Noland Journal of Statistics and Mathematics, Volume 13 (2), 2025 | ISSN: 3069-1419

Original Article

APPLICATION OF ELECTRICAL RESISTIVITY METHODS FOR GROUNDWATER ASSESSMENT IN BALOGUN, IBADAN

Olufemi Ayodele Bakare and Tunde Oluwaseun Adebayo

Department of Geology, Faculty of Science, The Polytechnic, Ibadan, Nigeria

DOI: https://doi.org/10.5281/zenodo.17152486

Abstract: A geoelectrical survey employing Vertical Electrical Sounding (VES) was conducted in the Balogun area of Ibadan, Southwestern Nigeria, to delineate aquifer units and assess the groundwater potential of the region. Located within the Precambrian basement complex of Southwestern Nigeria, the area is predominantly underlain by quartzite, quartz schist, undifferentiated gneisses/schists, and augen gneiss formations. A total of ten VES stations were surveyed using the Schlumberger electrode configuration with a maximum half-current electrode spacing of 100 meters, facilitated by the Allied Omega Resistivity Meter.

The collected field data were plotted on bi-logarithmic graphs and interpreted using partial curve matching techniques in combination with computer-aided modeling through the WINRESIST software. Interpretation of the VES results revealed five geoelectric layers: topsoil, lateritic soil/clay, quartzite and quartz schist, weathered basement, and fractured basement. Two key aquiferous units were identified—weathered basement and fractured basement—with resistivity values ranging from 41–310 Ωm and 118–653 Ωm respectively.

The weathered basement, primarily composed of sandy material, exhibits an average thickness of approximately 26.5 meters and is capable of yielding a substantial quantity of groundwater. The fractured basement aquifer, occurring at depths between 5.7 and 68.2 meters, was observed in 40% of the VES points, indicating its potential in enhancing groundwater discharge.

A groundwater potential map was produced by integrating geoelectric parameters from the delineated aquifer units. The area was categorized into zones of low, moderate, and high groundwater potential, with roughly 70% of the study area falling into moderate to high potential zones. These findings suggest that the Balogun area holds promising prospects for sustainable groundwater development, which could play a crucial role in addressing potable water scarcity and improving essential amenities for local residents—especially in regions where both aquifer units are present.

Keywords: Geoelectrical, Vertical Electrical Sounding (VES), groundwater potential, Resistivity, aquiferous units

Introduction

The problem of inadequate availability of potable water for various daily activities are being faced by most people in both urban and rural communities of Nigeria, with the impact often greatly felt mostly by dwellers of the rural communities across the country. The situation in Balogun community, Ibadan in the southwestern part of Nigeria is worrisome as many residents mostly rely on water from unprotected seasonal shallow hand dug wells and in some cases, surface water scheme like stream, ponds etc. There are various /numerous water borne diseases that resulted from the consumption of water from these unsuitable sources, apart from the fact that they sometimes run dry. Despite these unhygienic sources, there is still shortage of potable water in this locality due to its promixity to International Institute of Tropical Agriculture (IITA) where many staff of the institute and that of University of Ibadan are now residing as a result of over congestion at other neighbouring communities where they could as well reside. This has then imposed significant stress on the existing inadequate water sources and eventually increased the groundwater demand of the dwellers of the community resulting from this urban-semi rural migration. Groundwater is considered to be the best form of water and as the only reliable alternative means of water supply to the cities (Auwalu and Abubakar, 2012).Beside groundwater has an excellent natural microbiological quality and generally adequate chemical quality for most uses. The quality of groundwater in the basement complex area is generally good and free from pathogenic bacteria and hence very rarely needs to be treated (Abdullahi et al., 2005). The aforesaid, among others, have necessitated the need for groundwater exploration in Balogun community. However, to site highly productive well in these rock units remains a challenging and expensive task because fracture development at regional scale is both heterogeneous and anisotropic (Manda et al., 2006). Groundwater distribution in basement complex areas varies from place to place due to localized nature of basement aquifers (Dan- Hassan and Olorunfemi., 1999, Meli'i et al., 2011, 2012; Ekoro et al., 2012). They are usually contained in the weathered and / or fractured basement rocks. Groundwater occurrence in the basement complex terrain of Nigeria is highly unpredictable and hence requires a combination of hydrologic, geophysical and geologic surveys to achieve success in groundwater development programs (Olayinka, 1990).Therefore, a critical understanding of the hydro-geology and geophysical data types are required in such geologic setting to effectively characterize the hydro-geologic zones and to enhance successful identification of well locations. Geophysical survey involving electrical resistivity, seismic, gravity and electromagnetic methods constitutes the most reliable means, outside direct mechanical drilling, through which basement structures such as fractures zones, basement depressions and ancient river channels that are of hydrogeological significant can be mapped (Clark, 1985; Caruthers and Smith, 1992).Geophysical methods may provide a relatively low-cost approach to hydro-geologic characterization of an area. The geophysical survey technique has been relied on in this study using the electrical resistivity method to locate zones of high potential for groundwater yield. Electrical resistivity survey has proved to be an effective and a reliable tool in locating viable aquifers for continuous and regular water supply (Adeniji et al. 2013).The electrical resistivity method is based on the effective response of the earth to the flow of subsurface electrical currents. The method is the major geophysical application in hydrogeological investigation which is directed towards aquifer characterisation and groundwater quality study (Asfahani, 2006; Bello and Makinde, 2007). Electrical resistivity is widely used for hydrogeological studies, because the acquired data are mainly controlled by lithological conditions of the aquifer (Nwachukwu et al, 2019).The Vertical Electrical Soundings (VES) has proved very popular for groundwater investigation in hard rock area due to simplicity of the technique, hence employed in this work. This study aimed at unravel the subsurface geology and its associated features that are favourable for groundwater development at Balogun Southwestern Nigeria, for the purpose of serving as a working guide for future groundwater development in the area.

Location, Geology and Hydrogeological setting of the study area

The study area, Balogun lies between latitude 7° 28' 35"N to 7° 28' 55"N of the equator and longitude 3° 52' 30"E to 3° 52' 55"E of the Greenwich Meridian (Figure 1) and located at Akinyele Local Government area Oyo State in the Southwestern part of Nigeria. It is bounded by International Institute of Tropical Agriculture (IITA) and Laniba, University of Ibadan, Osaji and Lakoto in the North, East, West and South respectively. The topography is gentle, with surface elevation ranging from 199m to 234m above sea level. The area geologically fall within the Precambrian basement complex rocks of Southwestern Nigeria (Rahaman,1976) and underlain by three major petrologic units: the Quartzite and quartz schist, undifferentiated gneisses/ schists, and Augen gneiss rocks in order of abundance which generally strike NW-SE and dip to the east (Figure 2).Quartzite and quartz schist which dominated the area occur as elongated ridges striking NW-SE (Olorunfemi et al.,1999) while Gneisses are migmatized in places and are characterized by predominantly medium-sized grains. These rocks are hydrogeologically inherently characterized by low porosity and permeability (Abiola et al.,2013).The basement aquifers are often limited in extent both laterally and vertically (Olayinka,1990).The highest groundwater yield in basement terrain is found in areas where thick overburden overlies fracture zones; these zones are often characterized by relatively low resistivity value (Olayinka,1990).

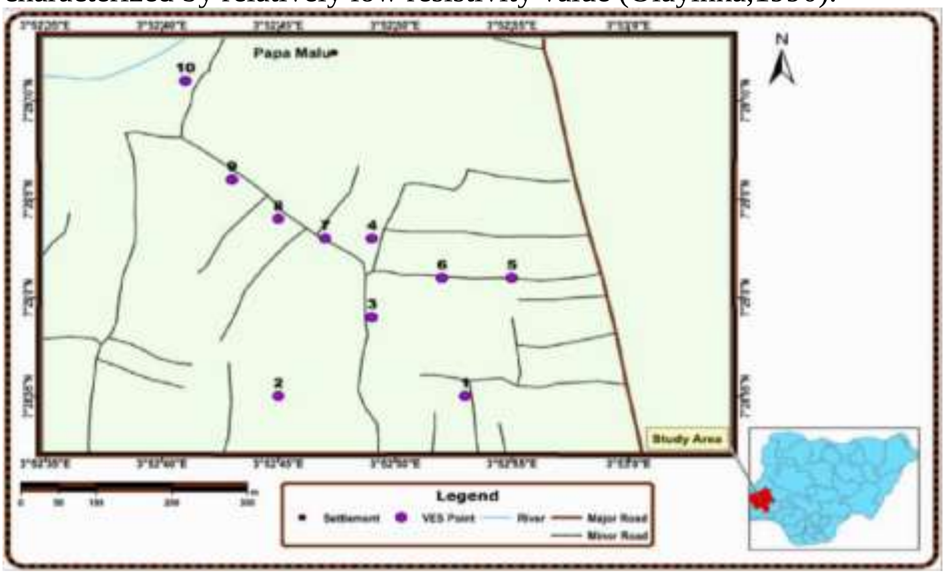


Figure 1: Location map of the study area.

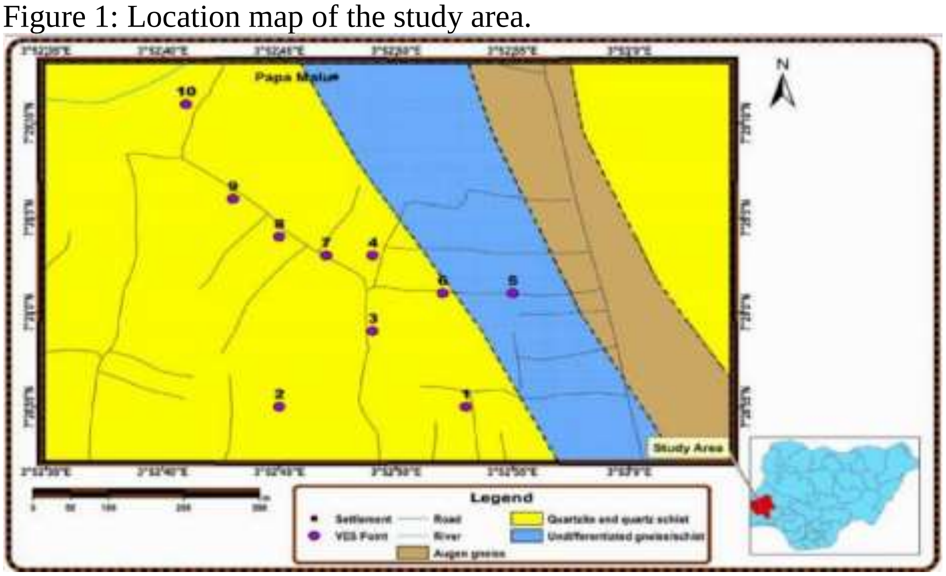


Figure.2: Geological map of the study area

Materials and Methods

Electrical resistivity method was mainly employed in this study, using conventional vertical electrical sounding (VES) technique. A total of Ten (10) VES survey was conducted at different locations within the study area (fig. 1) using Schlumberger electrode configuration. The maximum current electrode (AB) spacing used was 200 m as

Original Article

much as access allowed on the field. The current electrode (AB/2) spacing varied from 1 to 100 m and the potential electrode (MN/2) spacing varied from 0.5 to 5 m. The Omega resistivity meter was used for the data collection. The readings of ground resistance at each observatory point as obtained from the resistivity meter were multiplied by the corresponding geometric factor (K) in order to obtain the apparent resistivity (a) for each point. The apparent resistivities obtained were then plotted against corresponding electrode spacing (AB/2m) on bilogarithm graph paper to generate depth sounding curves. Among the merits of the bi-log plot is that it emphasizes near-surface resistivity variations and suppresses variations at greater depths. This is so important, because interpretation of the results depends largely on the small variations in resistivity occurring at shallow depths. The bi-log plot is also advantageous in that if at two different sites the resistivities of the underlying layers (or their thicknesses) increase or diminish by the same constant multiple, the two resistivity curves would look alike, although they may be shifted horizontally or vertically with respect to one another. The generated field curves were then visually inspected for identification of the curve type and manually interpreted (Koefoed, 1979) using Master curves (Orellana and Money, 1966) and auxiliary point charts (Keller and Frishnecht, 1966). The interpretation results (layer resistivity and thicknesses) were fed into computer for 1-D computer assisted interpretation program involving WinResist software (VarderVelper, 1988), Through an iterative process, the program varies the electrical resistivity and thickness of each layer until it finds a final geoelectric model that satisfactorily best fits the data. This inversion procedure involves, computing an apparent resistivity value and height from an initial layered model from the partial curve matching.

Comparing it with the measured resistivity and modifying the initial model unit into true layers of studied area. The final interpreted results were used for the preparation of geoelectric sections and maps.

RESULT AND DISCUSSION

Resistivity Sounding Curves characteristic

The processed and interpreted Vertical Electrical Sounding (VES) data by partial curve matching and computer iteration using WINRESIST software produced depth sounding curves of very short range: three layer case (Ktype) and four layer (HK,KH and AK type). The four layer case predominate with 90% occurrence (40% KH, 30% HK and 20%AK) while K-type, the three layer case constitute 10% of the total. Worthington (1977) showed that field curves often mirror image geo-electrically the nature of the successive lithologic sequence in an area and hence can be used qualitatively to assess the groundwater prospect of an area. It is often qualitatively possible to make hydrogeological deduction from curve types (Singh, 1984).In the study area, 50% of the investigated locations are characterized by H and KH curves which are often associated with groundwater possibilities (Sathpathy and Kanugo, 1976).Typical sounding curves obtained(K, HK,AK and KH) for the area are shown in Figure 3a-d while the results summary of the VES interpretation is shown in Table 1.

Table 1: Result Summary of VES interpretation in the area

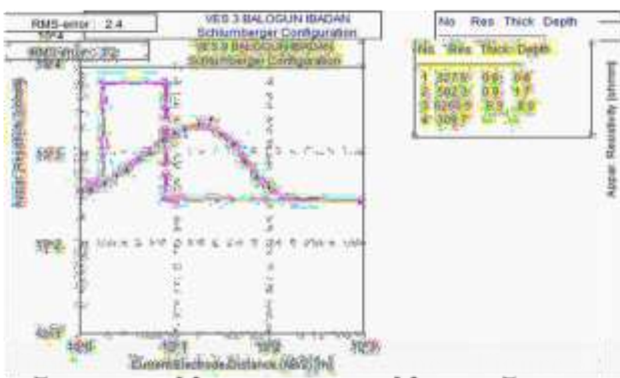
VES NO.	LAYER	RESISTIVITY (ohms – m)	LAYER THICKNESS (m)	DEPT H (m)	CURVE TYPE	PROBABLE LITHOLOGY
1	1	87	0.8	0.8		Top Soil (Clayey)
	2	162	9.8	10.6		Lateritic Soil
	3	41	23.4	34.0	KH	Weathered Basement
	4	653				Fractured Basement

Original Article

2	1	261	0.5 0.8	0.5		Top Soil (Sandy)
	2	46 257	13.3	1.3		Clayey Soil (Sub Soil)
	3			14.6	HK	Lateritic Soil
	4	103				Weathered Basement
3	1	314	1.2	1.2		Top Soil (Sandy)
	2	550	12.2	13.5	K	Lateritic Soil
	3	181				Weathered Basement
4	1	153	0.8	0.8		Top Soil (Clayey)
	2	61 199	1.1	1.9		Clayey Sub Soil
	3		11.9	13.8	HK	Lateritic Soil
	4	175				Weathered Basement
5	1	172	1.3	1.3		Top Soil
	2	423	7.5	8.9		Lateritic Soil
	3	207	40.1	48.9	KH	Weathered Basement
	4	444				Fractured Basement

6	1	181	0.6	0.6 1.5		Top Soil (Clayey Sand)
	2	430	0.8	4.7		Lateritic Soil
	3	123	3.3		KH	Weathered Basement
	4	251	-	-		Fractured basement
7	1	73	2.7	2.7		Top Soil (Clayey)
	2	321	16.9	19.6		Lateritic Soil
	3	118	48.6	68.2	KH	Weathered Basement
	4	375	-	-		Fractured Basement
8	1	79	0.9	0.9		Top Soil
	2	47	1.0	1.9		Clayey Sub
	3	287	16.5	18.3	HK	Soil Lateritic layer
	4	163	-	-		Weathered Basement
9	1	328	0.8	0.8 1.7		Top Soil
	2	582	0.9	8.0		Lateritic soil
	3	6261	6.3		AK	Quartzite and quartz schist Formation
	4	310	-	-		Weathered Basement
10	1	138	1.0	1.0 3.0		Top Soil (Sandy)
	2	293	2.0		AK	Lateritic Soil
	3	1612	12.7			Quartzite and quartz

4	310	-	-	Weathered Basement



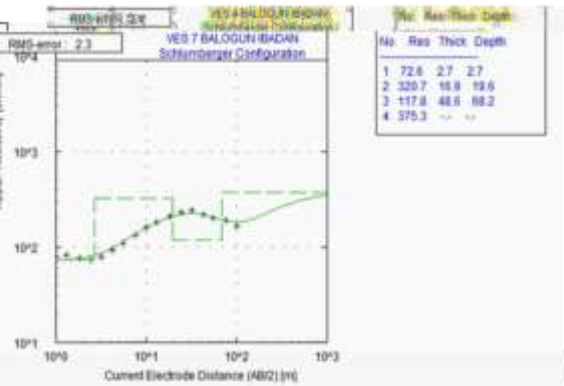


Figure 3c: Typical AK-curve type **Figure 3d:** Typical KH- curve type
Schist

Geoelectric section

The resistivity and thickness obtained primary geoelectric parameters from the inversion of the Vertical Electrical Sounding data are presented as geoelectric section and maps. Figure 4a shows geoelectric section drawn through VES locations 2, 3 and 6 in the South-Eastern direction of the study area. This section presented as profile 1 shows three – four geoelectric layers. The top soil which is the first layer has resistivity value varying from 181 – 314 Ohm-m, characteristics of sandy soil and thickness that range from 0.5 - 1.2m. Beneath this top soil only at VES 2 is thin layer (0.8m thick) of clay formation having resistivity value of 46 Ohm-m. Next to this clay subsoil and the top soil at VES 3 and 6 is a lateritic soil layer of resistivity value varying between 257 - 550 Ohm-m and thickness value ranging from 0.8 m – 13.3 m. This lateritic soil layer which is relatively thicker at the Southern end of the profile confines the underlying weathered basement layer of resistivity values of between 103 and 123Ohm-m.This weathered basement which is predominantly clayey sand and /or sandy clay in nature is recognized as the upper aquiferous unit across the profile with the overlying lateritic stratum protecting from it from any surface run off contamination. Beneath the 3.3m thick weathered basement layer at VES 6 is an occurrence of fractured basement of resistivity value of 251Ohm-m at a depth of about 7m from the surface which is presumed to be lower and major aquiferous unit in the area. This fracture basement aquifer greatly enhanced the groundwater discharge in that location, hence a good groundwater potential in that locality.

Figure 4b shows geoelectric section cutting across VES points 1, 3, 8 and 9 in the South Western direction of the study area. The interpretation of four VES data point along this section presented as Profile 2 reveals three to four geoelectric layers. The first layer is characterized by resistivity values ranging from 87 Ohm-m – 328 Ohm-m representing clayey and sandy top soil and thickness of between 0.8m and 1.2m.This layer overlies lateritic soil of resistivity varying between 162Ohmm-174Ohm-m across the profile with a thickness ranging from 0.9 m – 16.5 m except at VES 8 where a clayey soil exists as second layer. Beneath the lateritic soil layer is the weathered basement of resistivity value ranging from 41 Ohm-m – 331 Ohm-m and thickness that ranged from 16.5m - 23.4m, forming the only aquiferous unit across the profile. At VES 6, a 6.3m thick formation of resistivity value of 6261 Ohm-m overlies the weathered basement layer. This formation which is presumed to be Quartzite and quartz-schist capped the only water bearing unit (aquifer) in that locality.

Original Article

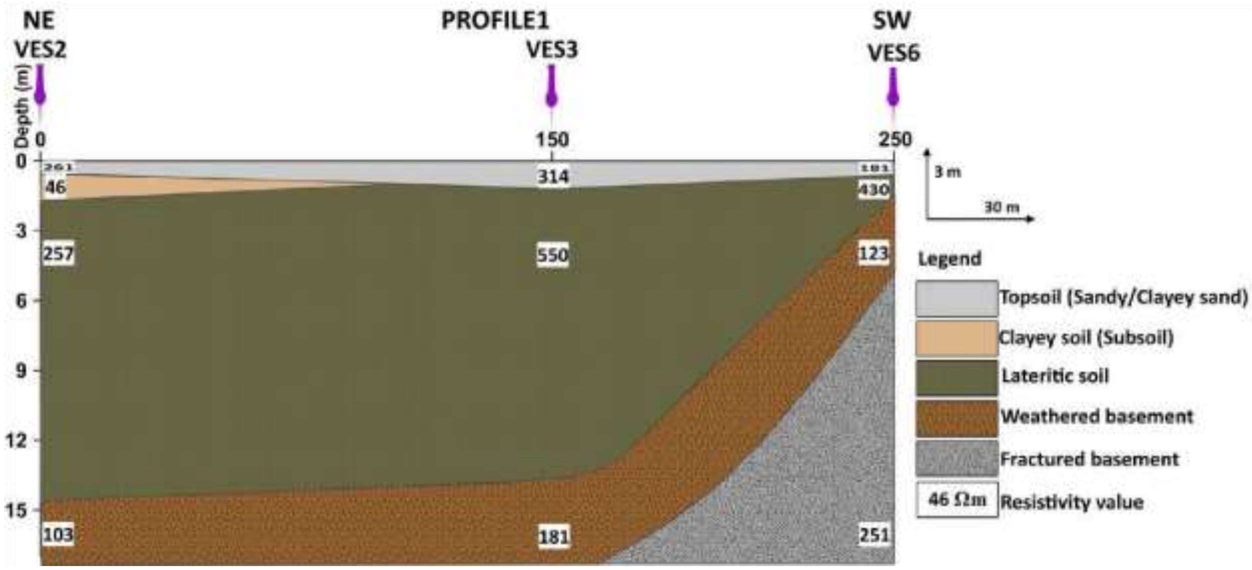


Figure 4a: Geo-electric section across VES 2, 3, and 6

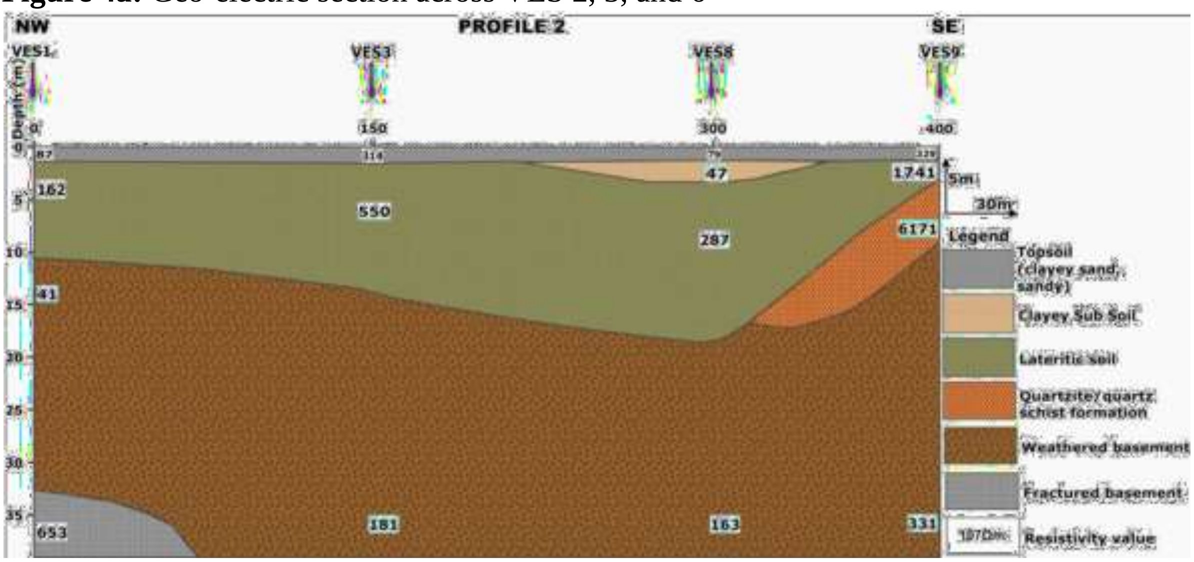


Figure 4b: Geo-electric section across VES 1, 3, 8, and 9

Isoresistivity and Isopach map of the Weathered Basement

Isoresistivity map of the weathered basement of the study area is as shown in figure 5. It shows the distribution of the resistivity of the weathered basement layer across the study area. The layer is characterized by resistivity value ranging from 41-310 Ohm-m with the most occurring resistivity value between 187 and 310 Ohm-m typical of clay free geomaterial. This layer which is considered as the upper aquiferous unit and found present at all investigated locations across the area is confined by lateritic soil and /or clay formation that overlain it .As revealed by the map about 80% of the study area has resistivity value typical of sand constituting the weathered basement notably in the Northern, Western, Eastern, central and southwestern part which could be regarded as aquiferous unit being porous and permeable formation. The remaining 20% portion is found to be sandy clay and /or clay which may constantly saturate but poorly permeably to the interstitial formation water for abstraction.

Original Article

Figure 6 Shows the Isopach map of the weathered basement layer representing the variation in the thickness of the weathered basement in the study area which ranges from 23.4 – 48.6m.As revealed by the map the Eastern, Northeastern, Southwestern and partly central of the region covering about 70% of the entire area is observed to be relatively thick than other regions. The area with weathered basement greater than 31m and clay free are recognized to be medium to high groundwater discharge area, hence presumed as good groundwater potential area.

Isoresistivity map of the fractured basement

Figure 7 Shows the isoresistivity map of the fractured basement which is the major aquiferous unit delineated in the area. It reflects the resistivity distribution of the fractured bedrock present in the area which varied from 251-653 Ohm-m. As revealed by the map only 40% of the bedrock in the surveyed area are fractured which are dominant in the southeastern and southern region. This suggest more productive basement aquiferous unit at those locations around the highly fractured bedrock and presumes to be good groundwater potential zone. The fractured basement is significant in enhancing the groundwater potential in this area as often obtainable in basement complex terrain due to its relatively low resistivity resulting from its high fracture frequency.

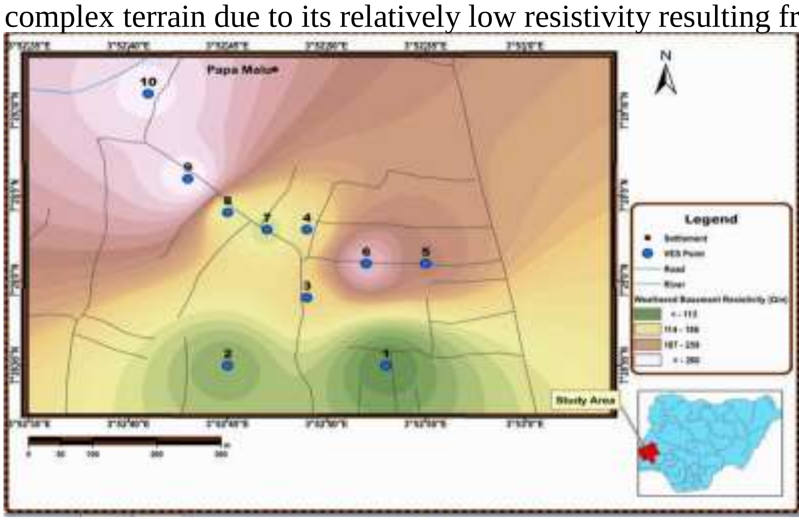


Figure 5: Isoresistivity map of weathered basement layer

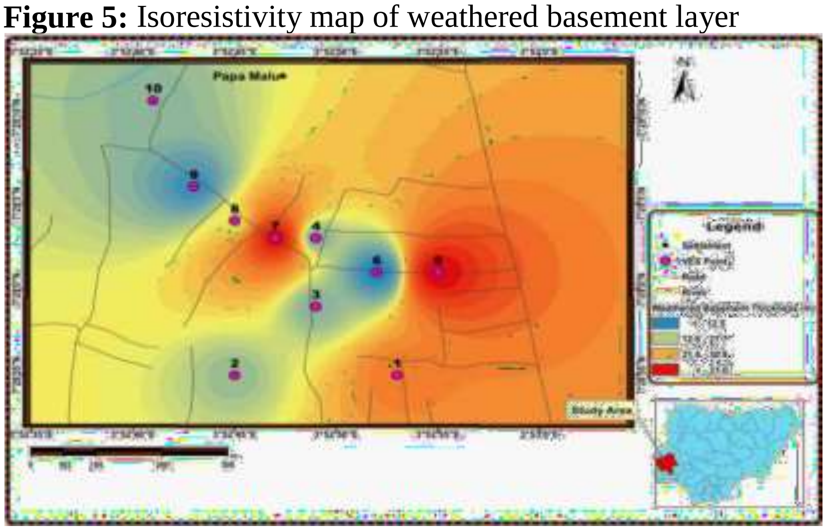


Figure 6: Isopach map of the weathered basement layer

Original Article

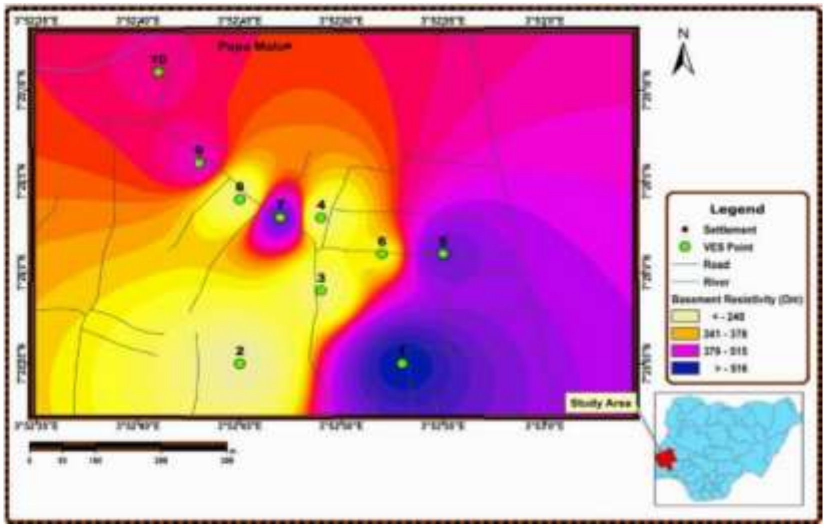


Figure 7: Isoresistivity map of fractured basement

Groundwater Potential Evaluation

The groundwater potential evaluation of the area has been based on various categories of maps; weathered basement layer isoresistivity map, fractured basement isoresistivity map, weathered basement layer isopach map and reflection coefficient map which were integrated and synthesized to serves as a thematic map using the primary geoelctric parameter obtained from the interpretation of VES result. In the evaluation of groundwater potential of basement complex terrain, the above observed weathered basement layer nature and thickness are important parameters (Zohdy, 1974, Zohdy, 1975).Both the weathered and fractured basement aquiferous units were delineated in the study area. In about 70% of the area, the weathered basement is sandy due to its observed relatively high resistivity fig 5 thereby contributing more to the groundwater discharge capability being porous and permeable lithologic unit. Furthermore, the fractured basement in about 40% of the map with relatively low resistivity constitute the major aquiferous unit owing to its high permeability which rendered it to have high groundwater discharge capability. Upon integrating various aquifer maps, the groundwater potential map produced zoned the area into low, moderate and high groundwater potential zones (figure 8) with about 70% of the entire region covered characterized by moderate to high groundwater discharge. Generally, the groundwater potential rating of the area is moderate/medium to high with the southeastern and partly central region being accorded more preference to well development in view of groundwater abstraction in the area.

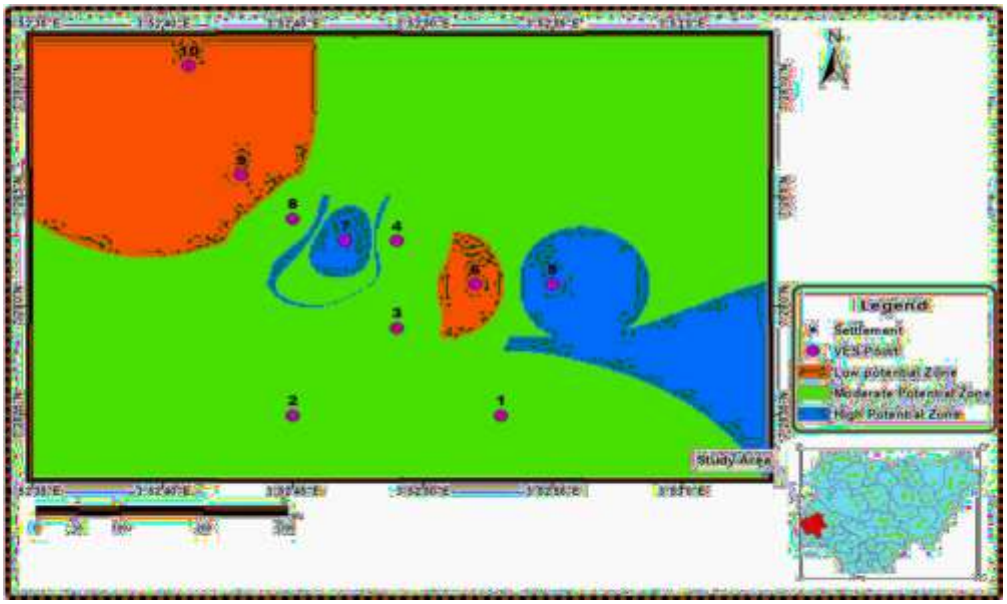


Figure 8: Groundwater potential map of study area.

Conclusion

The geophysical survey carried out at Balogun, Ibadan in the Southwestern part of Nigeria has revealed a maximum of five subsurface geologic sequences across the area out of which aquiferuos units were delineated to be weathered and fractured basement. The weathered basement is relatively thick and predominantly sandy in over 60% of the surveyed area. This indicate moderate to high groundwater discharge capacity but offers low to fair protective capacity. The weathered basement layer in turn is greatly protected from surface run-off contamination by overlying lateritic profile in most places. The fractured basement in about 40% of the area covered occurred at depth range of 5.7m – 68.2m. Due to its relatively low resistivity resulting from high fracture frequency, the fractured basement unit is significant in enhancing the groundwater resource potential of the area. In general, the groundwater potential of the area is rated low to high with about 70% area surveyed characterized by subsurface lithologic unit of moderate/medium to high groundwater discharge. The study has greatly shown that an adequate geophysical investigation is quite necessary to access the groundwater potential of an area in order to have a reliable sustainable groundwater development program for an improved basic amenity required of the residents and particularly as a means of finding lasting solution to potable water scarcity in the area.

References

Abdullahi, A. S., S. M., Musa and A. G. Illiya, (2005). Aquifer depletion and ground water situation in Damaturu, Northeastern Nigeria. Water Resour., 16: 59-64.

Abiola, O., Enikanselu, P.A and Oladapo, M..I(2013).Groundwater potential and aquifer protective capacity of overburden units in Ado Ekiti, Southwestern Nigeria. International Journal of physical sciences 4(3):120-132.

Adeniji A.E, Obiora D.N, OmononaO .V, Ayuba R (2013) Geoelectrical evaluation of groundwater potentials of Bwari basement area, Central Nigeria. Int J Phys Sci 8(25):1350–1361. https://doi.org/10.5897/IJPS2013.3951

Asfahani J., (2006). Geoelectrical investigation forcharacterizing the hydrogeological conditions insemi-arid region in Khanasser valley, Syria. J. Arid Environ., 68: 31-52.

Auwalu, L Y and Abubakar,Y. L, (2012). Application of Resistivity Sounding In Groundwater Investigation: A Case Study of RiminGado and Tofa Local Government Areas of Kano State, Nigeria. Journal of Applied Physics, Volume 2, Issue 1 (Sep-Oct. 2012), PP 1418

Bello, A. A. And Makinde V., (2007). Delineation of the aquifer in the South-Western part of the NupeBasin, Kwara State, Nigeria. J. Am. Sci., 3: 36-44

Caruthers R. M. and Smith I. F. (1992).The use of ground electrical survey methods for sitting water supply borehole in shallow christalline basement Terrain in F.P Wright and W.C.Burgess (eds).The hydrogeology of Crystalline basement Aquifer in Africa. Geological society special publication, London,UK,203-220

Clark, L. (1985). Groundwater abstraction from basement complex areas of Africa .Quart. J.Eng. Geol.,18:25-34.

Dan-Hassan M. A. and Olorunfemi M. O. (1999). Hydro-Geophysical Investigation of a BasementTerrain in the North-Central part of Kaduna State,Nigeria. Journal of Mining and Geology, 35 (2)189-206.

EkoroNkoungou H. L., NjandjockNouck P., Bisso D., Assembe S. and Manguelle-Dicoum E. (2012).Geophysical contribution for the determination of aquifer properties in memveele, South Cameroon Journal of Water Ressources and Protection (4) : 885-890.

Meli'i J. L., NjandjockNouck P. And Gouet D. H.(2011). Magnetotelluric method for groundwater exploration in crystalline basement complex, Cameroon. Journal of environmental hydrology, 19.Paper 16.

Meli'i J. L., NjandjockNouck P., Mbanga A. F. and Manguelle-Dicoum E. (2012). Spatial analyses of magnetotelluric data in the northern part of congo craton in south Cameroon region. Journal of emerging trends in engineering and applied sciences (jeteas) 3(4): 631-635.

Nwachukwu S., Bello R and Balogun A. O (2019). Evaluation of groundwater potentials of Orogun, South–South Part of Nigeria using electrical resistivity method.Applied water science 9: 184

Olayinka, A. I. (1990). Electromagnetic profiling and resistivity sounding in groundwater investigations near Egbeda-Kabba,Kwara State.J.Min.Geol.,26:243-250

Olorunfemi, M. O., Ojo, J. S., and Akintunde, O. M. (1999). Hydro-geophysical Evaluation of the Groundwater Potentials of the Akure Metropolis, South-Western Nigeria, Journal of Mining and Geology Vol. 35(2), 207-228.

Rahaman, M. A. (1976). Review of the basement geology of southwestern Nigeria. Elizabethan Publishing Company, Nigeria. pp 44-56.

Singh, C. L. (1984). Role of surface geophysical methods for groundwater exploration in hard rock areas. Proceedings of international workshop on rural hydrology and hydraulics in fissured basement zones,59
-68

Satpathy, B. N. and. Kanugo, B. N. (1976). Groundwater exploration in hard rock terrain. A case study. Geophysical Prospecting, 24(4):725-736.

Vander Velpen B. P. A. (1988). Resist Version 1.0,M.Sc Research project, ITC, Delft Nertherland,. Worthington, P. R. (1997).Geophysical investigation of groundwater resources in the Kalahari Basin. Geophysics,42(4):838-849

Zohdy, A.A.R (1974). Electrical methods in application of surface geophysics to groundwater investigation," Techniques of water resources investigation of the united states.Geol.Surv.Book, 2(D1):47-55

Zohdy, A. A. R. (1975).The auxiliary point method of electrical sounding interpretation and its relationship to Dar Zarrouk parameters.geophysics,30:644-650