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Original Research Article

Investigating Groundwater Challenge in Crystalline Basement Complex Terrain of South-Western Nigeria: Case Study of Aagba and Environs

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ABSTRACT

In an attempt to investigate the groundwater challenge in communities around Aagba and its environs despite their close proximity, hydrogeophysical and geological studies were carried out using an integrated approach that integrate the use of electrical resistivity method with flow direction determination. Nine (9) vertical electric soundings were carried out across the communities all of which are separated by short distances. Forty eight (48) hand dug wells were selected for the flow direction determination. Iteration and interpretation was done using the IPI2Win software while Surfer 12 used to generate a 2D isopach map, pseudo-section, 3D aquifer transverse resistance map, overburden anisotropic coefficient map. Well data were used to generate a 3D flow direction map of the study area. The result showed that the area is underlain by granite gneiss that exhibit shallow fracture around Iragbiji and Ororuwo located at the North western part of the study area while there are no shallow fracture in the eastern part of the area where communities such as Ada and Aagba are located. This accounts for the low groundwater potential in these two communities. Investigation of the flow direction reveals that the groundwater flow from east to west, an indication of a gaining stream at Iragbiji where River Ogun drains all the available water.

Keywords: Aagba, basement, challenge, groundwater, overburden, south-western

INTRODUCTION

The quest for potable groundwater, especially among urban dwellers and rural communities in developing world is becoming more of a hydra-headed challenge in recent times. This is not unconnected with the fact that government at all levels have failed to meet the ever-increasing demand for water for these sets of people. Conventional public water supply system through dams and waterworks remain the best and the most advisable form of water supply system. This is because it does not only supply water in large amount to residents, farms and industries but also it supplies the best quality of water that had undergone series of purification and treatments. However, residents in rural communities have had to find succor in surface streams, rivers and lakes. All these pose health risks to human lives and live stocks. Consequent upon this is the need to look elsewhere for potable water and so, the most readily available source of potable water for most of the inhabitants is to depend on groundwater sourced from hand dug wells as well as drilled boreholes.

Adelana and MacDonald (2008) observed that most of the rural dwellers in the sub-Saharan, and up to about 100 million, depend on the use of surface and groundwater for use in homes and in farms especially in villages and small towns (Masiyandima and Giordano, 2007). As a result, most settlements in the drier eastern and western as well as south eastern parts of Africa have enjoyed the use of this resource where annual rainfall has recorded low values up to 1,000 mm yr (Foster *et al.*, 2006). In recent time, groundwater via boreholes has been in high demand due to the fact that such water is free from dangerous pathogens. Seventy five percent (75%) of rural dwellers South of the Sahara depend on groundwater (from springs, boreholes and dug wells) as a source of rural water supply. (Foster *et al.*, 2006). And so, it is an alternative to surface water especially where pipe borne water is not functioning or is inadequate. A very common challenge that is peculiar to communities located in the vicinity of crystalline Basement Complex terrains is the problem of having access to drinkable groundwater supply due to the crystalline nature of the underlying rocks which lack primary porosity. Identification of potential groundwater regions does enhance development and utilization of groundwater resources (Rao, 2006). It is worthy of note that the yield of water from drilled well and hand dug well in crystalline basement environment is a function of a number of factors. The main factors in basement area that contribute towards making crystalline rocks potential aquifer include pattern of rainfall, geology, aquifer parameters, subsurface structural features such as faults, fractures and joints. A thorough understanding of the physiography of basement terrain and their characteristics is therefore necessary in order to conclude availability of groundwater/groundwater potential (Maggirwar and Umrikar 2011). Most times, shallow aquifers are phreatic in nature and do occur not more than 10m or 15m depth with massive basement constituting the lower part of the phreatic aquifer. The groundwater in shallow aquifers do get replenished yearly as the intensity of rainfall increases (Maggirwar and Umrikar 2011) and this occur in such a dynamic manner that the groundwater continues to flow along the surface gradient towards lower regions. The flow ends up in local streams and rivers causing loss of saturation and fluctuation in water level in the aquifers. Cause of most aquifers in basement environments has been traced to occurrence of secondary porosity due to disintegration and decomposition of basement rocks over geologic time. As a result, the groundwater potential of most basement rocks is concentrated within the fractured, weathered and vesicular intervals formed due to the development of secondary porosity in rocks at shallow depth (Singhal, 1973, 1986) generally up to the depth of 60 m.

However, it is worthy of note that basement aquifers are naturally limited in their potentials and occur with high heterogeneity. Most of the aquifers in basement environment are confined. A few are unconfined with the water level following the surface topography. Storage capacity in those areas is a function of depth of weathering and intensity of fracturing of the underlying rocks. High level fracturing and deep weathering makes basement complex rocks to become good aquifers and the thickness of the weathered overburden and fracture zone go a long way to determine the nature and degree of the hydrodynamics within the usually-discrete bodies of aquifers in the region. Hence, the characteristic discontinuous attribute of the basement aquifers makes detailed use of geophysical, geological and hydrogeological and investigations inevitable (Asiwaju-Bello *et al.*, 2013).

The study areas, Ada, Ororuwo, Iragbiji and Aagba are four settlements located within a total geographical area of about 1.5 square km expanse of land in Osun State, Nigeria, about 6 km south western part of Osogbo, the state capital.

The four communities are separated from one another by cultural features, yet they are four distinct settlements. Preliminary geologic study of the area suggests that about 95% of the entire study area is made up of granite gneiss mostly exposed in Iragbiji but buried in other communities. Over the years, Iragbiji has been noted as possessing more productive boreholes and hand dug while other settlements lack groundwater resource. In this research, an attempt is made to understudy the factors that may be responsible for the observed high groundwater potential in Iragbiji with a corresponding groundwater challenge in other communities despite the close the proximities of these communities. In this research, the use of combined electrical resistivity method of geophysics and flow direction determination was employed. This study also desires to investigate this challenge using conclusions from a number of aquifer parameters that could give a detailed explanation to this occurrence. These include information from the study of the overburden and overburden anisotropic coefficient, aquifer transverse resistance map using the transverse resistance value. This will go a long way to reveal the nature of the subsurface rocks in the vicinity and also throw more light on the geology of the study area. In order to achieve this, we intend to carry out a vertical electrical sounding within the study area using the Schlumberger electrode array, generate geo-electric section using the resistivity and thickness values, generate the overburden isopach map and overburden anisotropic coefficient map, using the overburden thickness and coefficient of anisotropy estimates respectively in Ada and its environs, generate the pseudosection of the subsurface resistivity values with depth, determine the depth to water in hand dug wells, determine the depth to bottom of hand dug well, generating the flow net using information obtained from depth to water and depth to bottom of well, generate the aquifer transverse resistance map using the transverse resistance value.

Location of Study Area

The study area arranged from east to west include Iragbiji, Ororuwo, Aagba and Ada and are all located within latitude $4^{o}41^{l}$ and $4^{o}42^{l}$ and longitude $7^{o}53^{l}$ and $7^{o}54^{l}$. Major towns located around the study area include Ikirun to the North, Obokun to the South while Osogbo and Ila are situated to the East and West of the study area respectively. Figure 1 shows the geographical location of Iragbiji and its environs. The study area has exhibited a warm tropical climate considered to be Aw according to Koppen-Geiger climate classification over the years with average annual temperature of 26.1 °C. Daily maximum temperature is between 25^{o}C and 29^{o}C (Iloeje 1981). Average annual precipitation is about 1241 mm. The driest month is January with a precipitation of 9 mm while the heaviest precipitation occurs in September where it peaks with an average of 1202 mm. With an average of 28.3 °C, March is the warmest month and with 23.7 °C on average, August is the coldest month of the year. The study area is covered mainly by secondary forest.

All parts of the study area have been dominated by typical tropical rainforest vegetation; however, this has since given way and now has been replaced by secondary forest re-growths due to fuel-wood production, road construction, and old methods of farming. Intensive farming of arable crops by man has also replaced the forest. Hence, the natural tree species have given way to agricultural products such as cocoa, kolanut, walnut and oil palm trees. Natural forests still exist in the eastern part of Iragbiji and western part of Aagba in the study area. (Iloeje, 1981). The study area is a localized part of the Basement complex rocks of the South western Nigeria and is underlain by extensive outcrops of mainly granite gneiss. Workers such as Oyawoye (1972), Rahaman (1976), Elueze (1982), Obaje (2009), as well as a host of others have described the geology of the study area. Soil types in the study area have been influenced by the climate and vegetation of the study area. The presence of high water content in and around a rock play a major factor to note in the determination of the overall soil productivity, fertility and soil reactions (Oyenuga 1967).

MATERIALS AND METHODS

Previous research works done within the study area on groundwater potential were not available. This work therefore represents the first attempt at investigating this challenge. A total of nine vertical electrical soundings were carried out using the Schlumberger electrode array with a total of 100 m spread to either side of the station position. Resistivity measurements were taken using the ABEM SAS 1000 resistivity meter. A total of forty-eight hand dug wells were sampled using Solint water level meter. The VES data obtained from field measurements were plotted against the electrode spacing on bilogarithmic coordinates with a preliminary interpretation of each VES curve carried out using partial curve-matching. This involves two-layer master curves and the appropriate auxiliary charts (Kearey *et al.,* 2002). The manually derived geoelectric parameters were subjected to inversion. The electrical resistivity contrasts existing between lithological sequences in the subsurface were used in the delineation of geoelectric layers, identification of aquiferous materials and assessment of groundwater prospect of the area. Also, the resistivity parameter of the uppermost geoelectric layer (topsoil) was used to evaluate, in quantitative terms, its permeability to surface /near surface contaminants, and hence the vulnerability of the underlying aquifers, as demonstrated in Draskovits *et al.*, (1995). The observed apparent resistivity data were inverted to true geological model of the surface using IPI2Winsoftware and the known geology of the study area. The interpretation of the VES results was used for producing the isopac map, pseudo section, aquifer transverse resistance map, overburden anisotropic coefficient map.

PRESENTATION AND DISCUSSION OF RESULT

Table 1 shows a summary of the results obtained from all the VES interpretation while Table 2 shows the depth to top of and depth to bottom of water in sampled hand-dug wells within the study area. Table 3 shows the values of the overburden coefficient anisotropy and values of aquifer transverse resistance for the area under investigation. Figure 2, 3, 4,5 and 6 represent the following in that order: geoelectric section of the study area showing the lithology of the area, flow directions of the study area, overburden isopac map of the study area, overburden anisotropic coefficient map and aquifer transverse resistance map. The iterative curve obtained from the study area is as presented in Figures 7. The results obtained using the Soling flow net equipment were used to generate the flow direction map of underground water in the study area and it is as shown in Figure 3. The result of VES interpretation within Iragbiji and earlier part of Ororuwo was observed to exhibit typical HA and K curves respectively. This is as shown in VES 1 and 2 with variation in resistivity from as low as 255 Ωm in the third geo-electric layer (fractured aquifer) to as high as 510000 Ωm in the basement rock. The topsoil is a relatively thin layer of less than 0.11 m thick material with relatively low resistivity, possible of clayey materials. Lateritic topsoil regolith derived from basement rock was also observed especially in VES 4 with a resistivity of about 505 Ωm. The low resistivity of the weathered layer (163 Ωm) in VES 1 and the descending portion of VES 2 make VES 1 and 2 possess a viable groundwater potential at shallow depth (Figure 7). However, VES 3 shows a weathered layer that is continuous with the fractured interval in other VES in this section of the study area. VES 4, 5 and 6 which lie within Ororuwo and earlier part of Aagba do not give any evidence of groundwater potential since it exhibit a typical A curve. This shows that the resistivity of the subsurface in this region is very high with no evidence of fracturing. This result is totally different from what is observed at Iragbiji and earlier part of Ororuwo where fracturing was observed to be closer to the surface and as so the overburden is thin. This explains why groundwater is seemed to be found only in this area. Hence, the immediate community would have access to groundwater resources. Generally, the area that exhibit more fracturing fall within the earlier part of Ororuwo compare to Aagba which shows no evidence of fracturing and/or weathered layer and this is likely responsible for groundwater scarcity in Ororuwo community. Findings from a nearby borehole drilled around this vicinity reveals that the borehole produces water but not at economic quantity. Several other boreholes drilled within Ororuwo failed to yield groundwater due to lack of wet fracture in these stations. This is as revealed in VES 5, 6 and 7 where about 90% of the entire area is covered with basement granitic gneiss rock overlaid with a thin lateritic overburden in VES 4 and 6 and clayey topsoil in VES 3 and VES 7. (Figure 7). In all these station positions, the overburden thickness is less than 1.0 m. In nature, the presence of subsurface fracture or faults contributes in no small way to groundwater availability and accessibility in crystalline environment. Investigation around Aagba and Ada Community township revealed that the area is underlain by high resistive lateritic material, mainly of which are crystalline basement rocks to greater depths. The topmost geo-electric layer in VES 6, 7 and 9 are probably composed of clayey materials. VES 5 is underlain with clayey topsoil material as wells while VES 7 topsoil is rich in clayey materials. In VES 5, VES 6, VES 7 and VES 9, there are no evidence of fracture which is the principal reason for groundwater scarcity in the southern part of Ororuwo, Aagba and Ada. It is evident that VES 8 could have be fractured. This is likely to be responsible for the availabilty of water in the hand dug wells within area. The second fracture in these VES stations is far from the surface. The resistivity of the acquiferous layer in VES 8 (256 Ωm) reveals that it is likely a wet fracture as a result of its low resistivity value while that of VES 7 (655 Ωm) is relatively high resistivity, an indication of the presence of dry fracture. This is seen in Figure 7.

Figure 1: Map of the Study Area Showing the Location of VES Points.

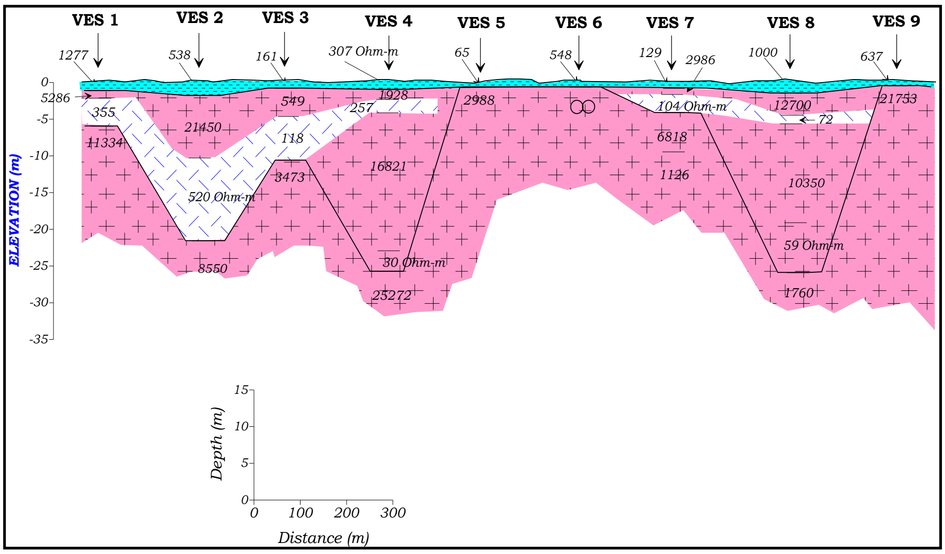

Figure 2. Geoelectric section of the study area showing the lithology across the communities.

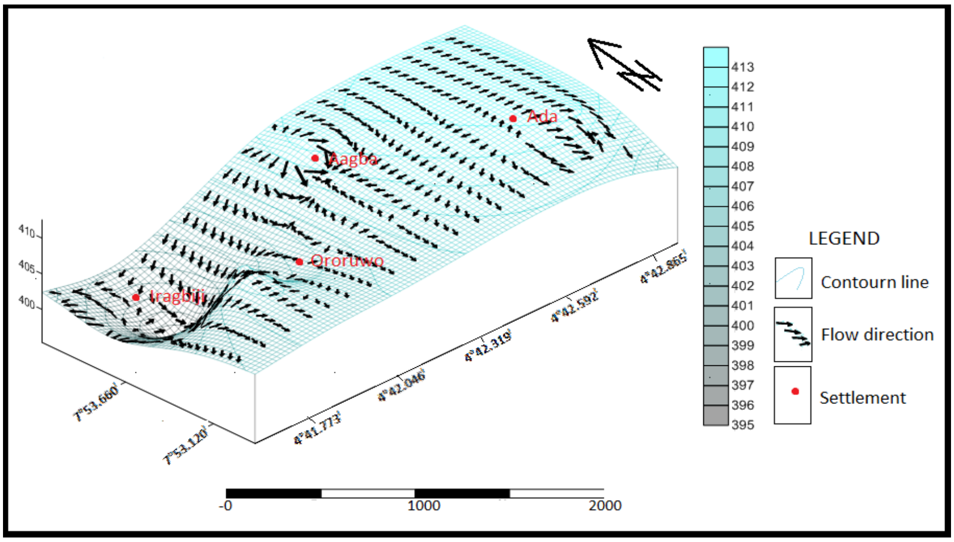

Figure 3: Flow Directions of the Study Area

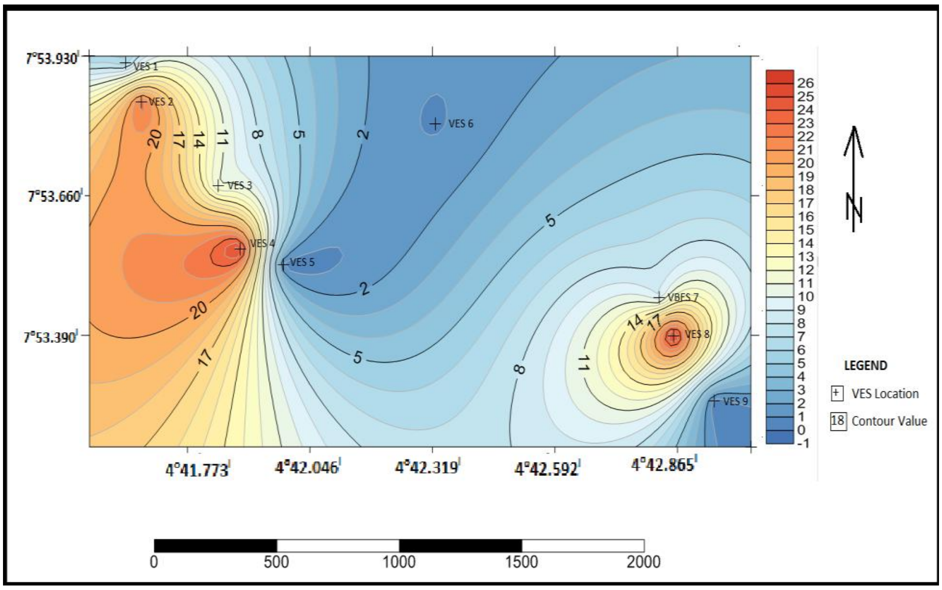

Figure 4: Overburden Isopac Map of the Study Area

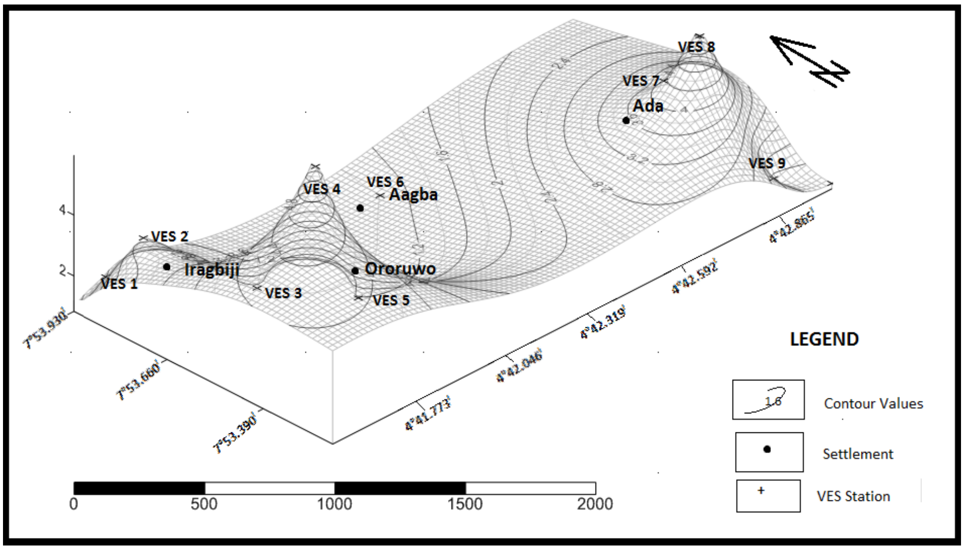

Figure 5: Overburden Anisotropic Coefficient Map

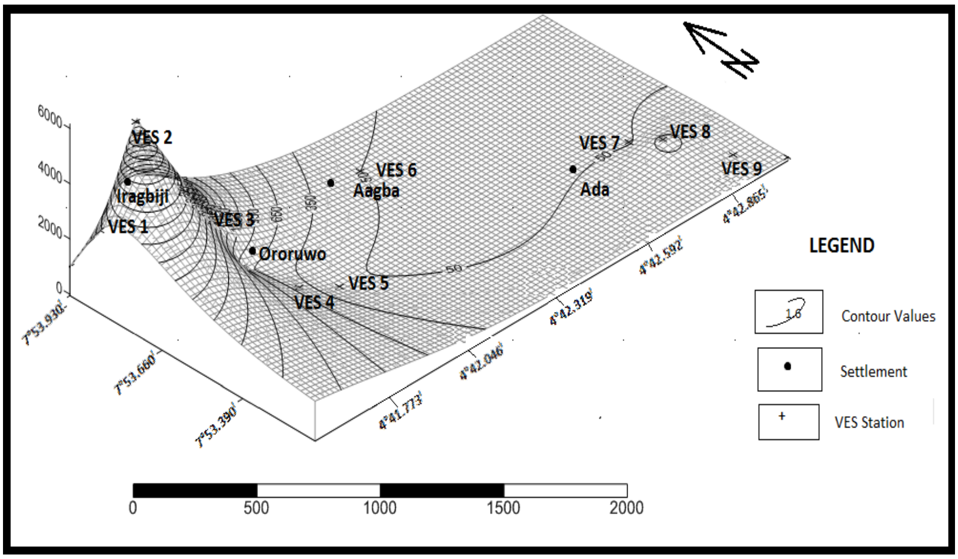

Figure 6: Aquifer Transverse Resistance Map

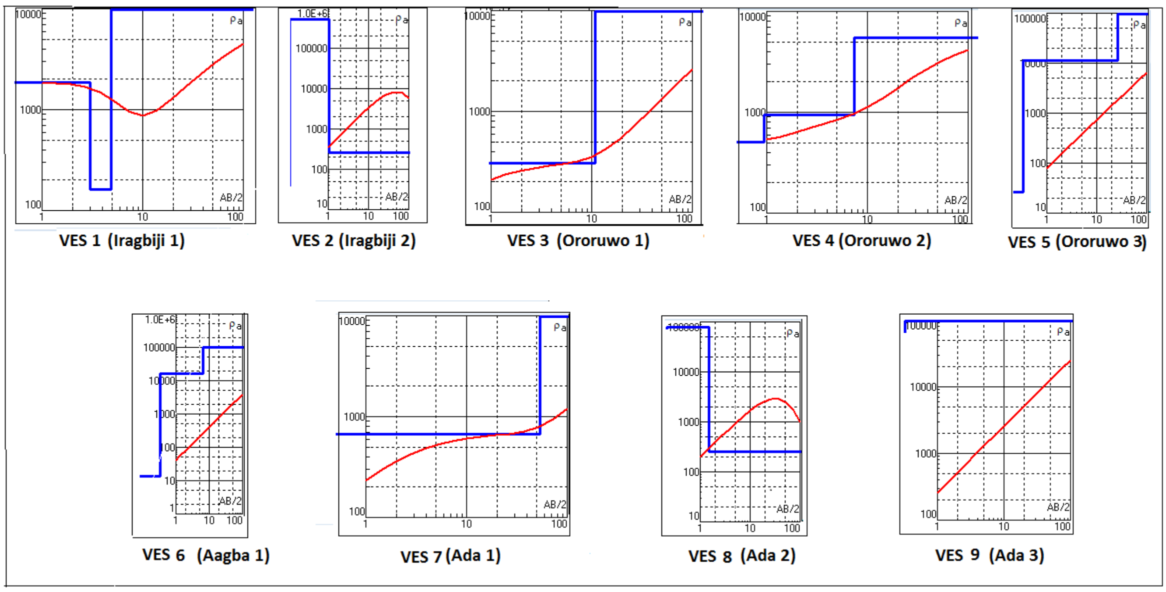

Figure 7: Iterative Curve for all VES soundings showing VES 1 to VES 9

Table 1: Summary table showing the resistivity, thickness and lithologic interpretation of the VES soundings

	Type Curve	RES (Ωm)	THK (m)	DEPTH (m)	LIT		Type Curve	RES (Ωm)	THK (m)	DEPTH (m)	LIT.		Type Curve	RES (Ωm)	THK (m)	DEPTH (m)	LIT.
VES 1	HA	185	2.99	2.99	T	**VES 2**	K	38.3	0.11	0.11	CT	**VES 3**	A	153	0.38	0.38	T
		163	1.92	4.91	W			510000	0.94	1.05	BM			308	10.5	10.88	L
		9787	-	-	FB			255	-	-	F			67373	-	-	FB
VES 4	A	505	0.944	0.944	LT	**VES 5**	A	26.6	0.34	0.34	CT	**VES 6**	A	13.5	0.33	0.33	CT
		937	6.44	7.38	BM			11422	25.9	26.2	BM			15995	6.07	6.40	BM
		5533	-	-	BM			370000	-	-	BM			98009	-	-	BM
VES 7	A	59.8	0.18	0.18	CT	**VES 8**	K	41.4	0.21	0.21	CT	**VES 9**	A	85.1	0.33	0.33	CT
		655	53.7	53.9	W			78452	1.29	1.50	FB			21753	5.15	5.48	FM
		100000	-	-	B			256	-	-	F			95000	-	-	B
CLT= Concretional Laterite, F=Fractured layer, BM: Basement, CT: Clayey Topsoil, T: Topsoil, W: Weathered layer, FB = Fresh Basement, B= Basement																	

Table 2: Overburden Coefficient Anisotropy.

S/N	VES Station	Transverse Resistance (ρ_t)	Longitudinal Resistance (ρ_l)	Overburden Coefficient of Anisotropy (λ)
1	VES 1	97	40	1.56
2	VES 2	5203	515	3.18
3	VES 3	196	119	1.28
4	VES 4	25374	660	6.20
5	VES 5	0.32	0.32	1.00
6	VES 6	0.76	0.76	1.00
7	VES 7	1201	84	3.78
8	VES 8	23599	681	5.88
9	VES 9	0.108	0.108	1.00

Flow Direction

The entire study area exhibit a slightly undulating topography that steep gently towards Iragbiji. Studying the behavior of flow of the groundwater, the flow direction of surface water in the study area was generated by employing the measured values of depth to water (depth to top) obtained from the hand dug wells sampled in the study area (Figure 3). Investigation revealed that regions around Ada and Aagba were observed to show evidence of discharge zone due to the underground water flowing away from the area into a nearby Ogun River, a major river that drains the entire study area. Hence, the river exhibit a gaining stream phenomeun. However, Iragbiji and Ororuwo were observed to be recharge zone. This is due to the fact that as most of the underground water present around Ada and Aagba flow away from the area, they move towards the depression caused as a result of the prescence of the River Ogun. Since the fractured zones around Iragbiji and Ororuwo are closer to the surface the underground water flowing towards Iragbiji and Ororuwo tends to recharge the aquiferous layer there by flowing directly into the fracture zones. Adeleke *et. al.*, (2011) observed that such a convergence of recharge zone in nature may be due to high thickness of weathering or the presence of fractured basement rocks. This is particularly evident in the result obtained, showing Iragbiji as a recharge area as a result of presence of fractured basement. In the southern region, the underground water flows in an E-W direction with an underground basin in the south western (Ororuwo). In the northern portion, the flow is westly with an underground basin in the north western (Iragbiji). Ada and Aagba which is situated in the eastern and northern part of the study area respectively. This area is seen as a watershed; it sheds underground water south westly and north westly. This means that groundwater could be problematic here. However, the north western and south western areas of the study area (Iragbiji and Ororuwo) would have a better potential for groundwater exploration.

Overburden Isopac Map

The depths to the basement (overburden thickness) beneath the sounding stations were plotted as shown in Figure 4. This was done to enable a general view of the aquifer geometry of the surveyed area. The overburden is assumed to include the topsoil, the clayey, sandy, lateritic horizon and the weathered rock. The overburden thickness varies from 0.38 m in VES 9 to 26.1 m in VES 8. The western side has a thick overburden ≥11 m with the exception of VES 7 and VES 8. According to Olorunfemi and Okhue (1992), the area with high overburden thickness has high groundwater potential. Hence, VES 1, VES 2, VES 3, VES 4, would have high groundwater potential due to the high overburden thickness in these stations. This is as shown in Figure 8.

Coefficient of Anisotropy of the Overburden

The overburden's coefficient of anisotropy (λ) was calculated for each VES Station using the layer resistivities and thicknesses (Olorunfemi and Okhue, 1992);

$$\lambda = \sqrt{\frac{\rho_t}{\rho_l}} = \sqrt{\frac{\sum_{i=1}^{n-1} h_i\rho_i \sum_{i=1}^{n-1}\frac{h_i}{\rho_i}}{(\sum_{i=1}^{n-1} h_i)^2}} \text{ (i)}$$

where ρ_t is the transverse resistance, ρ_l is the longitudinal resistance, i is the summation limit varying from 1 to n-1, h_i is the ith layer thickness and ρ_i is the ith layer resistivity. The λ are plotted as shown in Figure 11. The values of λ range from 1 to 6.20 with a mean value of 2.76. It is high (>1.56) at VES 1, VES 2, VES 4, VES 7 and VES 8. The area with high value falls within the north-eastern and the western flank of the study area. Low values were obtained at VES 3, VES 5, VES 6, and VES 9 which are located at the northern and the extreme north-eastern flank of the study area. Olorunfemi *et al.,* (1992) investigated the relationship between electrical anisotropy and groundwater yield in the basement complex area of the south-western Nigeria. Their findings include amongst others that the groundwater yield generally increases with increase in the overburden coefficient of anisotropy. All the values obtained in this study fall within the range obtained for areas underlain by metamorphic rocks in the south-western Nigeria. There is a higher coefficient of anisotropy on the eastern and western side than the northern and southern. This is an indication of greater fracture in east and western side than in the north and southern side. However, a combination of fractures and weathering is of great necessity in the determination of a viable groundwater prospect (Figure 4).

Aquifer Transverse Resistance Map

Maillet, 1974 defined transverse resistance (R_T) of a layer as:

$$R_T = h.\rho \text{ (ii)}$$

where, h and ρ are thickness and resistivity respectively, of the layer. Relating transverse resistance with aquifer transmitivity, we have:

$$T = \frac{K}{\rho} \cdot R_T = K\sigma \cdot R_T \text{ (iii)}$$

with the ratio $\frac{K}{\rho} = K\sigma$ taken to be constant in areas with similar geologic setting and water quality (Niwas and Singhal, 1981; Onuoha and Mbazi, 1988). This relationship is suitable for determination of aquifer transmissivity. Thus knowing the value of K (hydraulic conductivity) for some existing boreholes and the value of σ extracted from the sounding interpretation for the aquifer at the borehole locations, transmissivity of the aquifer can be computed. Transverse resistance map is used in determination of zones with high groundwater potential (Braga *et al.*, 2006) and zones suitable for drilling wells. On a purely empirical basis, it can be admitted that the transmissivity of an aquifer is directly proportional to its transverse resistance (Henriet, 1975). Hence, there exists a linear relationship between groundwater potential and the transverse resistance of an aquifer

(Aderinto, 1986).The western side of the study area has high transverse resistance as seen in Figure 6 and this corresponds to high transmissivity which in turn imply greater groundwater potential in the area.

CONCLUSION

In this study, geophysical investigation combine with flow direction determination have been used to integrate various geological, resistivity and overburden coefficient maps, which play major role in occurrence and movement of groundwater in a crystalline environment in Southwestern Nigeria. The integrated groundwater potential map includes that overburden coefficient map, coefficient of anisotropy map and aquifer transverse resistance map. The overall potential maps generated suggest the dominant influence of geologic structures and overburden in the delineation of the groundwater zone. Although the entire study area is underlain by granitic gneiss, Iragbiji community has high groundwater potentials compared to low potentials in other communities due to the presence of subsurface fracture at shallow depth and thin overburden. Areas of low groundwater potentials constitute about 70% of the total study area. Subsequent validation with information obtained from already existing boreholes revealed a good correlation with respect to the observed groundwater challenge in the areas affected. Fashae *et al.,* (2014) observed that wells/boreholes with yields greater than 150 m^3/day are generally characteristic of areas with high groundwater potential while those with yields of 75-150 and 75 m^3/day are typical of areas with medium and low groundwater potentials respectively. This observation clearly describes the potency and efficacy of the integrated electrical resistivity technique cum flow net methods employed in this study as useful and adequate approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential determination presented can be used only for studies for the purpose of groundwater development and it provides quick prospective guides for groundwater exploration and exploitation in such a crystalline basement environment. However, further works in the study area is encouraged especially using information from other methods such as multi-criteria decision analysis (MCDA), remote sensing (RS) and geographical information system (GIS) techniques.

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