Groundwater Prospectivity Assessment of a Field of Hand-Dug Wells in the Area Around the Murtala Muhammed Postgraduate Hall OAU, Ile-Ife, Using Geoelectric Parametric Soundings

Adedayo A. Akanji, B.Sc.*; Ademakinwa G. Oni, Ph.D.; and Martins O. Olorunfemi, Ph.D.

Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria.

E-mail: adesolaade111@gmail.com*

ABSTRACT

This paper presents the results of geoelectric parametric soundings carried out on a field of hand-dug wells within the Murtala Muhammed Postgraduate Hall in Obafemi Awolowo University (OAU), Ile-Ife, Southwest Nigeria, with a view to assessing the groundwater potential and establishing the feasibility of increasing the well depths, for enhanced groundwater yield. The Vertical Electrical Sounding (VES) utilized the Schlumberger array whose curves were interpreted quantitatively by partial curve matching and computer assisted 1D forward modeling. The VES interpretation results were used to generate 2D geoelectric sections and thematic maps of overburden thickness, aquifer resistivity and basement bedrock relief. Using multi-criteria evaluation in a GIS environment, the thematic maps were integrated to evolve the groundwater potential of the study area.

The feasibility of increasing the well depths was based on the current well depths, estimates of water column in the wells and estimated aquifer thicknesses. The topsoil; laterite; clay/sandy clay weathered layer; partly weathered/fractured basement and the fresh basement bedrock constitute the underlying geologic layers. The weathered layer constitutes the main aquifer unit. The depths to the basement bedrock ranged from 4.5 - 44.3 m but are generally >19.1 m except beneath wells 1 and 2 (<7.2 m). The groundwater potential rating for the study area ranged from very low (4.1%) to low (79%) and moderate (16.9%). The well depths ranged from 7.55 to 12.63 m which for most wells barely or rarely penetrated the 6.85 - 32.8 m thick weathered layer aquifer. The study concluded that there is prospect for enhanced and sustainable groundwater yield if the well depths are increased to a minimum of 19 m.

(Keywords: hand-dug wells, geoelectric parametric soundings, well depths, enhanced groundwater yield)

INTRODUCTION

Water constitutes a major component of all living matter and an essential part of man's daily needs. It is essential for sustenance of life and the ecosystem as man, animals and plants need water to exist. It is generally used by man for domestic purpose but also serves industrial, agricultural, transportation and renewable energy generation purposes (Bose *et al*., 1973; Microsoft Encarta, 2009).

Water occurs as surface water and groundwater. Surface water such as oceans, rivers and glaciers are not evenly distributed and are generally prone to pollution. However, groundwater, which is contained in the earth subsurface and below the water table, is fairly evenly distributed, less prone to pollution and can be developed close to point of use (Orakwe *et al*., 2018; Oni *et al*., 2020a). However, the spatial variability in the location of groundwater aquifers (sediments, weathered layer, fractured/fault/shear zones), their nature and areal/depth extent determine their potential and the feasibility of developing them as sources of water at any location (Olorunfemi and Oni, 2019). The implication of these is that some areas could be feasible for groundwater development with variable success rates and yields while groundwater development is practically not feasible in other areas (Oni *et al*., 2020a).

As reported by Olorunfemi *et al*. (2020), the Obafemi Awolowo University (OAU), Ile-Ife (Figure 1), depends significantly on the Opa Earth Dam reservoir as source of potable water for her residents'. Groundwater from boreholes and wells

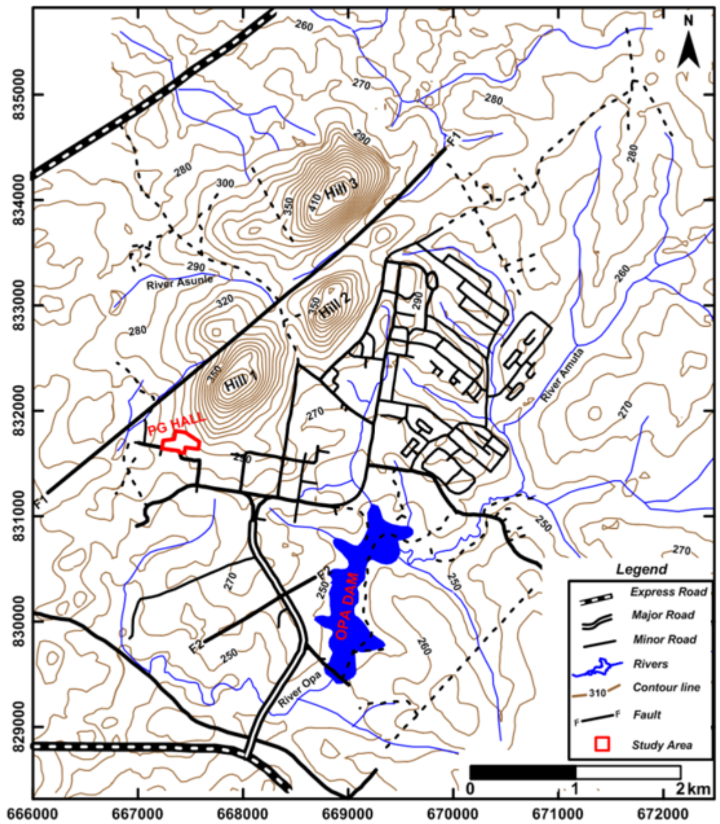

Figure 1: Topographic Map of OAU, Ile-Ife, Showing MMPGH and the Opa Earth Dam.

is also used to complement water from the dam in areas not serviced by the public water scheme. Water supply to the Murtala Muhammed Postgraduate Hall (MMPGH) of the university has in the recent past, been augmented by groundwater from a field of hand dug wells (Figure 2c) due to failure of several borehole drilling attempts (Olorunfemi and Oni, 2019; Olorunnfemi *et al*., 2020). Over dependent on the hand-dug wells has led to significant reduction in the yields, in recent time. This study therefore aims at assessing the feasibility of increasing depths of the wells, as a means of enhancing their yields, using geoelectric parametric soundings.

SITE DESCRIPTION

<u>Geographic Location, Geomorphology and Climate</u>

The MMPGH is located in Obafemi Awolowo University, Ile-Ife, in Ife Central Local Government Area of Osun State, Southwestern Nigeria (Figure 2). The study area falls within the western part of the campus and lies within Northings 831550 mN – 831800 mN and Eastings 667200 mE – 667550 mE of Minna datum (Zone 31N) coordinates system. The study area is accessible through networks of roads within the campus and particularly through the Angola/Mozambique-Awo road (Figure 2c). The topography of the university campus ranges from gently undulating within the lowland areas to highland on the hills with elevations varying from 250 to about 450 m above sea level.

The study area is relatively flat with a mean elevation value of 278 m above sea level (Figure 1). The climate is the tropical type that is characterized by the raining and the dry seasons. The raining season is between April and October with mean annual rainfall of between 1000 and 1500 mm while the dry season lasts for about five months between November and March (Iloeje, 1981). The area is characterized by high humidity, during the raining season, and dry harmattan dust and high level of sunshine with peak temperature of about 32ºC (NIMET, 2007) in the dry season.

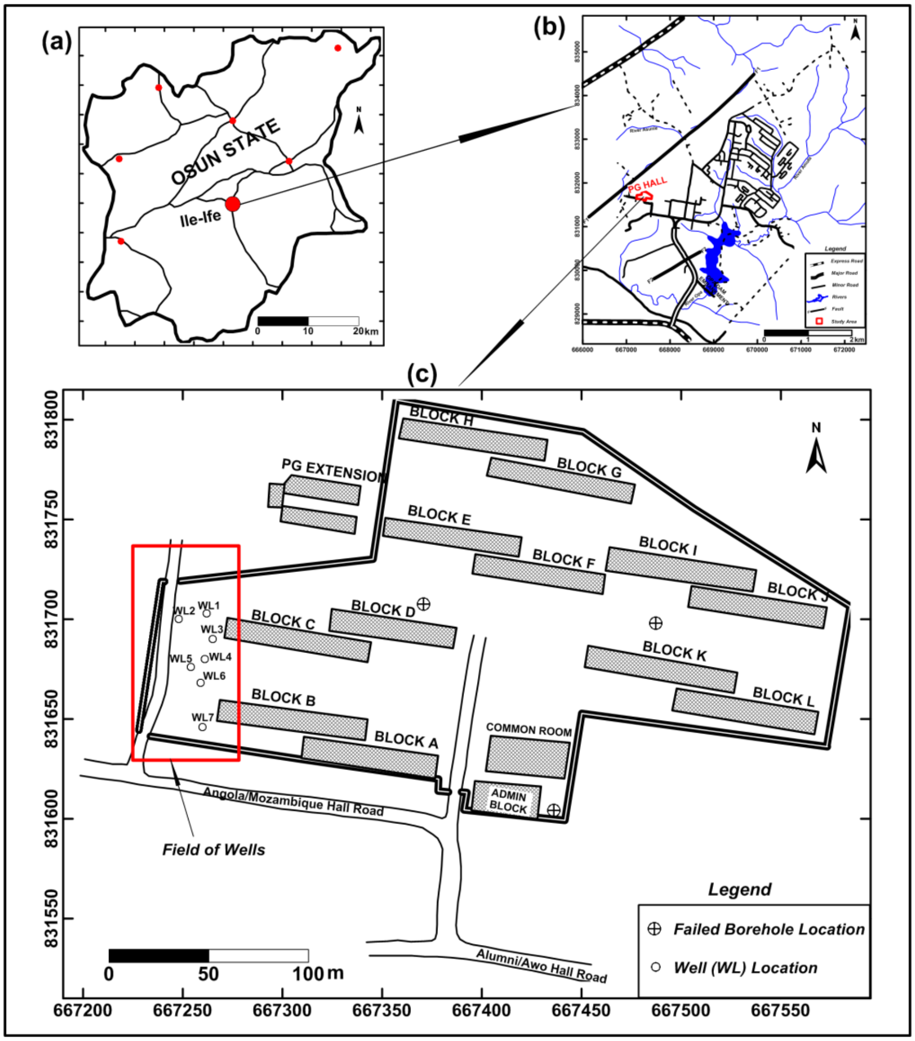

Figure 2: Location Maps of (a) Osun State (b) OAU Campus and (c) the Study Area Showing the Field of Hand-dug Wells.

Geology and Hydrogeology

The OAU campus falls within the Ilesha Schist Belt in the Precambrian Basement Complex of Southwest Nigeria. The geology of the campus comprises of four (4) major rock units that constitute an essential part of the migmatite-gneiss-quartzite complex classification by Rahaman (1976 and 1989). These rocks are granite gneiss, banded gneiss, mica schist, and gneiss and migmatite undifferentiated (Figure 3; Boesse, 1989).

Other minor rock units include micro granite, intrusive pegmatite and dolerite dykes. The study area is underlain by the low lying (where it outcrops) banded gneiss. The rock unit is fine to medium grained in texture with persistent mineralogical banding. Quartz, plagioclase feldspar, and biotite are the prominent mineral constituents. The granite gneiss manifests as Inselbergs (Hills 1-3) in the north (Figures 1 and 3). The pinkish medium to coarse grained rock is made up of quartz, plagioclase feldspar, zircon, and garnet. The southern and north-eastern parts of the campus are underlain by the mica schist. The schist is generally concealed by a variably thick clay/lateritic clay overburden with few outcrops along the river and stream channels. Episode of deformations that are attributed to the Pan African Orogeny have reshaped these rocks. The deformations manifest as joints, fractures, micro folds and foliation, and faults (strike slip faults).

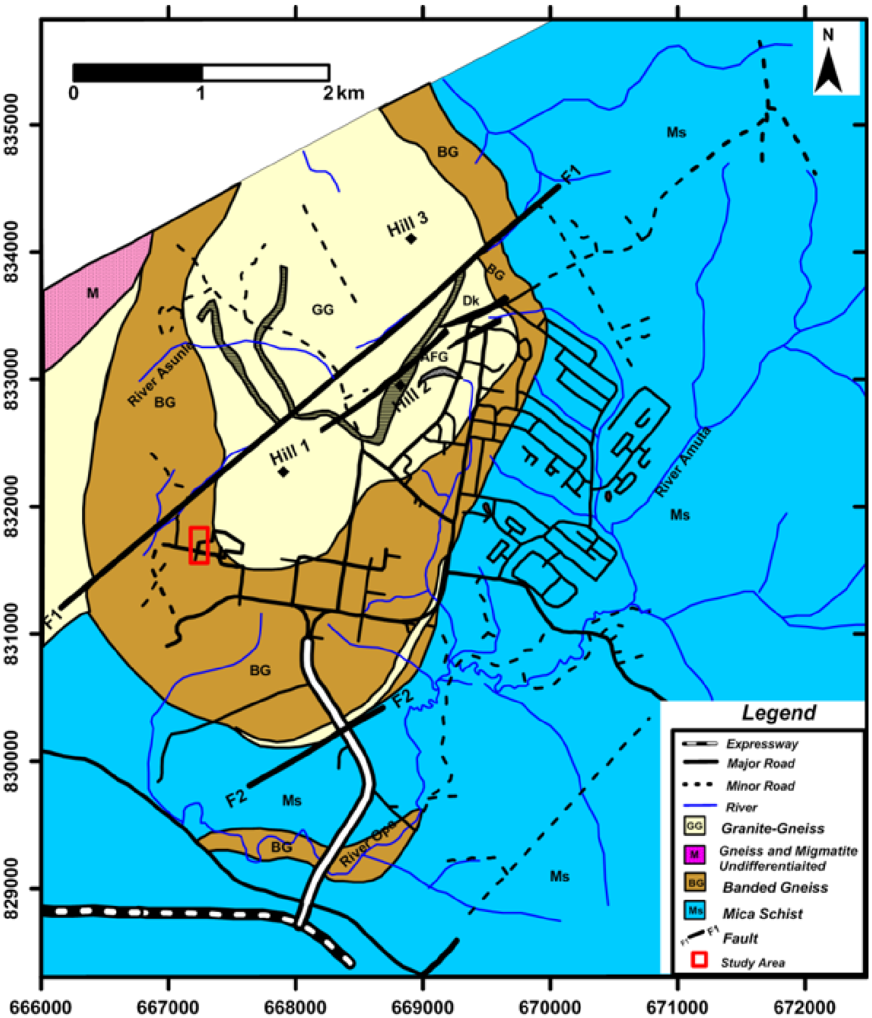

Figure 3: Geological Map of OAU, Ile-Ife, Showing the Study Area (Boesse, 1989).

Groundwater is contained in the weathered layer, fractured basement and jointed and or sheared basement columns (Olorunfemi and Olorunniwo, 1985; Olorunfemi and Fasuyi, 1993; Hasan *et al*., 2018 and Olorunfemi and Oni, 2019). Rainfall constitutes the major source of recharge for the groundwater system. The OAU campus is drained by the Opa River and its numerous streams that constitute a secondary source of groundwater recharge.

METHOD OF STUDY

The well locations were geo-referenced and well depths and static water levels determined. The geophysical investigation involved 1D Vertical Electrical Sounding (VES) utilizing the Schlumberger array. Eight (8) VES stations were occupied, seven (7) of which are parametric to the hang-dug wells while the remaining one was randomly located (Figure 4). The half current electrode spacing (AB/2) was varied from 1 m to a maximum of 100 m and measurements of ground resistivity values were made with the ABEM SAS300C Resistivity Meter.

The VES data were presented as sounding curves on bi-log graph paper and interpreted quantitatively by partial curve matching technique and the preliminary interpretation results refined through computer assisted 1D forward modeling with the WINRESIST version 1.0 software. The final VES interpretation results (layer resistivities and thicknesses) were used to generate 2D geoelectric sections, overburden thickness, aquifer resistivity and the basement bedrock relief thematic maps.

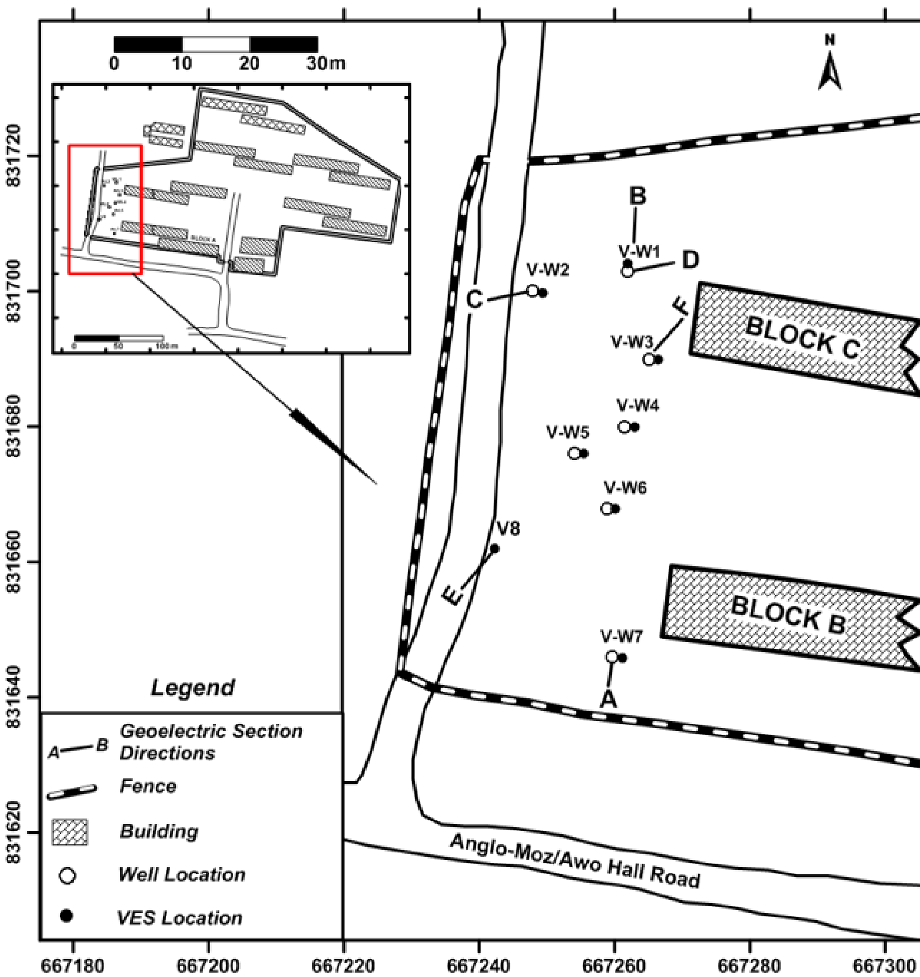

Figure 4: Map of the Study Area Showing the Hand-dug Wells, Vertical Electrical Sounding (VES) Locations and the Geoelectric Section Profiles

The groundwater potential of the study area was assessed by integrating the thematic maps in a GIS environment, involving multi criteria evaluation (MCE) technique adopted by Akinwumiju *et al*. (2016), and internal and relative weight distribution of factors in Table 1. The feasibility for increase in well depths, for improved groundwater yield, was assessed by comparing the current well depths to estimated overburden thicknesses (depths to rock head) from the VES at each well location.

RESULTS

VES Type Curves

The KH, HKH, KQH, KHA, and KHKH type are the characteristic VES type curves obtained from the study area (Figure 5). The HKH, KQH and KHKH are the dominant types with each having 25% frequency of occurrence. The significant variation in the VES type curves observed within the relatively small study area show the level of complexity/inhomogeneity in the subsurface sequence. In a typical basement complex terrain and where the basement rock is relatively deep, VES type curve beginning with the K or H type (100% in this study) are typical of tropical climatic region with a subsurface sequence composed of the topsoil (sometimes lateritic), laterite and weathered layer in the upper two - three geoelectric/geologic layers (Acworth, 1987).

The KH type is characteristic of four (4) geoelectric/geologic sequences including the topsoil, lateritic layer, weathered layer and the fresh basement. The complex KQH, HKH and

Table 1: Internal and Relative Weight of Each Groundwater Potential Rating Factor.

S/N	Factor		Domain of Influence	Internal Weight	Relative Weight
1	Aquifer/Overburden Thickness		0 – 10 m	1	30%
			11 – 25 m	2	
			25 – 50 m	3	
2	Nature of the Aquifer	Weathered Layer/Fractured Basement Resistivity	1 – 100 Ωm	1	20% (for weathered layer)
			101 – 250 Ωm	2	
			251 – 350 Ωm	3	
			351 – 550 Ωm	5	
			551 – 750 Ωm	4	35% (For fractured basement)
			751 – 1000 Ωm	2	
			>1000 Ωm	1	
3	Basement Bedrock Relief		Ridge	1	15%
			Pediment	3	
			Depression	5	

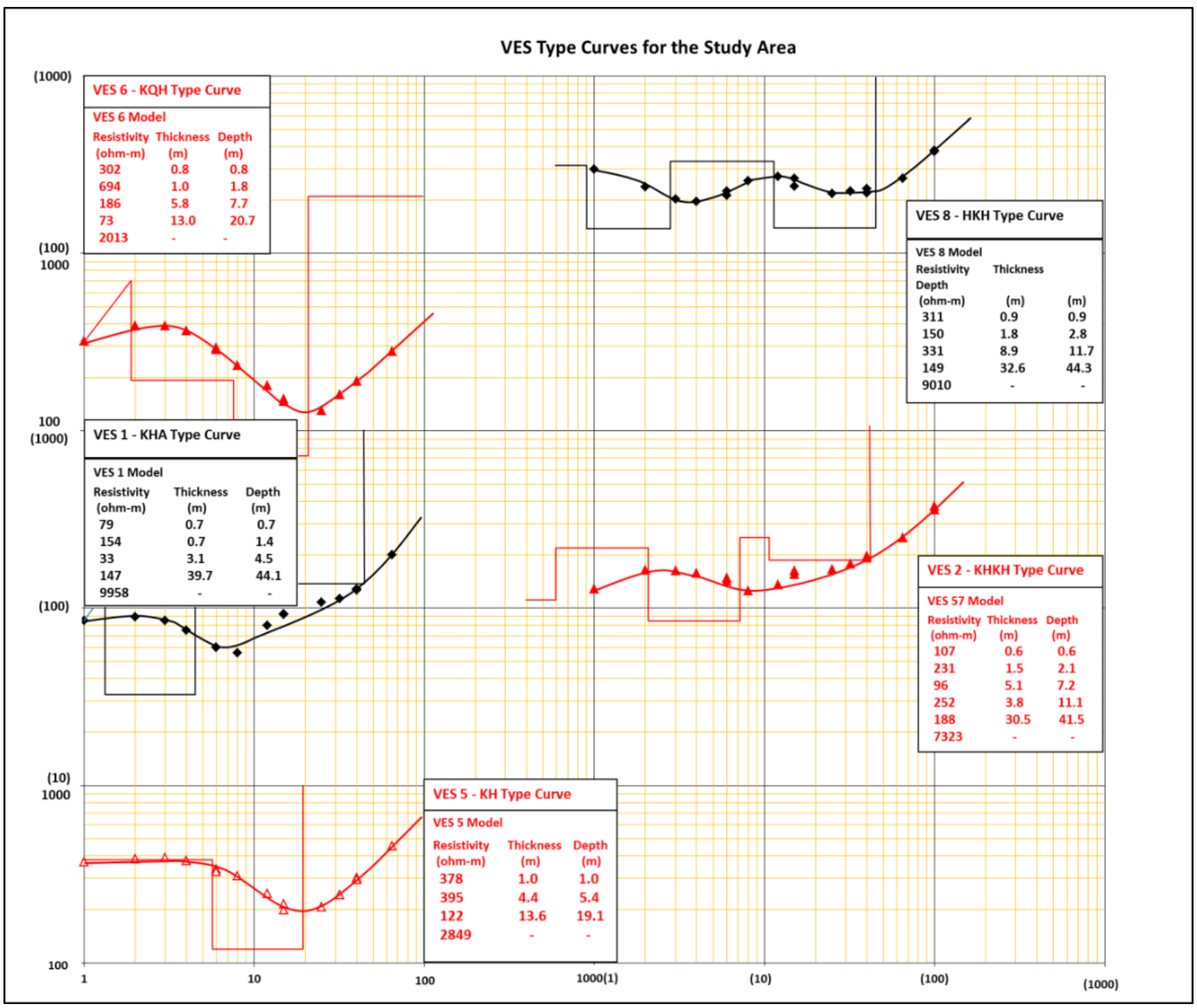

Figure 5: Typical VES Type Curves Obtained from the Study Area

KHKH type with five to six geoelectric/geologic layers could be made up of the topsoil, laterite, weathered layer, and fresh basement or the topsoil, weathered layer, fresh basement, fractured basement and fresh basement bedrock as observed by Olorunfemi and Fasuyi (1993); Olorunfemi *et al*. (2020), and Oni *et al*. (2020b).

Geoelectric Sections

Three (3) geoelectric sections (Figures 6a-c) were generated for subsurface sequence delineation and definition of the basement bedrock relief. Geoelectric sections along profiles A-B and C-D, displayed in Figures 6a and b, delineate five (5) geoelectric/geologic layers namely the topsoil, lateritic layer, weathered layer, partly weathered/fractured basement and the fresh basement bedrock. The topsoil resistivity values vary between 79 and 302 Ωm while the thicknesses range from 0.6 – 1.9 m. The topsoil is composed of clay/sandy clay/clayey sand. Lateritic layer underlies the topsoil with resistivities and thicknesses that vary from 45 – 697 Ωm and 0.7 – 9.1 m, respectively. The weathered layer underlies the lateritic layer. It is made up of clay/sand clay with resistivities varying from 33 – 186 Ωm and thicknesses of between 3.1 and 33.4 m. The partly weathered/fractured basement is localized beneath VES V1 and 2 with resistivity and thickness values of between 147 and 252 Ωm and 34.3 and 39.7 m, respectively. The fresh basement constitutes the last geologic layer with resistivities of between 1458 Ωm and ∞ Ωm. The depth to the basement rock (overburden) ranges from 4.5 – 37.8 m.

Along profile E-F, four (4) geologic layers including the topsoil, lateritic layer, weathered layer and the fresh basement bedrock were delineated (Figure 6c). The clay/sandy clay/clayey sand topsoil resistivities vary between 85 and 378 Ωm while the thicknesses range from 0.6 – 2.8 m. The topsoil is directly underlain by lateritic layer whose resistivities and thicknesses vary from 45 – 395 Ωm and 4.4 – 8.9 m, respectively. The weathered layer underlies the lateritic layer. It is composed of clay/sand clay with resistivities varying from 45 – 149 Ωm and thicknesses of between 13.1 and 32.6 m. The fresh basement constitutes the bedrock with resistivities of between 2849 Ωm and ∞ Ωm. The depth to the basement rock (overburden) ranges from 19.1 – 44.3 m.

The weathered layer and the localized partly weathered/fractured basement constitute the aquifer units. The clayey weathered layer aquifer is porous and of low permeability with characteristic low to moderate groundwater potential rating (Chirindja *et al*., 2017; Gao *et al*., 2018). The geoelectric sections with superimposed hand-dug well logs and static water level (Figures 6a-c) show that the current well depths, except beneath wells W1 and 2 where the overburden is relatively shallow, had not reached the rock head and hence the hand-dug wells may not have taken significant advantage of the groundwater in the entire overburden (4.5 - 37.8 m thick) (see Figures 6a-c) except for the referenced two wells W1 and 2.

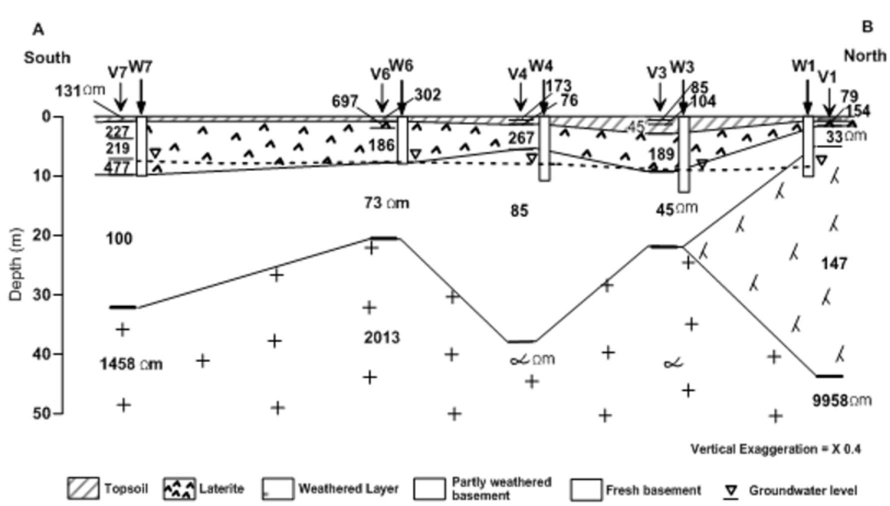

Figure 6a: Geoelectric Section along Profile A-B.

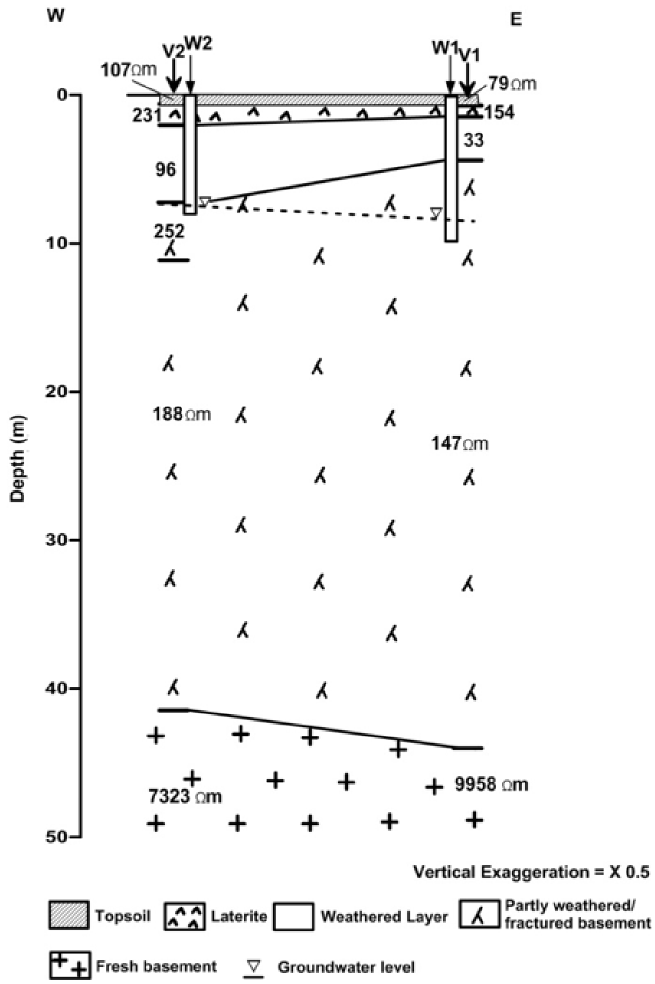

Figure 6b: Geoelectric Section along Profile C-D.

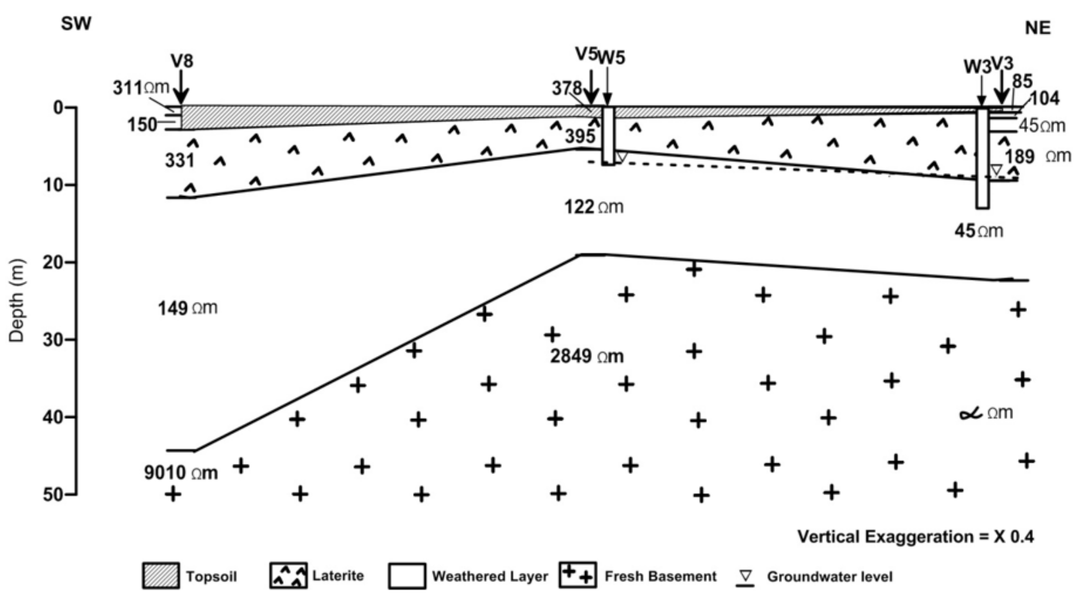

Figure 6c: Geoelectric Section along Profile E-F.

Overburden Thickness and Bedrock Relief

Figure 7 shows the overburden thickness map of the study area with thicknesses ranging from 4.5 to 44.3 m. The overburden thicknesses are observed to increase from the north to the south. A relatively thin overburden thickness area, in green color, is observed to bisect the relatively thick overburden zone in the southern part of the study area. Variations in the overburden thicknesses could be due to differential weathered rate or due to influence of basement bedrock structures such as ridges and depressions. The study area is classified into three (3) groundwater potential zones based on the overburden thickness distribution (Figure 7). Areas with thicknesses that are less than 10 m (ash/blue color band) in the northern part are characterized as low potential zone; areas with thicknesses between 10 and 30 m (cyan/green/brown color band) are classified as intermediate potential zone while areas with thicknesses greater than 30 m (red/purple color band) in the southwestern and eastern parts constitute high potential zone.

All the hand-dug wells penetrated the topsoil/lateritic layer and a bit of the weathered layer (the main aquifer unit) except beneath wells W1 and 2. The thin topsoil has no hydrogeologic significance except that it acts as a transport medium for infiltrated precipitation and pollutant. The high resistivity lateritic layer is compact (consolidated) with both low porosity and permeability characteristics and with virtually no hydrogeologic significance except that it acts as retardant for infiltrated pollutant and therefore offers protection for the underlying weathered layer aquifer. The weathered layer aquifer unit is

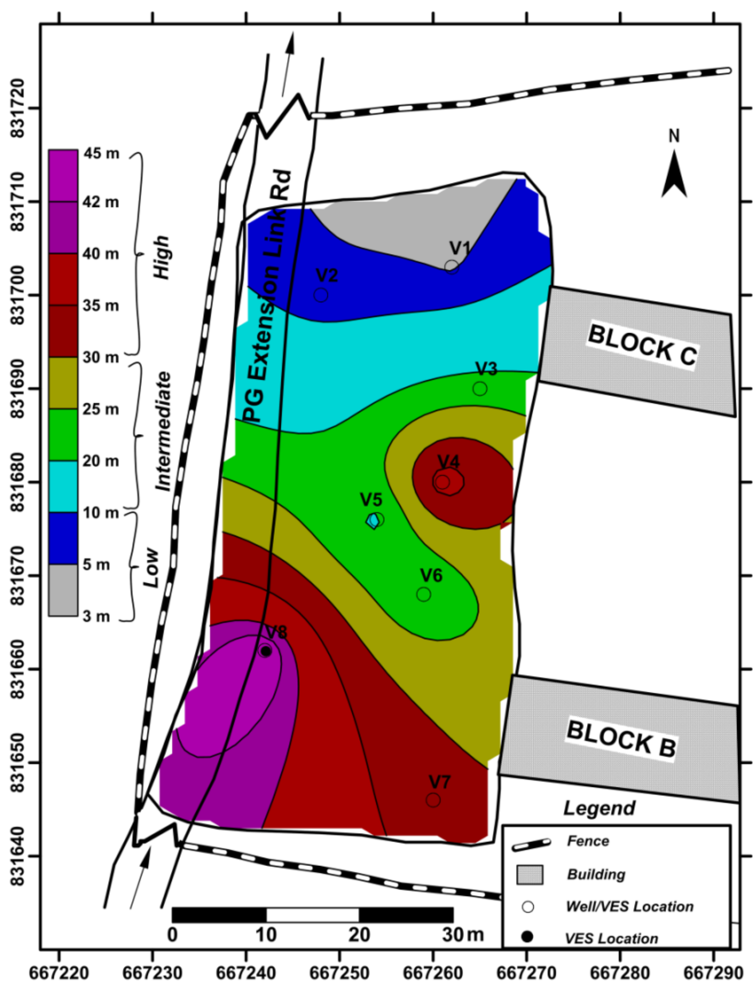

Figure 7: Overburden Thickness Map of the Study Area.

barely or not penetrated beneath wells W3, 4, 5, 6 and 7 and only fully penetrated beneath wells W1 and 2. The unit is very thin beneath well W1.

The fact that many of the wells did not penetrate the water bearing weathered layer may have been responsible for their poor yields. Hasan *et al.* (2018) established a direct relationship between overburden/aquifer thickness and groundwater potential in a weathered layer aquifer. The overburden thickness is therefore significant in the assessment of the groundwater potential of a weathered layer aquifer.

The bedrock relief map (Figure 8) is a contoured map of elevations of the basement bedrock obtained by subtracting the VES derived depths to the basement rock head from the surface elevation at the well heads (Table 2). The basement bedrock elevations vary between 234 and 272 m with a relief of 38 m. This map shows bedrock ridges (BR1 and BR2) and depressions (BD1 and BD2). Basement depressions favor groundwater accumulation while the basement ridges are groundwater divergent zones. This is due to the fact that groundwater flows into the depressions and away from the ridges (Figure 8). Although the direction of flow of the groundwater in the area is multi-directional, the overall groundwater flow direction is southernly/south-westerly (Figure 8).

Nature of the Aquifer Units

Although both the weathered layer and the partly weathered/fractured basement aquifers have been identified from the study area, the former predominates. Most hand-dug wells abstract from the low resistivity and easy to dig weathered basement. The nature of the weathered layer (its composition, porosity/permeability, degree of saturation and clay content) has significant influence on its groundwater accumulation and yielding capacities. These characteristics influence the aquifer resistivity (Telford *et al.,* 1990).

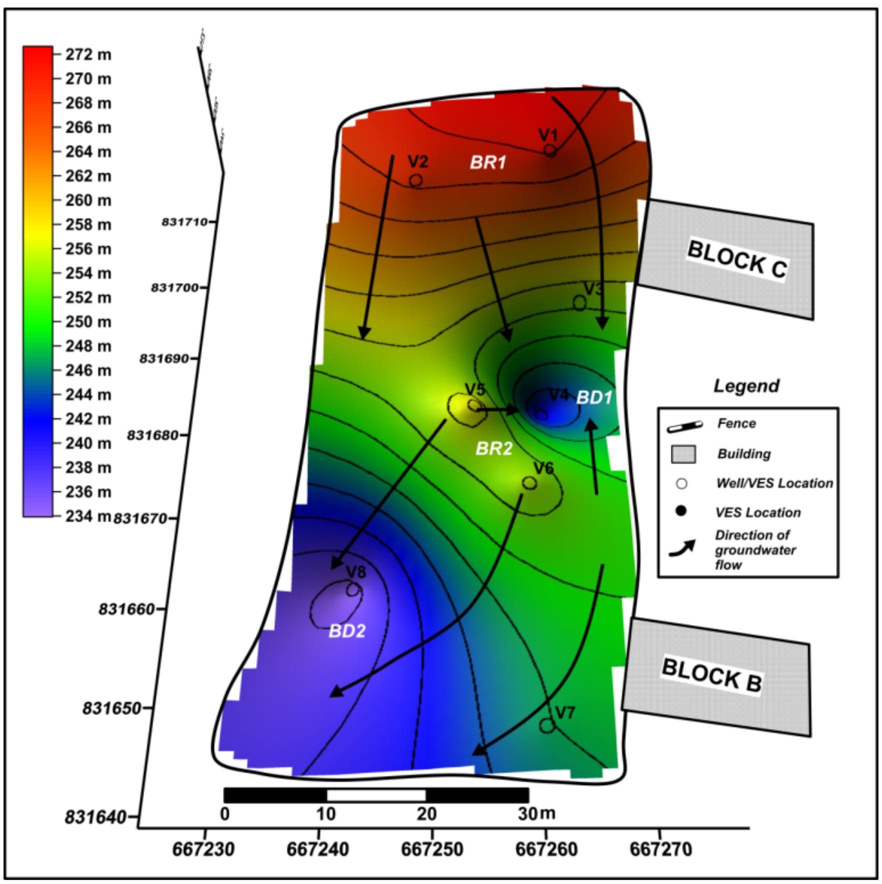

Figure 8: Bedrock Relief Map of the Study Area.

Table 2: Inventory of the Wells/VES Parameters.

No	Well Head Elevation (m)	Total Well Depth (m)	Depth to Rock Head (overburden thickness) (m)	Static Water Level (m)	Water Column (m)	Remarks
1[a]	276	10.05	4.5	8.45	1.60	Very low yield. However with lot of water at the peak of raining season
2	276	8.32	7.2	7.82	0.50	Low yield
3	276	12.63	22.5	9.00	3.63	Relatively moderate yield
4	278	10.70	37.8	8.00	2.70	Relatively moderate yield
5	277	7.55	19.1	6.85	0.70	Low yield
6	276	7.82	20.7	7.77	0.05	Low yield
7	279	9.55	32.1	7.40	2.15	Relatively moderate yield
VES 8	278	NA	44.3	NA	NA	NA

[a]: Well that penetrated beyond the relatively thin weathered layer into the more permeable partly weathered/fractured basement.

In this study, the weathered layer resistivity is used to assess its potential to accumulate and transmit groundwater and hence its groundwater potential. Figure 9 shows the iso-resistivity map of the weathered layer with values ranging from 25 to 149 Ωm. This resistivity range is typical of clayey subsoil that is porous but of low permeability capacity to discharge water into the wells.

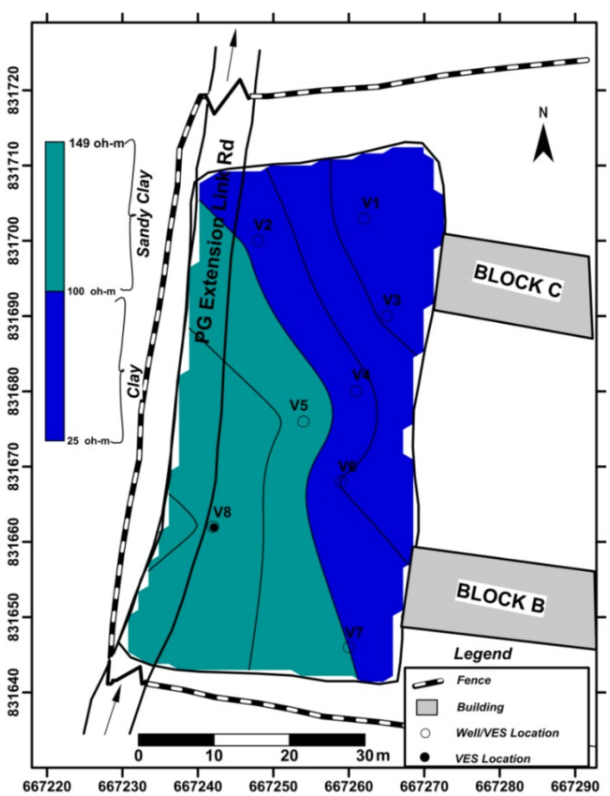

Figure 9: Iso-resistivity Map of the Weathered Aquifer.

DISCUSSION

Assessment of the Groundwater Potential of the Study Area

The weathered layer aquifer characteristics, most especially the storativity, in a typical basement complex terrain has been found to be related to overburden thickness (Ayoade, 1988; Olorunfemi, 1990; Hasan *et al*., 2018). However, the groundwater yield of such aquifer unit depends on its transmissivity, which is largely influenced by its clay content. Areas with thin (< 10 m), intermediate (10 - 30 m) and high (> 30 m) thicknesses are classified as low, intermediate, and high groundwater potential zones, respectively. The partly weathered/fractured aquifer is characterized by relatively high effective porosity and permeability with characteristic intermediate to high groundwater potential classification.

From the bedrock relief map (Figure 8), basement ridges (> 256 m), pediment (between 246 and 256 m) and basement depressions with elevation values < 246 m are characterized as low, intermediate, and high groundwater potential zones. The above factors were integrated in GIS platform while adopting the weighted averages in Table 1 and a groundwater potential map (Figure 10) was generated. The groundwater potential map rated most parts (79%) of the study area as low groundwater potential zone. This is typical of basement complex terrain (Akinwumiju *et* al., 2016; Oni *et al*., 2020b). The very low (around well W6/VES V6) and the moderate (near well W4/VES V4 and beneath VES V8) cover 4.1% and 16.9% of the study area, respectively.

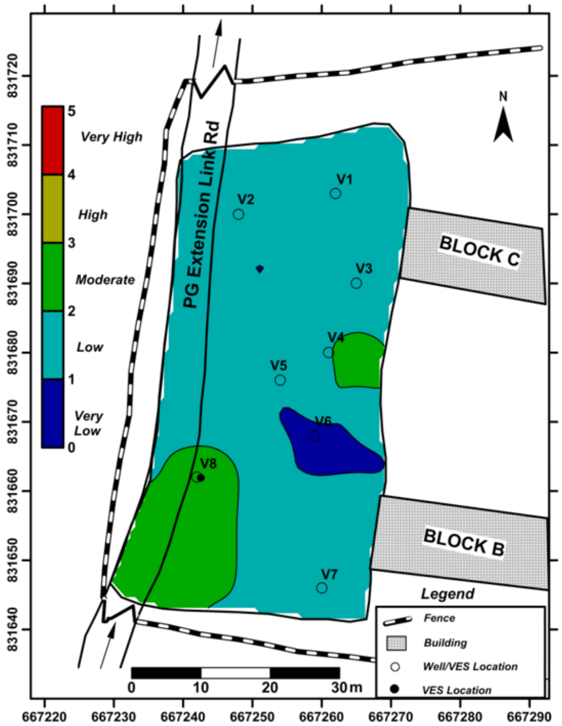

Figure 10: Groundwater Potential Map of the Study Area.

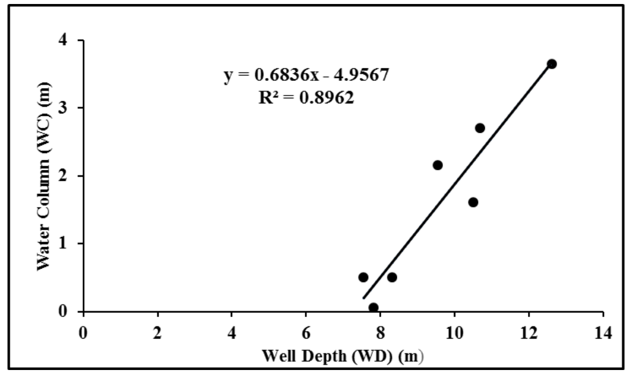

Figure 11: Correlation of Water Column Thickness with Well Depth.

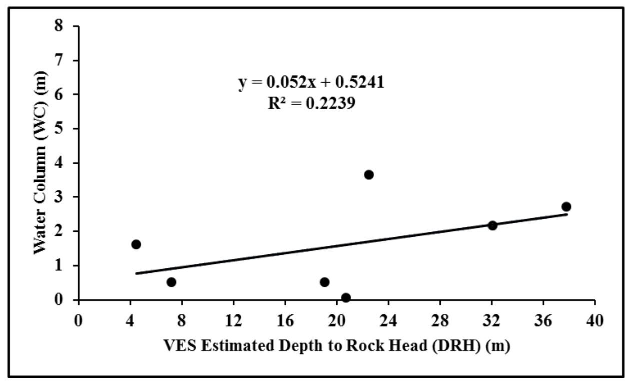

Figure 12: Correlation of Water Column Thickness with Depth to Rock Head.

Prospect for Enhanced Well Yield

Figure 11 correlates the wells water column (WC) thicknesses with well depths. The figure shows that water column thickness increases with well depth (WD) and that well depth in the survey area must be in excess of 7.25 m before there can be prospect of encountering groundwater. The relationship can be defined by a linear equation in the form WC = 0.6836(WD) – 4.9567 with a correlation coefficient of +0.95. This plot shows that water column and hence the groundwater potential increases with well depth.

Figure 12 correlates the wells water column (WC) thickness with VES estimated depth to rock head or overburden thickness. Although the data points show considerable scatter, a generally linear relationship is discernable, though with lower correlation coefficient of +0.47, indicating that water column in the well increase with depth to rock head or overburden thickness.

Even though the above analysis shows that except for wells W1 and 2, the other wells (W3 - 7) have not taken significant advantage of the groundwater which accumulates to depths in excess of 37.8 m (see Figures 6a-c, Table 2) in the weathered basement. There is therefore the prospect of enhanced and sustainable groundwater yield if the well depths are increase as detailed in Table 3.

CONCLUSION

Parametric geoelectric soundings were carried out on a field of hand-dug wells within the MMPGH in OAU, Ile-Ife, with a view to assessing the groundwater potential and the feasibility of increasing the well depths, to enhance the well yields. The study delineated five (5) subsurface geologic layers which include the topsoil, laterite, clay/sandy clay weathered layer, partly weathered/fractured basement, and the fresh basement bedrock.

Table 3: Summary on the Feasibility of Increasing the Wells Optimum Depth.

Well No	Eastings	Northings	Existing well depth (m)	Depth to bedrock from VES (m)	Feasibility of increasing the well optimum depth	Recommended well depth (m)
1	0667262	0831703	10.05	4.5	Not Feasible	N/A
2	0667248	0831700	8.32	7.2	Not Feasible	N/A
3	0667265	0831690	12.63	22.5	Feasible	20
4	0667261	0831680	10.70	37.8	Feasible	20
5	0667254	0831676	7.55	19.1	Feasible	19
6	0667259	0831668	7.82	20.7	Feasible	20
7	0667260	0831646	9.55	32.1	Feasible	20

The weathered layer and partly weathered/fractured basement constitute the aquifer units with the former predominating. The overburden that sustained the wells ranged in thickness from 4.5 – 44.3 m (and generally > 19 m). The weathered layer aquifer hosting the groundwater ranges in thickness from 6.85 - 37.8 m. However, the current well depths range from 7.55 – 12.63 m.

Statistical analysis shows that water column thicknesses generally increase with increase in well depth with a threshold of greater than 10.0 m for significant (> 2.0 m) water column. This shows that many of the wells except wells W1 and 2 have not taken significant advantage of the underlying groundwater. There is therefore the prospect of enhanced and sustainable groundwater yield if the well depths are increased to minimum of 19 m.

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ABOUT THE AUTHORS

Akanji Adedayo Adesola is an undergraduate student of the Department of Geology (Applied Geophysics Option), Obafemi Awolowo University, Ile-Ife, Nigeria. He has experience in geophysical field survey and prolific in the use of several geophysical and GIS software. His research interest is in near surface geophysics especially groundwater prospection with the use of electrical resistivity methods.

Oni Ademakinwa George is a Lecturer in the Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria. He received his B.Tech. degree in Applied Geophysics from Federal University of Technology, Akure, Nigeria. He proceeded to Obafemi Awolowo University, Ile-Ife, Nigeria where he earned his M.Sc. and Ph.D. degrees. His research interest is in near surface geophysics which include groundwater, archaeological, environmental, engineering, and mining geophysics.

Olorunfemi Martins Olusola is a Professor of Applied Geophysics in the Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria. He received his B.Sc. degree in Applied Geophysics from the University of Ife (now Obafemi Awolowo University), Ile-Ife, Nigeria, with first class honors after which he proceeded to the University of Birmingham, England for his M.Sc. and Ph.D. degrees in Applied Geophysics. He researches in groundwater, environmental, engineering, mining, and archaeological geophysics.

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