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Assessing the geo-electric characteristics of Basement Complex rocks and its implication for groundwater prospecting in Ilorin Metropolis, Nigeria

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Abstract. In Basement Complex rocks where rainfall is seasonal, water provision in dry season depends on regolith aquifer. For effective exploitation of groundwater resources, it is reasonable that geophysical investigation be conducted before development of well. In many instances, geophysical surveys may be expensive or nonexistent. Hence, there is a need for spatial analysis which might advise water engineers within such environments. Vertical Electrical Soundings (VES) data of 53 locations conducted with ABEM SAS-1000 terrameter using Schlumberger electrode configuration were obtained from the hydrogeology Department of Kwara state Ministry of Water Resources and Lower Niger River Basin and Rural Development Authority, Ilorin. VES locational coordinates were recorded using handheld GPS device. Sound curves were evaluated by partial curve matching approach and computer iteration using WinResist. The results depict six geo-electric regional successions, namely: top soil, lateritic clay, weathered basement, fairly-hard basement, thin fractured and hard basement. The geo-electric succession identified was plotted in Surfer 12 environment, using kriging interpolation method to show spatial distribution pattern of this zone. The spatial pattern is expected to give an insight to the nature of spatial variability of geo-electric layers and assist drillers as well as water resources policy makers in their operations.

Keywords. Geo-electric, groundwater, basement complex, geophysical, GIS

1 Introduction

Groundwater occurrence is often localized and confined to weathered or fractured zones in the Basement Complex region, and groundwater exploration in such terrain is always complex. The crystalline basement rocks have low porosity and permeability, hence, have no water storage capacity in their unaltered form; which makes their groundwater prospects to be limited and often restricted to features produced by weathering and tectonic processes (Olayinka and Olorunfemi, 1992; Olorunfemi and Fasuyi, 1993; Oyedele et al., 2013). In tropical basement rock, weathering process creates superficial layers, with varying degrees of porosity and permeability. This unconsolidated superficial layers, if significantly thick, porous and permeable, makes good aquifer units. It is important to note that the concealed basement rock may contain faulted areas, incipient joints and fracture systems derived from earlier tectonic processes in such region. The detection and delineation of these hydro-geologic structures may facilitate the location of groundwater potential zones in a typical basement rock environment (Omosuyi, et al., 2003; Oyedele, et. al., 2013).

Olorunfemi and Fasuyi (1993) submitted that the highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones. These fractured zones are often characterized by relatively low resistivity values. Olayinka and Olorunfemi (1992) argued that before a borehole is sited, a surface geophysical survey such as Vertical Electrical Resistivity Sounding (VES) should be conducted to identify the localized aquifer for a productive well. The Vertical Electrical Resistivity Sounding survey provides information about the subsurface that aid in aquifer delineation and identification of lithologic boundaries and geological structures (Bose, et al., 1973; Abiola, et al., 2013).

Vertical Electrical Resistivity Sounding method has been used widely by scholars in groundwater prospecting especially in the Basement Complex terrains to get detailed information about hydrogeological settings for groundwater potentials (Olorunfemi, 1990; Olorunfemi and Olayinka, 1992; Olorunfemi and Fasuyi, 1993; Oladapo, et al., 2009; Anohanmoran. 2013; Ogundana and Talabi, 2014). VES is used to determine the vertical variation of electrical resistivity below the earth surface and the potential field generated by the current, and this is because electrical resistivity of most rock depends on the amount of water in their pores. This method proved useful in groundwater studies because neither the structure nor the dynamics of the soil was disturbed (Otobo and Ifedili, 2005; Adiat et al., 2009; Ariyo and Adeyemi, 2009; Anomoharan, 2011; Anomoharan, 2013).

Despite the importance of VES in groundwater prospecting in a Basement Complex terrain, a better interpretation of hydrogeological data generated from this method often requires that their spatial location be incorporated into the analysis (Shahid and Nath, 2002). This will reveal the spatial variation of different geo-electric section of Basement Complex rock which can give a

better understanding of the hydrogeological prospect, especially of a large area. Consequently, the incorporation of Geographical Information System (GIS) into studies of groundwater prospecting becomes imperative. According to Shahid and Nath (2002), in recent time, GIS is widely used for spatial modeling of hydrogeological prospect of a large area with more reliability on groundwater exploration. Further, GIS has proved to be an efficient tool in groundwater researches and the inclusion of subsurface information deduced from geo-electric survey can give more realistic picture of groundwater potentiality of an area (Saraf, et.al., 1998; Krishnamurthy, et.al., 1996; Murthy, 2000; Shahid and Nath, 2002; Amaresh and Ravi Prakash, 2003).
Ilorin city is underlain by Precambrian Basement Complex; comprising mostly gneiss, granite, schist, undifferentiated meta-sediments rocks and overburden that are composed mainly of clay, sand and silt soils. The residents of this area often augment the public water supply by the Kwara State Water Corporation with groundwater (shallow and deep) because the supply is erratic and unreliable (Ifabiyi and Ahmed, 2011) and the coverage is limited to some areas (Ifabiyi and Ashaolu, 2013). The population of this city is rapidly increasing as new residential areas have sprung up and continue springing up in the last decade. All these new residential areas depend solely on groundwater for their domestic needs. On this basis, this study assessed and mapped the geo-electric characteristics of Basement Complex Rock of Ilorin, Nigeria in order to identify their spatial variation and implication on groundwater prospects of the city.

2 Material and Methods

2.1 The study area

Ilorin the Kwara state capital is located between latitude 08°24'N and 08°38'N of the equator, and longitude 04°26' E and 04°37'E of the Greenwich meridian, and covers about 12km. Ilorin is one of the fastest growing urban centers in Nigeria. There has been a huge increase in the population of Ilorin since it became the state capital in 1976. The population growth rate is much higher than other cities at 2.9 percent of the national growth rate. The 2006 census put the population of Ilorin city to about 847,582 (NPC, 2006 provisional results). Ilorin has a tropical wet and dry climate. Wet season is experienced from April to October and dry season from November to March. Rainfall condition in Ilorin exhibits greater variability both temporarily and spatial. The annual mean rainfall is about 1,200mm, exhibiting the double maximal pattern between April and October of every year. Relative humidity varies seasonally with an average of 79.7%.

The city is underlain by Precambrian Basement Complex, comprising mostly gneiss, granite, schist, undifferentiated meta-sediments rocks and overburden that are composed mainly of clay, sand and silt soils. The underlying pre-Cambrian igneous-metamorphic rock of Basement Complex is neither porous nor permeable except in places where they are deeply weathered or have zones of weakness. Some part of the town is also laid by Sedimentary rocks, which contains both primary and secondary laterites and alluvial deposits. Groundwater on the alluvium is recharged directly by rainfall or the adjoining overflowing river system. In the dry season, the alluvium sustains considerable subsurface groundwater flow. The alluvial deposits have been exploited, with successful wells and boreholes in Ilorin metropolis and its surrounding. The drainage system of Ilorin is dendritic in nature, and is dominated by Asa River, which flows from south to north and divides the city into two parts, the western and eastern parts. The map of the study area is presented in Figure 1.

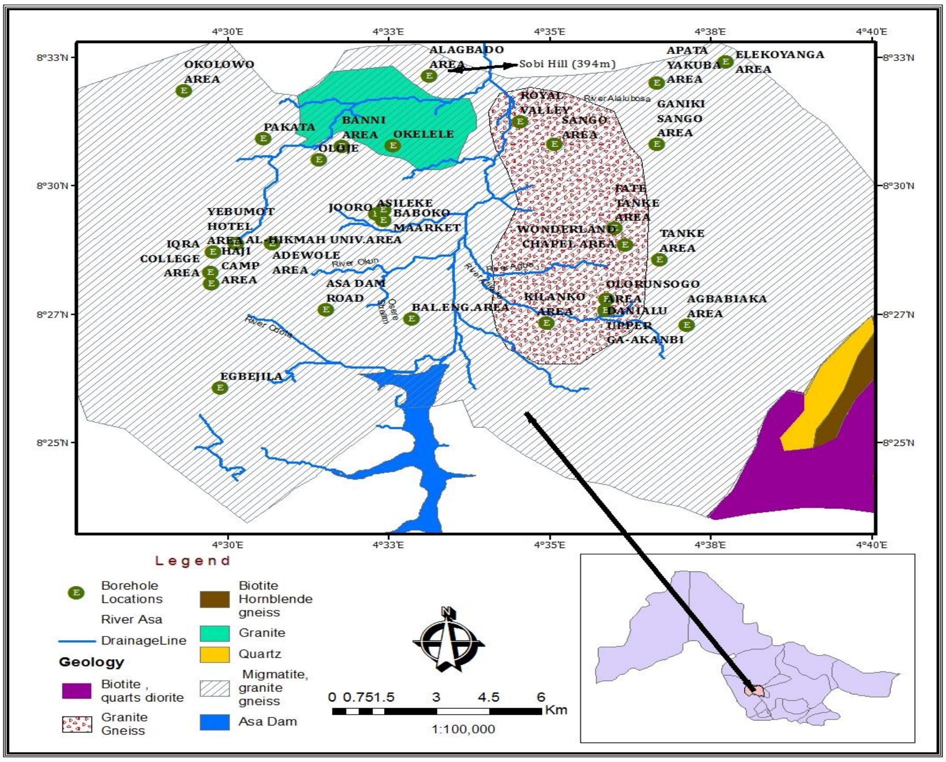

Fig 1. Geological map of the study area showing the sampled points

2.2 Methods

This study adopted the combination of secondary and primary (field work) data. The secondary data collected are the Vertical Electrical Soundings (VES) data conducted by the Kwara State Ministry of Water Resources and Lower Niger River Basin Development Authority, Ilorin. All the Vertical Electrical Soundings (VES) data collected were conducted with ABEM SAS-1000 Terrameter using the Schlumberger electrode configuration, and the electrode spacing (AB/2) varied from 0.1 m to 200m. The results of geophysical survey carried out in 53 different locations in Ilorin were collected. The minimum number of VES carried out in each of these 53 locations was 9 and the maximum were 12. The sounding curves were evaluated by partial curve matching method and computer iterations using WinResist. The field work was carried out to get the coordinates (locations) of the sampled points using handheld Global Positioning System device. This was carried out to get the coordinates of all the locations used in the study, which facilitated the plotting of the data in Surfer 12 GIS software. The resistivity values from the interpretation of the field data using curve matching were used to generate geo-electrical succession. The data on geo-electric layers and the point location collected were used to plot the geo-electric map of the study area. This was carried out in Surfer 12 GIS software using kriging interpolation method to determine the spatial distribution of the identified layers in the study area.

3 Results and Discussion

3.1 General Pattern of Geophysical Characteristics of Groundwater in Ilorin

The identified layers resistivity and thickness ranges across the sampled points in the study area are presented in Table 1. From the table, six regional geo-electric patterns are discernable, namely: top lateritic sand, lateritic clay, weathered basement, fairly hard basement, thin fractured and hard basement. However, the study looks at the vertical variations of the electrical resistivity recorded from one point to another across the study area, hence, overlaps observed in the reported VES range. The first layer consists of the top soil with resistivity values ranging from 30-3000 ohm-m and thickness ranging from 0.2-1.0 m. The lateritic clay layer is where resistivity ranges between 23-1400 Ohm-m and thickness from 2-20 m. The third lithologic layer is characterized by highly weathered basement with resistivity values between 22-1000 Ohm-m and thickness of 2-45 m. Electrical resistivity values here are controlled by the degree of water saturation (Odunsanya and Amadi, 1990; Oladipo et al., 2009).

Table 1: Ranges of geo-electric succession in Ilorin, Nigeria

SN	Layers	Resistivity (ohms)	Thickness (m)
1	Top Lateritic Soil	30-3000	0.2-1.0
2	Lateritic Clay	23-1400	2-20
3	Weathered Basement	25-1000	2-45
4	Fairly Hard Basement	22-600	6-42
5	Thin Fractured	55-145	20-40
6	Hard Basement	35-780	15-42 above

The fourth layer is a fairly hard basement weathered and resistivity ranging from 22-600 ohm-m and thickness between 6-42m. The fifth layer represents a thin fractured zone and resistivity ranging from 55- 145 Ohm-m and thickness between 20-40m. The sixth layer represents the hard basement with resistivity values ranging from 35- 780 Ohm-m and thickness between 15-42m and above across the study area. Figure 2 and Table 2 show the resistivity value of each geo-electric succession in the 53 sampled locations across the study area.

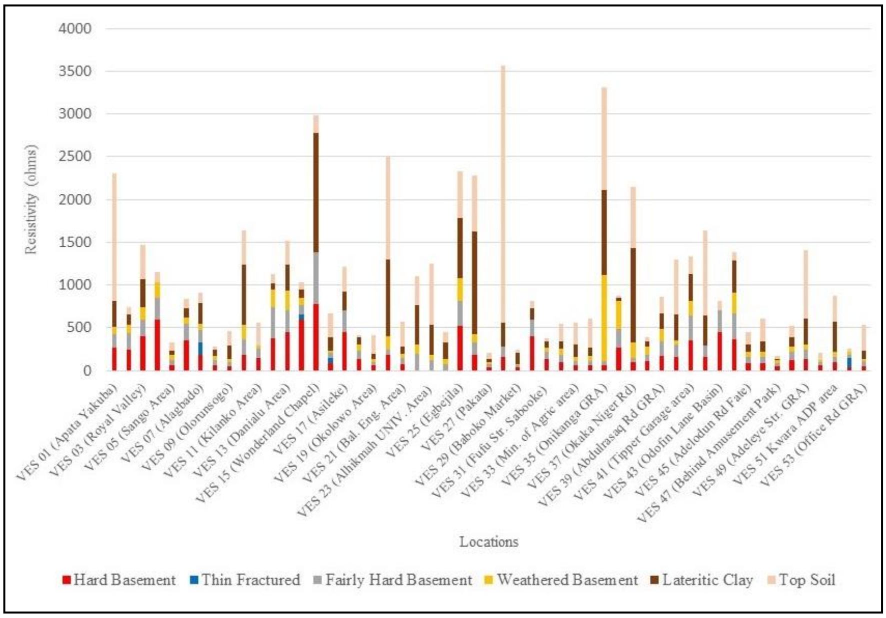

Fig 2. Geo-electric section of Vertical Electrical Sounding in Ilorin Metropolis

Table 2: Geo-electric succession in the study area (Res: Resistivity Ω-m; T: Thickness, m)

SN	Description	**Top Lateritic Soil**		**Lateritic Clay**		**Weathered Basement**		**Fairly Hard Basement**		**Thin fractured**		**Hard Basement**	
		Res. (Ω-m)	T (m)	Res. (Ω-m)	T (m)	Res. (Ω-m)	T (m)	Res. (Ω-m)	T (m)	Res. (Ω-m)	T (m)	Res. (Ω-m)	T (m)
1	Apata Yakuba	1500	0-1	300	2-3	80	3-20	160	20-40	0	0	270	40-above
2	Ganiki Sango	85	0-1	130	2-6	90	6-20	190	20-35	0	0	250	35-above
3	Royal Valley	400	0-1	320	2-3	145	3-15	200	15-30	0	0	400	30-above
4	Elekoyangan	120	0-1	NA	NA	180	2-15	250	15-20	0	0	600	20-above
5	Sango Area	100	0-1	50	2-10	65	10-30	52	30-40	0	0	68	40-above
6	Oyun Area	100	0-1	120	2-3	65	3-10	200	10-30	0	0	350	30-above
7	Alagbado	120	0-1	250	2-6	70	6-20	150	20-35	145	35-40	180	40-above
8	Okelele	30	0-1	68	2-8	52	8-25	60	25-35	0	0	66	35-above
9	Olorunsogo	170	0-1	160	2-3	35	3-20	40	20-40	0	0	55	40-above
10	Agbabiaka area	400	0-1	700	2-15	170	15-30	180	30-40	0	0	190	42-above
11	Kilanko Area	270	0-1	NA	NA	35	2-20	110	20-40	0	0	150	40-above
12	Tanke Area	110	0-1	80	2-20	200	20-40	365	40-40	0	0	380	42-above
13	Danialu	280	0-1	300	2-3	225	3-20	260	20-30	0	0	450	30-above
14	Fate Tanke	80	0-1	100	2-5	90	5-10	105	10-20	55	20-30	600	15-30
15	Wonderland Chapel	200	0-1	1400	2-15	0	0	600	15-30	0	0	780	30-above
16	Oloje Area	270	0-1	160	2-5	32	5-6	58	20-30	60	30-35	85	35-above
17	Asileke	290	0-1	220	2-15	0	0	250	15-25	0	0	450	25-above
18	Jooro	25	0-1	85	2-10	72	10-20	100	20-35	0	0	130	30-above
19	Okolowo Area	220	0-1	70	2-3	30	3-20	40	20-40	0	0	60	42-above
20	Yebumot Area	1200	0-1	900	2-10	150	10-35	70	35-42	0	0	180	42-above
21	Bal. Eng. Area	300	0-1	80	2-6	52	6-30	65	30-40	0	0	80	40-above
22	Hajj Camp	340	0-1	450	2-6	110	6-20	200	20-40	0	0	0	0
23	Alhikmah UNIV. Area)	710	0-1	350	2-6	60	6-25	125	25-40	0	0	0	0
24	Adewole Area	120	0-1	200	2-10	50	10-30	80	30-40	0	0	0	0
25	Egbejila	550	0-1	700	2-8	260	8-45	300	15-25	0	0	520	25-above
26	Asa Dam	650	0-1	1200	2-8	100	8-20	150	20-40	0	0	180	42-above
27	Pakata	80	0-1	30	2-6	25	6-15	35	15-30	0	0	40	30-above
28	Iqra college	3000	0-1	280	25	0	0	120	8-40	0	0	160	40-above
29	Baboko Market	38	0-1	130	2-5	13	5-30	22	30-40	0	0	40	40-above
30	Banni Area	80	0-1	130	2-6	0	0	200	6-23	0	0	400	25-above
31	Fufu Str. Sabooke	32	0-1	74	2-10	50	10-30	92	30-35	0	0	130	35-above
32	Post office area	200	0-1	92	2-10	70	10-30	85	30-35	0	0	100	35-above
33	Min. of Agric area	260	0-1	150	2-10	45	10-30	50	30-35 above	0	0	60	35-above
34	Ododosowapo Amilegbe	340	0-1	100	2-10	56	10-30	43	30-35	0	0	68	35-above
35	Onikanga GRA	1200	0-1	1000	2-10	1000	10-30	55	30-35	0	0	60	35-above
36	Sakama Niger Rd	20	0-1	35	2-10	330	10-30	220	30-35	0	0	270	35-above
37	Okaka Niger Rd	720	0-1	1102	2-10	180	10-30	50	30-30	0	0	99	30-above
38	Agbadam Lake Rd	50	0-1	65	2-10	90	10-30	80	30-35 above	0	0	110	30-40
39	Abdulrasaq Rd GRA	200	0-1	180	2-8	140	8-30	170	30-35 above	0	0	175	35-above
40	Unilorin Garden	650	0-1	300	2-8	50	8-30	145	30-35 above	0	0	160	40-above

41	Tipper Garage area	200	0-1	310	2-8	170	8-30	300	30-35 above	0	0	350	30-above
42	Behind Fed Sec.	1000	0-1	350	2-10		10-30	128	30-35	0	0	165	35-above
43	Odofin Lane Basin	100	0-11					260	30-35 above	0	0	450	40-above
44	Water View area	100	0-1	380	2-8	240	8-30	300	30-35	0	0	370	35-above
45	Adelodun Rd Fate	140	0-1	90	2-8	55	8-30	70	30-35	0	0	92	35-above
46	Edun area	265	0-1	130	2-8	55	8-30	78	30-35	0	0	82	35-above
47	Behind Amusement Park	35	0-1	23	2-10	33	10-30	40	30-35	0	0	45	35-above
48	Mustapha Idiagbede Basin	140	0-1	100	2-10	70	10-30	95	30-35	0	0	120	35-above
49	Adeleye Str. GRA	800	0-1	300	2-10	55	10-30	120	30-35	0	0	130	35-above
50	GSS Area	80	0-1		2-10	28	10-30	40	30-35	0	0	60	35-above
51	Kwara ADP area	300	0-1	360	2-10	55	10-30	60	30-35	0	0	100	35-above
52	Ile eleru Ojagbooro	40	0-1		2-10	35	10-30	30	30-35	115		35	35-above
53	Office Rd GRA	300	0-1	97	2-10	32	10-30	51	30-35 above	0	0	55	40-above

3.2 Geo-electric Succession and their characteristics in Ilorin Metropolis

3.2.1 Top Lateritic Soil and Lateritic Clay

The average resistivity and thickness values of top lateritic soil in Apata Yakuba, Ganiki Sango and Royal Valley are 662 ohm-m and 1m respectively which indicate lower clay proportion. The average resistivity and thickness values of top lateritic soil in Elekoyangan, Sango area and Oyun area are 106 ohm-m and 2m respectively which indicated that the predominant composition of the top soil is lateritic clay. In Apata Yakuba, Ganiki Sango and Royal Valley, the average resistivity values and thickness of lateritic layer are 250ohm-m and 4m which implies that the layers composed of clayey sand. Also, the average resistivity and thickness values of top lateritic soil in Alagbado, Okelele and Olorunshogo areas are 107 ohm-m and 2m respectively which indicates that the predominant composition of the top soil is lateritic clay. The average resistivity and thickness values of top lateritic soil in Agbabiaka area, Kilanko area and Tanke area are 107 ohm-m and 2m respectively which is an indication that the predominant composition of the top soil is lateritic clay. Figure 3 shows map of the spatial distribution pattern of lateritic clay in the study area as it varies from one location to another.

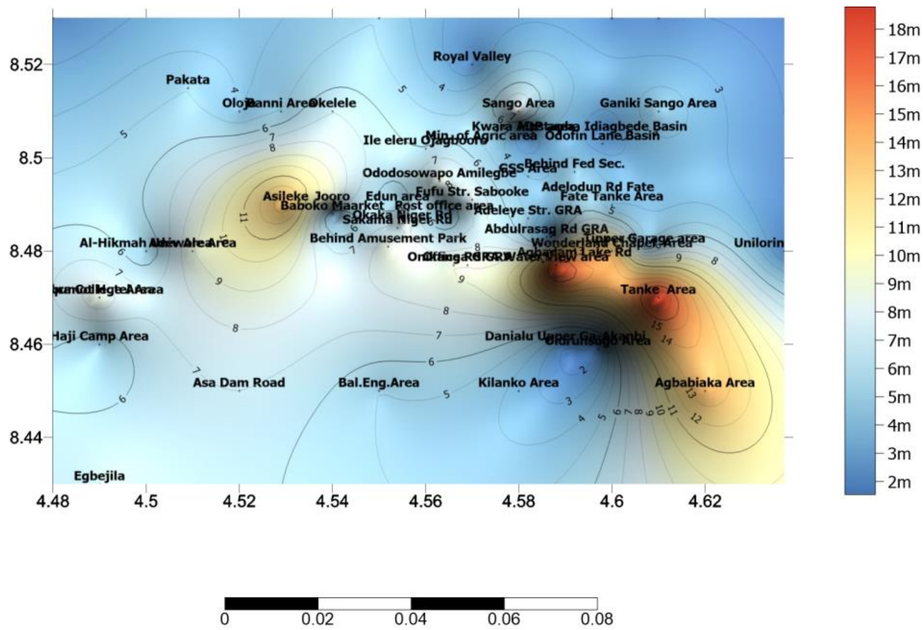

Fig 3. Distribution pattern of Lateritic clay depth (m) in Ilorin

3.2.2 Weathered Basement

In Apata Yakuba, Ganiki Sango and Royal Valley, the weathered basement average resistivity and thickness are 105ohm-m and 18m which indicates a saturation characterized by a moderately low resistivity layer. The weathered basement average resistivity and thickness are 103ohm-m and 18m in Elekoyangan, Sango area and Oyun area, suggesting some level of saturation characterized a moderately lower resistivity layer. In Alagbado, Okelele and Olorunshogo, the weathered basement average resistivity and thickness are 51ohm-m and 22m, respectively. This agrees with the findings of Ogunlana and Talabi (2014), indicating that the material composition is largely clay, sandy clay and clayey sand. This is evidenced in the high degree of water logging of this area, particularly in dry season. In Agbabiaka, Kilanko and Tanke area of the city. The weathered basement average resistivity and thickness are 135ohm-m and 30m respectively, which indicates existence of some degree of fractures and water saturation weathered basement. The weathered basement average resistivity and thickness for Danialu and Fate Tanke are 158ohm-m and 15m respectively, indicating a saturation characterized by a moderately low resistivity layer. Figure 4 shows map of the spatial distribution pattern of weathered basement in the study area as it varies from one location to another.

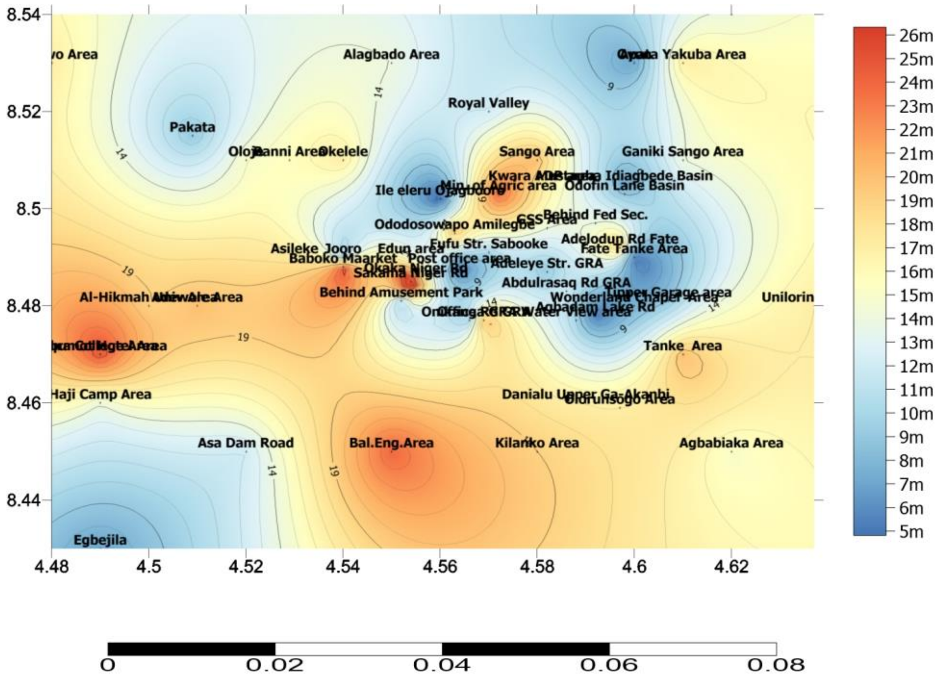

Fig 4. Distribution pattern of Weathered Basement Depth (m) in Ilorin

3.2.3 Fairly Hard Basement

The fairly hard basement in Elekoyangan, Sango area and Oyun area, average and thickness resistivity are 167ohm-m and 30m. This falls within the weathered and fresh basement rock which is also characterized by potential aquiferous units and hard rock in the areas. Also, its resistivity and thickness values are 339ohm-m and 30m, the result agree with Oyedele and Olayinka (2012) that the groundwater potential of the aquifer may be significantly enhanced if the geo-electric basement has a fairly low resistivity. Relatively low values of geo-electric basement resistivity (200 – 640 Ωm) are indicative of good groundwater potential. The fairly low bedrock resistivity confirms the presence of fractures and hence water contained within the fissures (Becson and Jones, 1988; Olayinka and Olorunfemi, 1992; Ayodele and Olayinka, 2012). Figure 5 shows map of the spatial distribution pattern of fairly hard basement in the study area as it varies from one location to another.

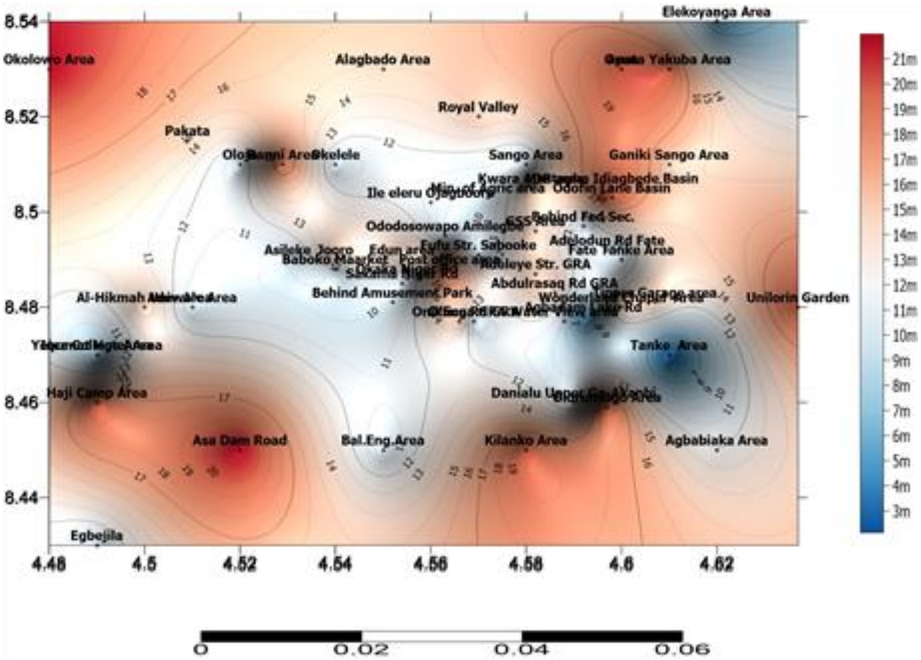

Fig 5. Distribution pattern of Fairly Weathered Basement Depth (m) in Ilorin

3.2.4 Thin Fractured

In Alagbado, there is a presence of thin fracture zone which indicates a good potential aquiferous units in the area. Fate Tanke area also show thin fractured zone in the study area which served as reservoir in the area. Oloje area have thin fractured zone. The resistivity and the thickness values are 60ohm-m and 35m which indicates that the area are water bearing zone due to its low resistivity values. The coloured part of Figure 6, shows map of the spatial distribution pattern of thin fractured in Ilorin, while the plain area are the locations without thin fracture zone in the study area.

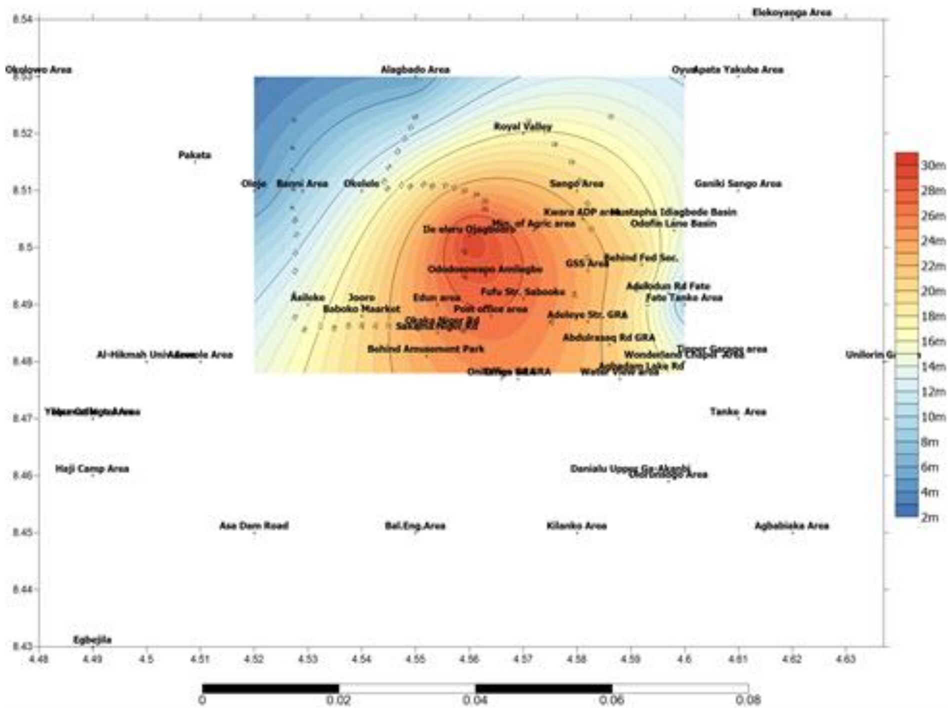

Fig 6. Distribution pattern of Thin Fractured Depth (m) in Ilorin

3.2.5 Hard Basement

The hard basement in Alagbado, Okelele and Olorunshogo, also varies and the average resistivity and thickness values are 100ohm-m and 38m which indicate fine grained with intercalation of sandy clay. Fresh hard rock is the last layer in Apata Yakuba, Ganiki Sango and Royal Valley, the section is relatively deep in the area and average resistivity and thickness values are 307ohm-m and 35m, the resistivity values are somehow high because of its crystalline nature. The hard basement in Agbabiaka area, Kilanko area and Tanke area also varies and the average resistivity and thickness values are 240ohm-m and 41m which indicate fine grained with intercalation of sandy clay. The hard rock average resistivity and thickness values for Danialu, Fate Tanke and Wonderland Chapel area, are 439ohm-m and 30m. The result agrees with Oyedele and Olayinka (2012), that the groundwater potential of the aquifer may be significantly enhanced if the geo-electric basement has a fairly low resistivity. Relatively low values of geo-electric basement resistivity are indicative of good groundwater potential and the fairly low bedrock resistivity confirms the presence of fractures, which shows that water is contained within the fissures (Becson and Jones, 1988, and Olayinka and Olorunfemi, 1992; Ayodele and Olayinka, 2012). Figure 7 shows the spatial distribution pattern of hard basement in the study area as it varies from one location to another.

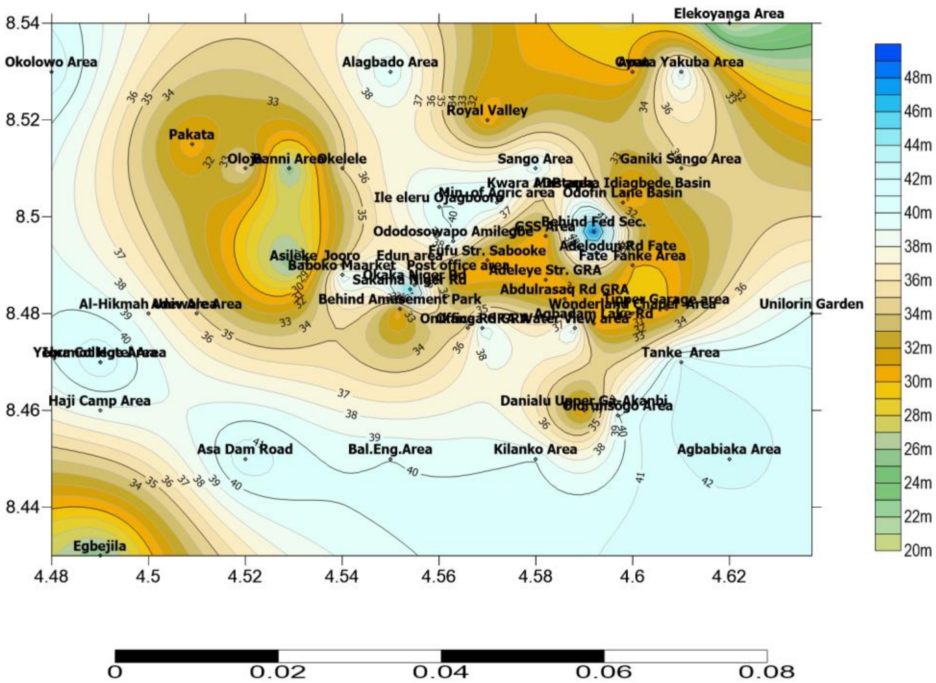

Fig 7. Spatial Distribution Pattern of Hard Basement Depth (m) in Ilorin

4 Conclusion

In conclusion, understanding the spatial distribution of geo-electric succession, especially in a large area is a key to maximizing groundwater prospecting. This study has revealed four to six geo-electric successions in Ilorin metropolis and took a step further to present a spatial distribution pattern of the identified layers in the study area. As revealed by the study, from the third layer to the sixth layer shows good groundwater potential. In addition, the resistivity values obtained shows that there are economically viable groundwater resources in the study area, especially in the weathered basement, fairly hard basement, thin fractured and hard basement lithology. Although, the level of groundwater availability varies from one location to the other as the depth and resistivity of these layers varies from place to place. The spatial distribution pattern of the geo-electric succession presented in this study would aid driller in siting boreholes in Ilorin metropolis, without necessarily conducting geophysical survey, which will in turn reduce the cost of drilling borehole in the study area.

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