Zion Estate, Akure, Southwest, Nigeria, International Journal of Water Resources and Environmental Engineering. 2013;5(1): 12-28.
6. Fashae OA, Tijani MN, Talabi AO, Adedeji OI. Delineation of groundwater potetial zones in the crystalline basement terrain of SW-Nigeria: An integrated GIS and Remote Sensing approach, Applied Water Science, Springer Link. 2013;(4):19-38
7. Nwankwo LI, Olasehinde PI, Osundele OE. Application of electrical resistivity survey for groundwater investigation in a basement rock region: A case study of Akobo-Ibadan, Nigeria Ethiopian Journal of Environmental Studies and Management. 2013;6(2):124-134.
8. Adeyemo IA, Bamidele OE, Obatayo OB. Geoelectric survey for post-foundation investigation of a distressed building at Ade Super Hotel Akure, Southwestern Nigeria, International Journal of Engineering and Sciences. 2014a;3(2):35-42
9. Adeyemo IA, Omosuyi GO, Olayanju GM, Omoniyi GK. Hydrogeologic and geoelectric determination of groundwater flow pattern in Alaba-Apatapiti layouts, Akure, Nigeria, International Journal of Engineering and Sciences. 2014b;3(2):43-52.
10. Adeyemo IA, Omosuyi GO, Ojo BT, Adekunle A. Groundwater potential evaluation in a typical basement complex environment Using GRT Index - A Case Study of Ipinsa-Okeodu Area, Near Akure, Nigeria, Journal of Geoscience and Environment Protection Scientific Research. 2017;5(3):240-251. DOI: org/10.4236/gep.2017.53017
11. Owate IO, Ezi CWI, Avwiri G. Impact of environmental conditions on sub-surface storage tank (Part 1). International Journal Environmental Management. 2002;6(2): 79-83.
12. Najjaran H, Sadiq R, Rajani B. Modeling pipe deterioration using soil properties – An application of fuzzy logic expert system. National Research Council Canada A version of this document is published in ACSE International Conference on Pipeline Engineering and Construction, San Diego, CA. 2004; 1-10.
13. Idornigie AI, Olorunfemi MO, Omitogun AA. Electrical resistivity determination of subsurface layers soil competence and soil corrosivity at engineering site location in Akungba-Akoko, Southwestern Nigeria, Ife Journal of Science. 2006;8(2):159-177.
14. Oyedele KF, Meshida EA, Obidike CC. Assessment of coastal soil corrosivity using resistivity tomography at Lekki. Lagos, Nigeria, International Journal of

Science and Advanced Technology. 2012;2 (6):77-81.
15. Gebremedhin B. Tesfahunegn A, Solomon G. Implications of groundwater quality to corrosion problem and urban planning in Mekelle Area, Northern Ethiopia. Momona Ethiopian Journal of Science. 2013;(MEJS)5(1):51-70.
16. Adeyemo IA, Olumilola OA, Ibitomi MA. Geoelectrical and geotechnical investigations of subsurface corrosivity in ondo state industrial layout, Akure, Southwestern Nigeria, Ghana Mining Journal. 2018;18(1):20-31.
DOI: org/10.4314/gm/v18i1.3
17. Adeyemo IA, Karounwi SA, Oladeji JF. Geoelectric sounding and soil physico-chemical tests for subsurface layers corrosivity investigations at Ilaramokin, near Akure, Southwestern Nigeria, IOSR Journal of Applied Geology and Geophysics. 2019;7(6) Series III:25-36.
DOI: 10.9790/0990-0706032536.
18. Olorunfemi MO, Idornigie AI, Coker AT, Babadiya GE. On the application of the electrical resistivity method in foundation failure investigation - A case study. Global Journal of Geological Sciences. 2004;2(1): 139-151.
19. Olorunfemi MO, Ojo JS, Idornigie AI, Oyetoran WE. Geophysical investigation of structural failure at a factory site in Asaba area, Southern Nigeria, Journal of Mining and Geology. 2005;41(1):111-121.
20. Adepelumi AA, Olorunfemi MO, Falebita DE. Structural mapping of coastal plain sands using engineering geophysical technique: Lagos Nigeria Case Study, Natural Science. 2009;1:2-9.
21. Osinowo OO, Akanji AO, Akinmosin A. integrated geophysical and geotechnical investigation of the failed portion of a road in basement complex Terrain, Southwestern Nigeria, Material and Geo-environment. 2011;58(2):143-162.
22. Adiat KAN, Akinlalu AA, Adegoroye AA. Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies, NRIAG Journal of Astronomy and Geophysics. 2017;(6):244-255.
23. Olayanju GM, Mogaji KA, Lim HS, Ojo TS. Foundation integrity assessment using integrated geophysical and geotechnical techniques: Case study in crystalline basement complex, Southwestern Nigeria Journal of Geophysics and Engineering. 2017;14:675-690.
DOI: org/10.1088/1742-2140/aa64f7
24. Rahaman MA. Recent advances in the study of the basement complex of Nigeria in precambrian geology of Nigeria, Geological Survey Nig. 1988;11-43.
25. Vander Velpen BPA. Window resist version 1.0, M. Sc. Research Project, ITC, Delf Netherland; 1989.
26. Chachadi AG. Seawater intrusion mapping using modified GALDIT Indicator Model - Case Study in Goa. Jalvigyan Sameeksha. 2005;(20):29-45.
27. Adeyemo IA, Karounwi SA, Oladeji JF. Geoelectric sounding and soil physico-chemical tests for subsurface layers corrosivity investigations at Ilaramokin, near Akure, Southwestern Nigeria.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/57889