NJBAS

Available online at http://www.ajol.info/index.php/njbas/index
Nigerian Journal of Basic and Applied Sciences (June, 2022), 30(1):68-76
DOI: http://dx.doi.org/10.4314/njbas.v30i1.10

ISSN 0794-5698

Full Length Research Article

Integrated Geophysical Methods and Techniques for Studying the Perennial Springs in Ikanje-Share, Kwara State, Nigeria

***[1]A. K. Olawuyi and [2]M. A. Bawallah**
[1]Geophysics Department, University of Ilorin, Nigeria
[2]Geophysics Department, Federal University of Technology, Akure
[*Corresponding Author: E-mail: gideonola2001@yahoo.com]

ABSTRACT

An integrated magnetic, self-potential (S.P.) and electrical resistivity survey involving magnetic profiling and 1D Vertical Electrical Sounding (VES) electrical imaging techniques were carried out in the transition environment between the Nupe Basin and Southwestern Nigeria Basement Complex at Ikanje-Share in Kwara State, Nigeria. The Ikanje-Share perennial springs started gaining a lot of attention after many travelers and tertiary institutions in Nigeria made it a good choice for their fieldwork exercise. The surveys were done in order to delineate the subsurface layers, determine the geoelectrical characteristics and identify geological structures (e.g., faults and fractures) that are responsible for the perennial spring formation. The magnetic profiling was used as reconnaissance technique to identify lineament features that are favourable to groundwater accumulation and transmission. Some magnetic lineaments were qualitatively inferred from some profiles in the study area. The fault locations coincide with inflection points in S.P. curves and occur as horizontal and consistent planes of discontinuities at depths of approximately 1.25, 4.25, 8.75, 13.15 and 21.25 m, respectively. The VES interpretation results indicated four to five major geologic units, which include: the topsoil/clay/lateritic layer, the lateritic layer, the weathered basement, the weathered/fractured basement and the fresh bedrock. The weathered and fractured basements constitute the main aquifer units and the overburden thickness varies from 5.0 to 16.8 m. The study has shown the usefulness of integrated geophysical methods and techniques in subsurface structural and groundwater development study over the perennial springs in the transition environment between the Nupe Basin and the Southwestern Nigeria Basement complex.

Keywords: Magnetic, Self-potential, Electrical resistivity, Profiling, Basement, Groundwater.

INTRODUCTION

Groundwater is water contained in the voids of the geologic materials that comprise the crust of the earth and exists at a pressure greater than or equal to atmospheric pressure (Al Sabahi *et al*., 2009; Obiora *et al.,* 2015). There must be space between the rock particles for groundwater to flow and the earth's material becomes denser with more depth. Essentially the weights of the rock above condense the rock below and squeeze out to open the pore spaces deeper in the earth. That is why groundwater can only be found within a few kilometers of the earth's surface. Observation shows that groundwater comes from rain, snow, sheet and hail that soak into the ground and become the groundwater responsible for the spring, wells and bore holes (Oseji *et al*., 2005; Alabi *et al*., 2010).

The Ikanje-Share springs discharge water at the rate of between 8 to 63 mL/s (2 pints to 1 gal/min) and belongs to the 7th magnitude springs (chemeurope.com). It has permanently or perennially met human needs as drinking, domestic and mills water supply. It is a point of convergence for travelers and residents throughout the year and it is fast becoming a point of attraction to many Nigerian tertiary institutions that routinely go to Share town for fieldworks. However, inadequate supply of water in terms of quality and quantity is influenced by factors such as climate, geomorphology, physiography, geology and hydrogeologic settings. Unfortunately, these limited water resources shared between humans and animals are often contaminated (Bello and Makinde, 2009). To overcome these problems, the Kwara State government, National and International agencies for groundwater exploration have drilled many boreholes and modern wells to address shortages of potable water for domestic and industrial purposes. Consequently, detailed geophysical investigations must precede boreholes drilling in order to evaluate the geologic and geoelectric characteristics of the aquifers. Methods such as the electrical resistivity have been used to delineate aquiferous units in many parts of the world (Ako and Olorunfemi, 1989; Anudu *et al*., 2008; Idornighie and Olorunfemi, 1992; Olorunfemi and Oni, 2019; Omosuyi *et al*., 2008). This method is preferable because of the resistivity contrasts obtained when the groundwater zone is reached. In the basement area, several authors have researched groundwater exploration, evaluation and delineation using geophysical methods (Obiora *et al.,* 2016).

The self-potential (or spontaneous polarization, SP) method is based on the surface measurement of natural potential differences resulting from electrochemical reactions in the subsurface (Kearey *et al*., 2002). Natural, unidirectional currents flow in the ground and produce voltage (self-potential) anomalies that can amount to several hundreds of millivolts between points on the ground surface. They have applications in explorations and several other situations (Milsom, 2003). Self-potential method has been increasingly used in groundwater and geothermal investigation, environmental and engineering applications, mapping seepage flow associated with dams, geological mapping, delineation of shear zone and near-surface faults (Odek, 2018). The SP method has been extended further to groundwater and geothermal explorations as well as aid in geological mapping to delineate shear zones and near-surface faults (Reynolds, 1998). This study therefore, intends to evaluate the usefulness of integrated geophysical methods and techniques in subsurface structural and groundwater development study over a perennial spring in a transition environment.

Location, Geomorphology and Physiography

The study area is situated at the transition environment between the Nupe Basin and the Southwestern Nigerian Basement Complex (Figure 1). It is bounded by latitudes 8.821552 ° N and 8.822292 ° N and longitude 4.948813 ° E and 4.949775 ° E covering a total area of approximately 20000 m^2 in the Ikanje village at Share town in Ifelodun Local Government Area (LGA) of Kwara State, Nigeria. Guinea savannah type vegetation with two distinct seasons (rainy and dry) is found in the study area. The Nupe Basin is a NW-SE trending embayment perpendicular to the main axis of the Benue Trough and the Niger Delta Basin of Nigeria. The sedimentary basin is flanked by the Basement Complex rocks of Southwestern and Northcentral Nigeria (Olawuyi, 2015).

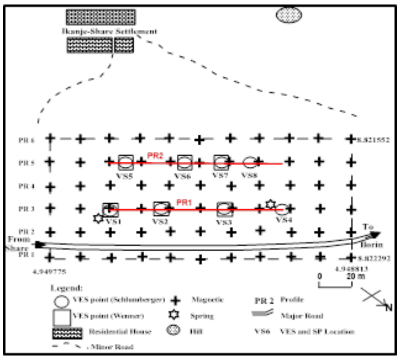


Figure 1: Sketch map of Ikanje-Sharesettlement showing the study locations

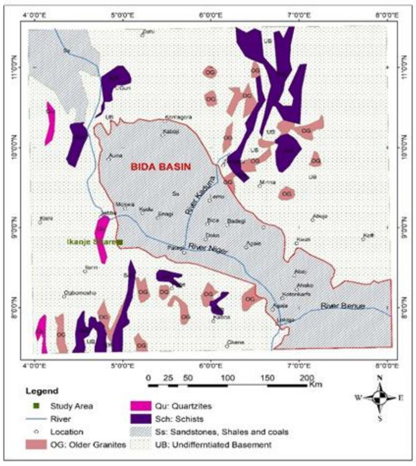


Figure 2: Geological map of Bida basin and environs showing the study area (Adapted from Obaje *et. al.,* 2011).

Geology and Hydrogeology of the Area

The study area is underlain by the sedimentary terrain of the transition zone of Share (Sheet 202 in the Nigerian topographical map) (Figure 2). It consists of mainly Santonian to Maestrichtian sediments of sandstones, siltstones and superficial alluvial deposits (Adeleye, 1976). The lithology of these formations, according to Idornighie and Olorunfemi' (1992); Mallam and Ajayi, (2000), are alluvium, weathered laterite, sandy clay and clayey sand. Ojo, (2012) have explained that the northern Bida Basin has been divided into (i) areas north of Niger River and (ii) areas south of the Niger River (Share - Pategi), and that the sediment in the areas south of the Niger River have similar characteristics with that of Bida Formation.

Based on sedimentary structures and texture, the sedimentary facies of the Bida Formation recognized by Ojo, (2012) in the Share area include: (i) Conglomerate (ii) Sandstone and (iii) Claystone. Generally, the rock units in this region is said to be highly characterized by intercalations of claystone, siltstone, silt, clay and weathered bedrock (Biwater Shellabear, 1985; UNICEF-RUWATSAN Project, 1988). These geological materials are usually liable to act as aquitard or aquifer zone in both the sedimentary terrain and the crystalline basement complex existing in this area.

MATERIALS AND METHODS

The integrated approach for this study was based on the a priori knowledge that this area is sedimentary in nature though it is part of the transition environment between the Bida basin and the southwestern Nigeria basement complex. The proper geophysical methods to delineate the subsurface structures and physical property of subsurface earth materials included ground magnetic, electrical resistivity and self-potential methods. The methodology of the Vertical Electrical Soundings and the collection of resistivity and SP data are as earlier discussed and the magnetic profiling was collected at grid spacing of 20 m while standard field procedures were followed.

The Magnetic Data

The study area covers about 20,000 m^2 within the vicinity believed to be the immediate catchment area for the two perennial springs. GEMS Proton Precession Magnetometer (GSM19T) was employed in ground magnetic data collection. The information consists of profiles of magnetic data collected on the ground along NW-SE direction spaced 20m apart. For ease of processing, the magnetic data was reduced of a common value of 32,000 nT. This value may therefore be added to every data point to get the exact regional field; however, doing this will not change the grid in any way since the value is common to all the data points. The TMI map obtained can give information enough to qualitatively infer the presence of a fault or fracture.

The Vertical Electrical Sounding

The Vertical Electrical Soundings (VES) method was employed in this work with the use of DDC-8 Electron-Automatic-Compensator (Resistivity meter). The Schlumberger array was used for the VES data acquisition. The electrode spreading followed the description (Kearey, 2002) where half electrode spacing (AB/2; Figure3) range of 1 – 100 m was used to generate maximum information about the subsurface lithology and overburden thickness. Eight VES stations (Figure 1) were occupied whose locations were carefully chosen based on that of the two springs and the area covered by the magnetic profiles. The VES data were used to investigate the suspected discontinuities and overburden thicknesses as well as the geoelectrical characteristics of the study area. Apparent resistivity (ℓa) for the Schlumberger array is computed from the equation (1) below (Kearey, 2002):

$$\ell_a = \frac{\pi L^2}{2l} \frac{\Delta V}{I} \qquad \text{Eqn. (1)}$$

where (L) is half the distance between the current electrodes (AB), (l) is half the distance between the potential electrodes (MN), $\frac{\Delta V}{I}$ is the resistance of the ground, and I is the input current.

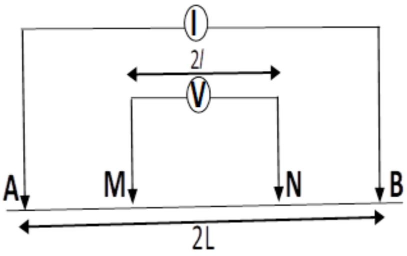


Figure 3: Diagram of VES Schlumberger configuration (Adapted from Milsom, 2003).

The apparent resistivity value for the different electrode spacing which was obtained by multiplying the resistance with the geometric factor were quantitatively interpreted by partial curve matching and computer iteration techniques (Kearey, 2002). The WinResist™ Version 1.0 of Vander Velpen (1988) was used for the resistivity inversion.

The Self-Potential Data

The self-potential data were collected simultaneously but sequentially along two profiles after the electrical resistivity data using the VES method and DDC-8 Electron-Automatic-Compensator (Resistivity meter). The equipment is in-built with resistivity, SP and IP measuring mechanisms and each reading could be obtained by simply pressing the necessary buttons as contained in the manual. The Schlumberger array was used for the VES data acquisition. All other steps are the same as that for electrical resistivity data acquisition. The eight SP points were adequate enough for the study on the springs and the subsurface lithologies in the study area (Figure 1). The natural current flow in the subsurface due to electrochemical reaction gives rise to self-potential that is measured on the surface as negative potential (Biswas and Sharma, 2016).

Data Analysis

The Total Magnetic Intensity (TMI) field data were recorded in nT while the SP voltage anomalies determined in millivolts between points on the ground surface were qualitatively and quantitatively interpreted to infer joints/fractures and discontinuities at inflection points as well as deduce their approximate depths of occurrence. The apparent resistivity values obtained for the different electrode spacing were quantitatively interpreted by partial curve matching and computer iteration techniques (Kearey, 2002). The WinResist™ Version 1.0 of Vander Velpen (1988) was used for the resistivity inversion. The 2D models for the subsurface imaging were created using the IP2Win™software.

RESULTS AND DISCUSSIONS

The Magnetic TMI Map and the Magnetic Anomalies Profiles

The magnetic TMI contour map is shown in Figure 4. The TMI values range from a minimum of about 1360 nT to about 1520 nT. The presence of smooth short wavelength TMI contours is evident on this map. 'The magnetic field is bipolar in nature and induced magnetic field is a function of latitude or magnetic inclination and as a result, anomaly pattern becomes complex to interpret. The anomaly pattern assumes an asymmetric shape, whenever induced field is located anywhere except pole or equator. To negate the complexities of magnetic interpretation reduced to magnetic pole (RTP) or reduced to magnetic equator (RTE) transformations are used. Reduction to equator (RTE) is the preferred operation for lower magnetic latitude. In case of RTE, geomagnetic field is predominantly horizontal (Ganguli *et al.,* 2019). The mean magnetic latitude of the present study is 8.82 ° N. Since the magnetic anomalies pattern over the present study area is not very complex and the area of study is very small, the data will not be processed with RTE filter. Figure 5 (a and b) show profiles each having lengths of 120 m and the presence of faults/fractures were qualitatively deduced and inferred as dashed lines.

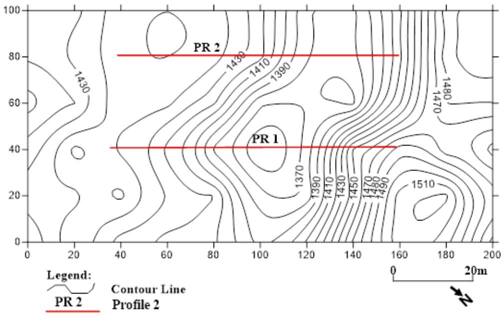


Figure 4: Ikanje Share ground magnetic TMI contour map

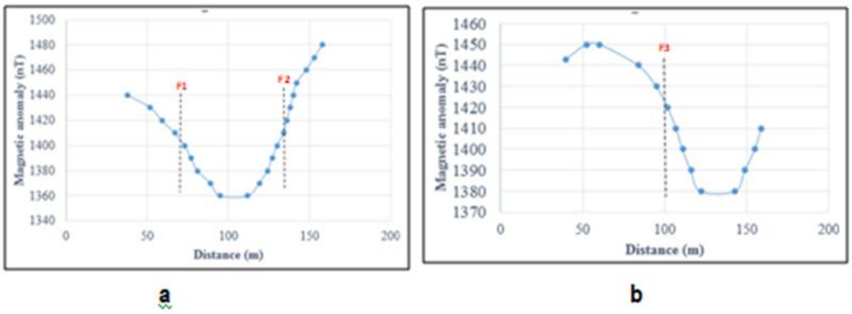
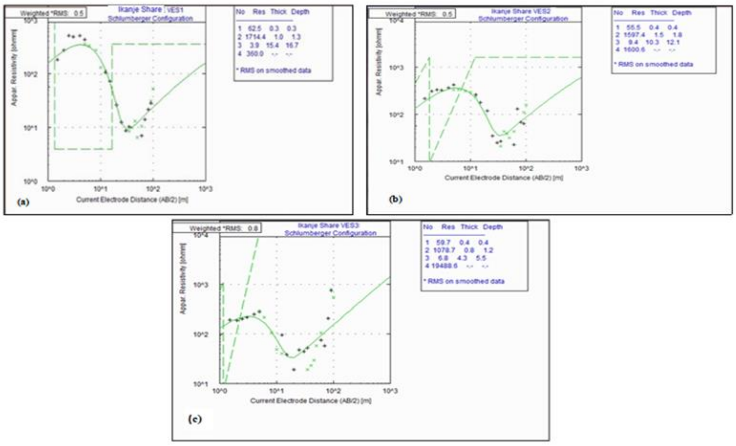


Figure 5: (a) Mag. anomaly along Profile 1 **(b)** Mag. anomaly along Profile 2.



(a)

No	Res	Thick	Depth
1	62.5	0.3	0.3
2	1714.4	1.0	1.3
3	3.9	15.4	16.7
4	360.0	-.-	-.-

* RMS on smoothed data

(b)

No	Res	Thick	Depth
1	55.5	0.4	0.4
2	1597.4	1.5	1.8
3	9.4	10.3	12.1
4	1600.6	-.-	-.-

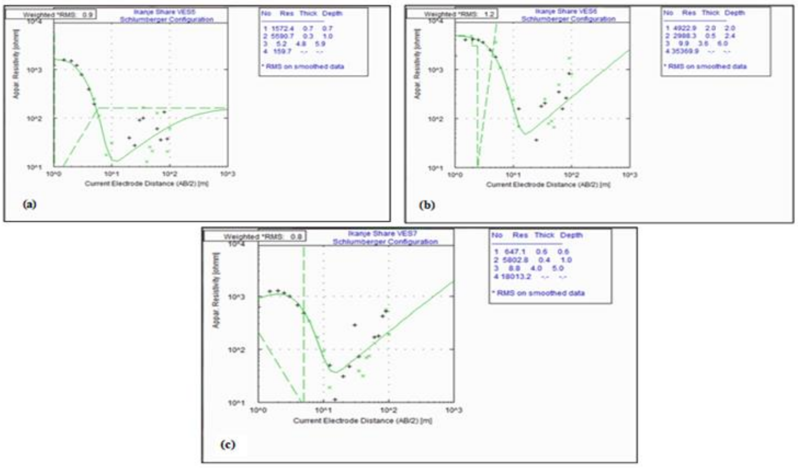
* RMS on smoothed data

(c)

No	Res	Thick	Depth
1	59.7	0.4	0.4
2	1078.7	0.8	1.2
3	6.8	4.3	5.5
4	19488.6	-.-	-.-

* RMS on smoothed data

Figure 6: Typical VES curves for Ikanje-Share (a) VS1 (b) VS2 (c) VS3



(a)

No	Res	Thick	Depth
1	1572.4	0.7	0.7
2	5590.7	0.3	1.0
3	5.2	4.8	5.9
4	159.7	-.-	-.-

* RMS on smoothed data

(b)

No	Res	Thick	Depth
1	4922.9	2.0	2.0
2	2988.3	0.5	2.4
3	9.9	3.6	6.0
4	35369.9	-.-	-.-

* RMS on smoothed data

(c)

No	Res	Thick	Depth
1	647.1	0.6	0.6
2	5802.8	0.4	1.0
3	8.8	4.0	5.0
4	18013.2	-.-	-.-

* RMS on smoothed data

Figure 7: Typical VES Curves for Ikanje-Share (a) VS5 (b) VS6 (c) VS7

The VES Curves

The typical VES curves are displayed in Figures 6 and 7. The VES interpretation results in the study area indicated four to five major geologic units: the top soil/clay/lateritic layer, the lateritic layer, the weathered basement, the weathered/fractured basement and the fresh bedrock. The curve types range from KH, QH to KQH in the study area. The KH type is the most predominant as it accounts for more than 75 % of the curve types. The predominance of the 4-layer (KH) type shows that most of the area is covered by not less than four lithologies, one of which is either fractured or weathered basement (i.e., aquiferous layer). This could be one of the reasons for the abundance and perennial nature of the groundwater in this environment. The different rock types and their respective resistivities, thicknesses and depths are recorded in Table 1, while Table 2 shows the resistivity values of weathered and or fractured layer and the depth to dry bedrock at these locations. The weathered and fractured basements constitute the main aquifer units in the study area.

The Iso-Depth Contour and 3D Surface Maps of Depth to Dry Bedrock.

The iso-depth contour map of depth to dry bedrock is shown in Figure 8. The deepest region occurs at the southwestern side (indicated in blue) and hosts the most active spring while the second spring occurs at the southeastern side. The relatively thicker overburden in these areas makes them better reservoirs to the springs associated with them. They are expected to be more productive, groundwater wise. The deepest point is about 17m. The shallowest area is shown in green colour on the contour map. The pattern of depth distribution in the 3D surface map (Figure 9) is similar to that of the contour map. The depths to dry bedrock vary from approximately 5 to 16.5 m in the study area.

The Geoelectrical Sections for Profiles 1 and 2

Figures 10 and 11 are the geoelectric sections for profiles 1 and 2 (Figure 1). The aquiferous lithologies (i.e., weathered and fractured basements) with mostly low resistivities are generally between five and nine metres across the two profiles and they are overlain by not very thicklithologies which make them easily accessible for exploitation. The areas with thick overburden that also harbor fracture zones are expected to contain more groundwater (e.g., VS 1 and 4). From observation, the two springs occur in the areas with thick overburden.

The Self-Potential Curves

Figures 12 and 13 are the SP anomaly curves obtained in the study area. The SP method is bipolar and has some similarities with magnetic method (Kearey *et al.*, 2002). It has been used in groundwater study (Fournier, 1989). The anomaly shape observed in the SP is similar to that for contact (Fault and Fractures) in magnetic method. The fault locations are therefore taken to be at the inflection points and since the curves here represent changes in S.P. values with depth, the numerous repetitions of the lineament features (dashed lines) at almost the same depth on the different SP curves (representing the different locations) show that the planes of discontinuities are consistent at each depth and that the area is highly fractured which makes the springs to flourish and abide.

These faults and fractures are most likely to occur as horizontal discontinuities and the values of their depth can be obtained by calculation (e.g., Depth = 0.125AB; i.e. 1.25, 4.25, 8.75, 13.15 and 21.25m respectively) using the Schlumberger array apparent resistivity VES approach. About six lithologies can be delineated from the graphs based on the dashed lines at the inflection points.

The Iso-potential Contour Maps of AB/2 = 5m and AB/2 = 20m

The Iso-potential Contour Maps of AB/2 = 5m and AB/2 = 20m are presented as Figures14 and 15 respectively. Figure 14 is the iso-potential contour map of AB/2 = 5m.

It represents the first set of inflection points and the first discontinuity where the first set of faults and fractures occur. The natural current flow in the subsurface due to electrochemical reaction gives rise to self-potential that is measured on the surface as negative potential (Biswas and Sharma, 2016). In Figure 14, the region with negative potential at the centre of the map (blue colour) and the negative SP anomaly observed in Figures 12 and 13 are attributable to electrochemical reaction with mineral grain and ground water, while the region with positive potential represents the zone for water accumulation or aquifer. In like manner, Figure 15 is the iso-potential contour map of AB/2 = 20m.It represents the second set of inflection points and the second discontinuity where the second set of faults and fractures occur. In Figure 15, the region with negative potential at the centre of the map (blue colour) is attributable to electrochemical reaction with mineral grain and ground water, while the region with positive potential represents the zone for water accumulation or aquifer. Here the two springs are located and the overburden is thick and suitable for water accumulation. The central area with shallower overburden acts as a divide between the two springs.

The SP Profiles between VS1 and VS4 at AB/2 = 5 m and AB/2 = 20 m respectively

The SP profiles 3 and 4 between VS1 and VS4 at AB/2 = 5m and AB/2 = 20m (between the two springs) are shown in Figures16a and b respectively. As in magnetic method, the qualitative interpretation of the SP anomaly in Figures 16a and b show that the anomaly minimum for each profile may be assumed to occur directly over the anomalous body. The symmetry or asymmetry of the anomalies only provides information on the attitude of the body.

Table 1: Summary of VES data Interpretation

VES	RESISTIVITY (ℓ_1,ℓ_2)	THICKNESS (t_1,t_2)	DEPTH (d_1,..)	CURVE TYPE	PROBABLE LITHOLOGY (LAYERS 1, 2, ..)
VS1	625,1714, 3.9,360	0.4,1.0, 15.4,inf	0.4,1.4, 16.8,inf	KH	Topsoil, Lateritic layer, weathered/ fractured basement, fresh bedrock
VS2	56,1597, 9.4,1600	0.4,1.5, 10.3,inf	0.4,1.9, 12.2,inf	KH	Topsoil, lateritic layer, weathered/ fractured basement, fresh bedrock
VS3	60,1079, 6.8,19488	0.4,0.8, 4.3,inf	0.4,1.2, 5.5,inf	KH	Topsoil, lateritic layer, weathered/ fractured basement, fresh bedrock
VS4	21,1882, 359,4,3095	0.4,0.4, 0.9,6.5,Inf	0.4,0.8, 1.7,8.2,inf	KQH	Clay, lateritic layer, weathered basement, fractured basement, fresh bedrock
VS5	1572,5591, 5.2, 160	0.7,0.3, 4.8,inf	0.7,1.0, 5.8,inf	KH	Topsoil, partly weathered basement, weathered/fractured basement, fresh Bedrock
VS6	4923,2988, 10,35370	2.0,0.5, 3.6,inf	2.0,2.5, 6.1,inf	QH	Lateritic layer, partly weathered basement, weathered/fractured basement, fresh Bedrock
VS7	647,5803, 8.8,18013	0.6,0.4, 4.0, inf	0.6,1.0, 5.0,inf	KH	Topsoil, partly weathered basement, fractured basement, fresh bedrock
VS8	1043,32714, 59,15793	0.2,0.5, 4.9, inf	0.2,0.7, 5.6,inf	KH	Topsoil, partly weathered basement, fractured basement, fresh bedrock

Table 2: Weathered basement resistivity, depth to dry bedrock and SP values for Ikanje-Share study location

VES Location	X (m)	Y (m)	Res. of Weathered (W) and/or Fractured (F) Layer (Ω-m)	Depth to Dry Bedrock (m)	SP val. at AB/2 =5m (mV)	SP val. at AB/2 =20m (mV)
VS1	39.05	40.20	3.9 (W/F)	-16.8	48.2	87.6
VS2	73.77	40.94	9.4 (W/F)	-12.2	-13.4	-78.7
VS3	115.76	41.69	6.8 (W/F)	-5.5	-131.2	-28.1
VS4	155.10	40.20	359 (W) 4.4 (F)	-8.2	44.7	50.6
VS5	50.17	80.59	5.2 (W/F)	-5.8	78.7	102.9
VS6	88.86	81.33	10 (W/F)	-6.1	3.4	-8.8
VS7	114.45	79.80	8.8 (W/F)	-5.0	-8.7	-26.5
VS8	134.77	80.59	59 (F)	-5.6	-10	-50

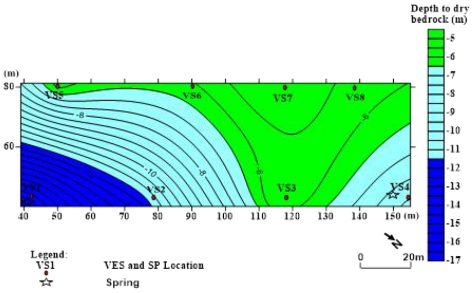


Figure 8: Contour map of depth to dry bedrock

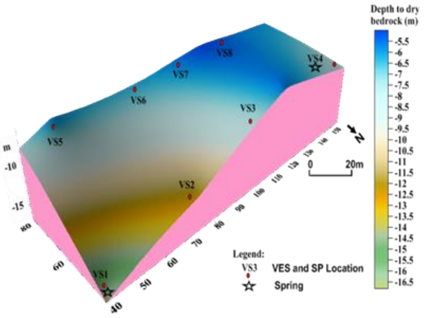


Figure 9: 3D surface map of depth to dry bedrock

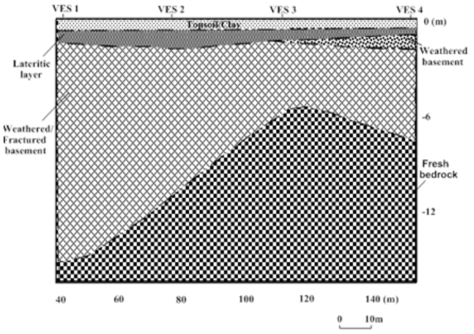


Figure 10: Geoelectrical section for profile 1(VES 1-4)

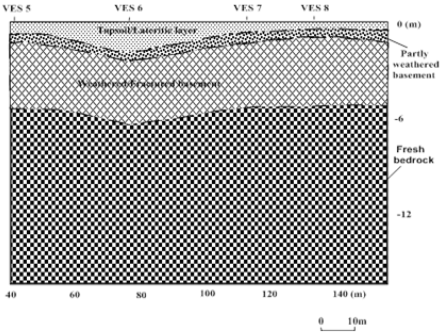


Figure 11: Geoelectrical section for profile 2 (VES 5-8)

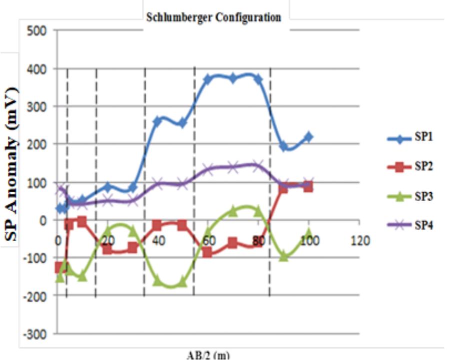


Figure 12: Typical SP curves for Ikanje-Share VS1 –4

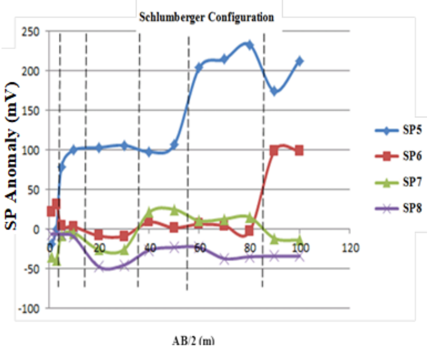


Figure 13: Typical SP Curves for Ikanje-Share VS5 – 8

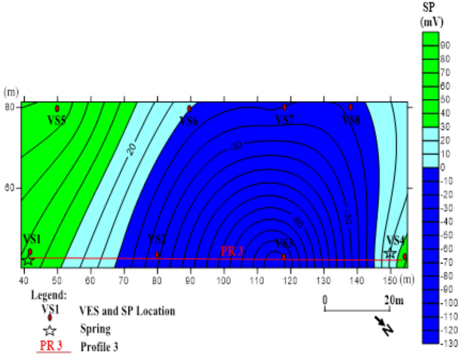


Figure 14: Iso-potential contour map of SP at AB/2 = 5m

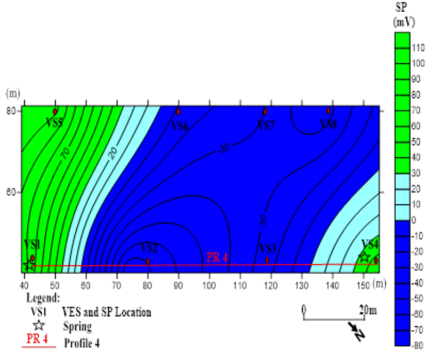


Figure15: Iso-potential Contour map of SP at AB/2 = 20m

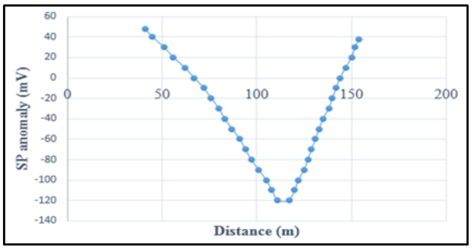


Figure16a: SP anomaly of profile 3 at AB/2 = 5m

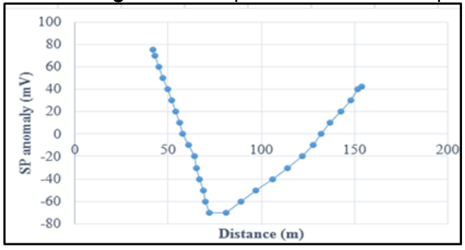


Figure 16b: SP anomaly of profile 4 at AB/2 = 20m

CONCLUSIONS

Some magnetic lineaments (faults/fractures) were qualitatively deduced and inferred in the Ikanje-Share study area. Findings in this study suggest the fault locations in SP occur as numerous repetitions at almost the same depth on the different SP curves, indicating that the planes of discontinuities are horizontal and consistent at each depth and the high level of fracturing in the area contributes to the consistency of the springs. The fault locations coincide with inflection points in SP curves and occur as horizontal and consistent planes of discontinuities at depths of approximately 1.25, 4.25, 8.75, 13.15 and 21.25 m respectively. Five major geologic units are identified: the top soil/clay/lateritic layer, the lateritic layer, the weathered basement, the weathered/fractured basement and the fresh bedrock. The curve types range from KH, QH to KQH, the KH type being the most predominant accounting for more than 75 % of the curve types. The weathered and fractured basements constitute the main aquifer units with depths to dry bedrock varying from 5.0 to 16.8 m. The deepest region hosts the most active spring while the relatively thicker overburdens in these spring areas are better reservoirs to them. This study demonstrates the applicability of magnetic, SP and electrical resistivity integrated geophysical techniques in subsurface structural and groundwater development study over the perennial spring in the transition environment between the Bida Basin and the Southwestern Nigeria Basement Complex.

REFERENCES

Adeleye, D.R. (1976). The Geology of Middle Niger Basin. In Kogbe C.A. (Editor), Geology of Nigeria. Elizabethan Publishing Company Limited, Lagos.

Ako, B. D. and Olorunfemi, M. O. (1989). Geoelectric survey of groundwater in the newer basalts of Vom, Plateau State. *Journal of Mining and Geology*, **25**(1&2): 247-250.

Alabi, A. A., Bello, R., Ogungbe, A. S. and Oyerinde, H. O. (2010). Determination of ground water potential in Lagos State University, Ojo; using geoelectric methods (Vertical Electric Sounding and Horizontal Profilling). *Report and Opinion*, **2**(5): 68-75.

Al Sabahi, E., Rahim, S. A., Wan Zahairi W. Y., Nozaily A. I. and Alshaebi, F. (2009). The Characteristics of leachate and groundwater pollution at municipal solid waste landfill of Ibb City, Yemen. *American Journal of Environmental Science,* **5**(3): 256-266.

Anudu, G. K., Onwuemesi, A. G., Ajaegwu, N. E., Onuba, L. N. and Omali, A. O. (2008). Electrical Resistivity investigation for Groundwater in the Basement Complex terrain: A Case Study of Idi-Ayunre and its Environs, Oyo State, Southwestern Nigeria. *Natural and Applied Science Journal,* **9**(2): 1-12.

Bello, A. A. and Makinde, V. (2009). Geophysical Investigation for Groundwater in Edu and Pategi Local Government Areas (Kwara State), Middle Niger Basin, Nigeria. *Academic Arena,* **1**(3): 47-50.

Biswas, A. and Sharma, S. P. (2016). Integrated Geophysical Studies to elicit the subsurface structures associated with Uranium mineralization around South Purulia Shear Zone, India: A review. *Ore Geology Reviews*, **72**:1307-1326.

Biwater Shellabear (Nigeria) Limited (1985). Kwara State Water Supply Scheme. Unpublished Report Submitted to Kwara State Utility Board.

Chemeurope.com: https://www.chemeurope.com, encyclopedia, Spring, retrieved on 10 March 2022.

Fournier, C. (1989). Spontaneous potentials and resistivity surveys appliedto hydrogeology in a volcanic area: case history of the Chaine des Puys (Puy de Dome, France). *Geophysical Prospecting*, **37**: 647 – 668.

Ganguli, S. S., Singh, S., Das, N., Maurya, D., Pal, S. K. and Rama Rao, J. V. (2019). Gravity and Magnetic Survey in Southwestern Part of Cuddapah Basin, India and its Implication for Shallow Crustal Architecture and Mineralization. *Journal of Geological Society of India*, **93** (4):419-430.

Idornighie, A. I. and Olorunfemi, M. O. (1992). A geoelectric mapping of the basement structures of the southcentral part of the Bida basin and its hydrogeological implications: *Journal of Mining and Geology,* **28**(1): 93 – 103.

Kearey, P., Brooks, M. and Hill, I. (2002). An Introduction to Geophysical Exploration. Blackwell Science Ltd. Oxford, U.K.

Mallam, A. and Ajayi, C.O. (2000). Resistivity Method for Ground water Investigation in Sedimentary Area. *Nigerian Journal of Physics,* **12:** 34-38.

Milsom, J. (2003). Field Geophysics: The Geological Field Guide Series (Third Edition), Wiley and Sons Ltd., University College London. 232 pp.

Obaje, N. G., Moumouni, A., Goki, N. G. and Chaanda, M. S. (2011). Stratigraphy, Paleogeography and Hydrocarbon Resource Potentials of the Bida Basin in North-Central Nigeria. *Journal of Mining and Geology,* **47**(2): 97–114.

Obiora, D.N., Ibuot, J. C. and George, N. J. (2015). Evaluation of aquifer potential, geoelectric and hydraulic parameters in Essa North, southeastern Nigeria, using geoelectric sounding. International *Journal of Environmental Science and Technology,***13**:435-444.

Obiora, D. N., Alhasan, U. D., Ibuot, J. C. and Okeke, F. N. (2016). Geoelectric Evaluation of Aquifer Potential and Vulnerabilityof Northern Paiko, Niger State, Nigeria. *Water Environment Research*, **88(**7): 644-651.

Odek, A. K. (2018). Groundwater prospecting using Self Potential (SP) method in Mungoni Area of Tharaka Nithi, Kenya. *International Journal of Scientific and Education Research*, **2**(6), 34-41.

Ojo, O. J. (2012). Depositional environments and petrographic characteristics of Bida formation around Share – Pategi, Northern Bida Basin, Nigeria. *Journal of Geography and Geology*, **4**(1): 224-241.

Olawuyi, A. K. (2015). Lineaments mapping for hydrogeological study using aeromagnetic and pseudogravity data: A case study of Lafiagi, southwestern Nigeria: *Zimbabwe Journal of Science and Technology,* **10:** 40- 54.

Olorunfemi, M. O. and Oni, A. G. (2019). Integrated Geophysical Methods and Techniques for Siting Productive Boreholes in Basement Complex Terrain of Southwestern Nigeria. *Ife Journal of Science*, **21**(1): 13-26.

Omosuyi, G. O, Ojo, J. S. and Olorunfemi, M.O. (2008). Geoelectric Sounding to Delineate Shallow Aquifer in the Coastal Plain Sands of Okitipupa Area, South Western Nigeria. *Pacific Journal of Science and Technology*, **9**(2): 562-577.

Oseji, J. O., Atakpo, E. A. and Okolie, E. C. (2005). Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta State, Nigeria. *Journal of Applied Science Environmental Management*, **9**: 157-160.

Reynolds, J. M. (1998): Introduction to Applied and Environmental Geophysics. Reynolds Geosciences Ltd. John Willey (Publisher), U.K.

UNICEF-RUWATSAN Project (1988). Borehole logs and VES data of Boreholes Drilled in Edu LGA, Kwara State, Nigeria.

Vander Velpen, B. P. A. (1988). “WinResist Version 1.0”. M. Sc. Research Project. ITC: Delft, Netherlands.