



Seasonal Comparison of Potential Groundwater Aquifer in Ijebu-Ife, South-West, Nigeria, using Dipole-Dipole Array and Electromagnetic Methods

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Abstract

Seasonal comparison of potential groundwater aquifer unit using integrated geophysical methods at Ijebu-Ife, Ogun State, South-west, Nigeria was investigated. The fieldwork employed two seasons (dry and wet seasons). The electromagnetic method employed the Very low frequency and its data was acquired during the dry and wet seasons along with five profiles of Dipole-dipole array covering 500 m length using ABEM WADI VLF equipment and was processed using the KAROUS-HJELT software. The 2 – D Dipole-dipole data were also acquired along with five (5) traverse for both seasons making a total number of ten (10) and was processed with DIPROFWIN software. The results of the Integrated Dipole-Dipole and VLF-EM data identified three geoelectric layers based on its electrical resistivity and conductivity distribution. The study identified a clayey sand horizon which constitutes a good aquifer zone. The study reveals in, comparison, that during the dry season, all layer resistivities are high with low depth while during the wet season; all layer resistivities are low with high depth. Also, conductivity during the wet season is high at high depth than conductivity which is low at low depth during the dry season. The study concluded that, in water exploration, drilling of water should be done during the dry season in other to locate the exact depth of water.

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1. Introduction

Water that flows on the earth's surface due to rainfalls, finds its way to the river while others sink into the ground. Plants use some while some evaporate and return to the atmosphere. Water found below and above the ground is termed groundwater and surface water respectively. Groundwater found below

the ground, percolate the soil, and can be collected in wells, tunnels, or drainage galleries [1].

Water extracted from the ground has three main uses: agriculture (irrigation), domestic consumption (source of drinking) as a source of potable water, and industrially with little, or no purification before it can be used for achieving sustainable development). Groundwater has a larger storage capacity than surface water [2]. Groundwater is very useful; an estimation of about 2 billion people in urban and rural communities world-

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wide depends on groundwater for daily consumption [3]. The need for the exploration of a sedimentary aquifer in the study area is necessary to identify potential groundwater aquifer and this could be achieved by a combination of two detailed integrated geophysical methods, which are the electrical resistivity and electromagnetic methods.

Oladunjoye *et al.* [4] investigated the localized nature of groundwater occurrence in Ogbomosho North to solve the scarcity of potable water in the area by employing the very low frequency electromagnetic and electrical resistivity methods. The data acquisition involved four electrical resistivity profiles and five VLF-EM carried out parallel to the two major azimuths in the study area. The result obtained reveals the usefulness of combining electromagnetic and electrical resistivity methods to locate suitable sites for water borehole drilling.

Coker *et al.* [5] employed resistivity method for groundwater potential comparison in Oke – Badan, data acquisition was done in the peak of a dry season – March and the peak of a wet season – July. The major rocks in the study area are pegmatite, quartzite, and quartz schist. The investigated area delineated five subsurface layers. The value of apparent resistivity ranges from $13.76 \Omega m$ and $4828.26 \Omega m$ during the dry season while during the wet season; it was low ranges between $11.6 \Omega m$ and $2878.2 \Omega m$ with high depth to basement rocks varies from $0.2 m$ and $91.3 m$. The same pattern was delineated for both the seasons with an increase in thickness hence; a good groundwater potential zone was identified at the southwestern part of the weathered layer maps.

1.1. Location and the Geologic Settings of the Study Area

Ogun state geology is made of sedimentary and basement complex terrains, with intercalations of argillaceous sediment [6]. Figure 1 shows the sedimentary rock of the state which consists of Abeokuta formation underlying by basement complex terrain, above by Ewekoro, Oshosun and Ilaro formations follow by the Benin formation [6]. Ijebu Ife the study area, is situated within Ijebu East of Ogun state with latitude $6.78^\circ N$ of the equator and longitude $4.03^\circ E$ of the Greenwich meridian. It lies within the sedimentary terrain on the eastern part of the Dahomey basin with a population of 5733 [7]. Ogun State has two seasons such as the rainy season from March to October and the dry season for the remaining part of the year, though there is always a very low rainfall in August and it is referred to as the “August break”. A climate in Ijebu Ife is tropical with much more rainfall during the rainy season. The topography of Ijebu Ife has a wide area of undulating lowlands, Figure 2, tropical of the coastal sedimentary terrain of southwestern Nigeria. Water drains out of Ijebu Ife passing through tributaries which flows into the Ogun River. Ogun River discharges into the Lagos lagoon which flows into the Atlantic Ocean. The availability of water for domestic, agriculture, and industries (small scale industries) is a function of seasonality since groundwater yield is generally associated with seasonal varieties of factors such as climatic conditions, weather, etc. The geological terrains of Ijebu Ife contribute to the fluctuation of groundwater level and aquifer during the wet and dry season, though Ogun State with

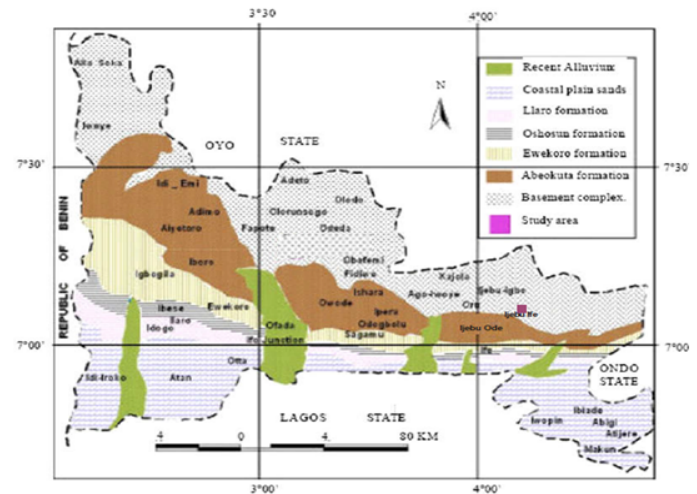


Figure 1. Geological map of Ogun State [6].

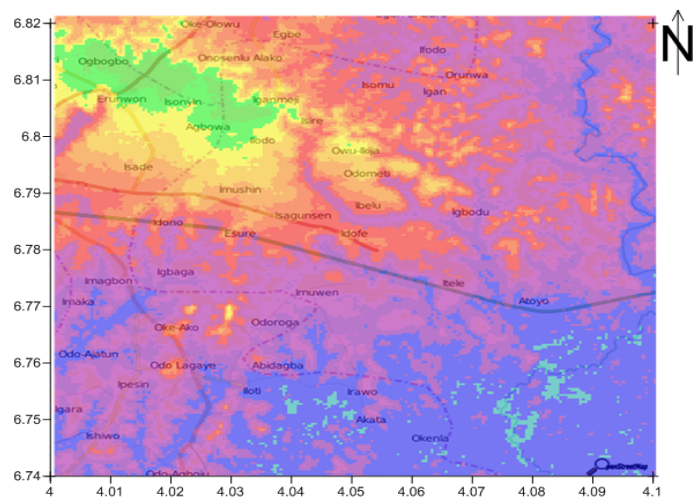


Figure 2. Topographical map of Ijebu Ife [8].

monsoon climate is characterized with high rainfall and high evaporation. The size of the field is 8000 sqm .

2. Materials and Method

The two major techniques conducted for the fieldwork are electromagnetic method and the dipole – dipole method. The electromagnetic method makes use of very low frequency, primarily as a reconnaissance tool as large areas of land can be rapidly covered, with other geophysical methods combine with it. For this work, a dipole-dipole array was combined with the VLF-EM method to explore potential groundwater aquifer in Ijebu Ife.

A total of 10 traverses were covered for both wet and dry seasons within Ijebu Ife, Ogun State as shown on the location map (Figure 3). Each traverse has a length of $500 m$ and at $10 m$ fixed spacing measured using a measuring tape. An ABEM WADI VLF transmitter was used to measure and generate data on the field. The data were subject to filtering using Karous and

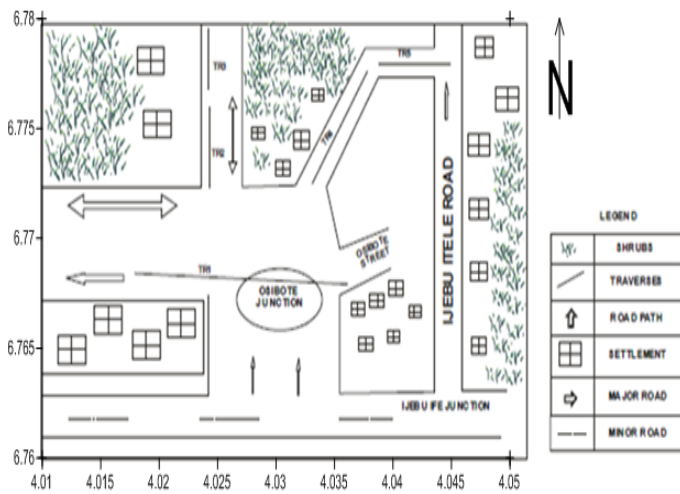


Figure 3. Location map showing VLF - EM traverse.



Figure 4. Location map showing dipole - dipole traverse.

Fraser filter to increase the signal to noise ratio and enhance the response signatures.

Dipole – dipole on the other hand is one of the widely used resistivity methods because of its low EM coupling between the current and potential circuits. A total of 10 traverses were investigated in both seasons with each traverse length covered 160 m of distance and at 5 m fixed spacing of the current and potential electrode measured from measuring tape. Data were generated on the field using ABEM SAS1000 Terrameter as shown on the location map (Figure 4). Subsequently, reading on the field was taking every 5 m and the data was processed with DIPROFWIN software to obtain pseudosection.

3. Results and Discussion

3.1. Discussion of results during the dry season

The results of the processed 2D resistivity imaging are shown in colour format in form of pseudosections (Figure 5a - e). The geoelectric section is indicative of the resistivity characterization of the subsurface as presented in Table 1.

Table 1. Table of geoelectric parameter for electrical resistivity (Dipole – Dipole) of Traverse 1 to 5 in dry season.

Traverse	Layer	Geoelectric Layer	Relativity (Ωm)	Depth (m)
1	1	Top Soil	35 - 488	0 - 3
	2	Clayey Sand	85 - 774	3 - 11
	3	Sandy Clay	152 - 218	5 - 25
2	1	Top Soil	126 - 1946	0 - 3
	2	Clayey Sand	228 - 1580	3 - 7
	3	Sandy Clay	1502 - 25092	7 - 25
3	1	Top Soil	260 - 2105	0 - 3
	2	Clayey Sand	292 - 3258	3 - 11
	3	Sandy Clay	500 - 11410	7 - 25
4	1	Top Soil	190 - 886	0 - 3
	2	Clayey Sand	190 - 2673	3 - 10
	3	Sandy Clay	543 - 5008	7 - 25
5	1	Top Soil	495 - 886	0 - 3
	2	Clayey Sand	495 - 2324	3 - 11
	3	Sandy Clay	19 - 1071	5 - 25

The electrical resistivity profile for traverse one which is 120 m in length found at the south western part and its measured apparent resistivity pseudosection is presented in Figure 5a. The overview of the inverted resistivity profile of this profile line is described below. Layer one reveals resistivity value between 35 Ωm –488 Ωm and extends to a depth of about 3 m beneath the surface. Layer two is inferred as the weathered layer with the value of resistivity from 85 Ωm – 774 Ωm at a depth of 3–11 m thus highly indicating the presence of clayey sand soils. The third layer has a resistivity values that range from 152 Ωm – 218 Ωm at a depth of about 5 m – 25 m is indicative of a groundwater deposit, the resistivity value is very low thus, interpreted as sandy clay.

The traverse line 2 is 140 m in length at the north-western part with the measured apparent resistivity pseudosection shown in Figure 5b. Layer 1 is interpreted as topsoil has a resistivity value ranging from 126 Ωm –1946 Ωm from the surface to 3 m depth. Layer 2 inferred as the weathered layer interpreted as clayey- sand has a value of resistivity between 228 Ωm and 1580 Ωm from a depth of about 3–7 m. The third layer interpreted as sand extends from the depth range of about 7–25 m and has a value of resistivity between 1502 Ωm and 25092 Ωm .

The electrical resistivity profile for traverse line 3 occurred in the northwestern area. A Dipole-dipole array was used for this traverse line which measures 140 m. The measured apparent resistivity pseudosection is presented in Figure 5c. The first layer interpreted as topsoil with resistivity value between 260 Ωm and 2105 Ωm from the surface to 3 m depth. Layer 2 is inferred as the weathered layer, interpreted as clayey- sand with resistivity values between 292–3258 Ωm from a depth range of about 3–11 m. The Third layer interpreted as sand has resistivity values between 500 and 11410 Ωm .

The traverse line 4 is 140 m length found at the North-eastern area with a measured apparent resistivity pseudosection shown in Figure 5d. Layer 1 is the topsoil with resistivity

tivity value between 190 Ωm and 886 Ωm from the surface to 3 m depth. Layer 2 inferred as the weathered layer, interpreted as clayey sand has resistivity values between 190 Ωm and 2673 Ωm . Layer 3, interpreted as sand extends from a depth range of about 7 – 25 m and has resistivity values between 543 – 5008 Ωm .

The traverse line 5 is found at the Northeastern area with a traverse length of 140 m. Layer 1 is the topsoil with values of resistivity ranges from 495 - 886 Ωm from the surface to 3 m depth. Layer 2 is the weathered layer, inferred as clayey sand with values of resistivity between 495 - 2324 Ωm with a range of depth between 3 – 11 m. Layer 3 inferred as sand extends from a depth range of about 5 – 25 m with values of resistivity between 19 and 1071 Ωm .

Figure 6a shows the pseudosection VLF results generated from the interpreted data along with profile 1. The real component varies from -60% to +20%. The section indicates possible anomalous zones that range from -10 to +10 $mmho/m$ (conductive region) with lateral distance of 200 – 350 m that could favor groundwater exploration. These zones were indicated by the high conductive zone in yellow to red colors. However, the low conductive region identified in green to blue colors at both ends of the traverse indicates that the subsurface has similar conductivity values along the profile.

Figure 6b shows the pseudo-section VLF results generated from the interpreted data along with profile 2. The real component varies from -60% to +20%. From the section, the subsurface is indicative of similar conductivity values that range from -10 to +10 $mmho/m$. However, the pocket of high conductivity regions was observed at lateral distance of 60, 200, 320, and 450 m respectively.

Figure 6c shows the pseudo-section VLF results generated from the interpreted data along with profile 3. The real component varies from -60% to +20%. From the section, the subsurface is indicative of conductivity values that range from -10 to +15 $mmho/m$. However, no distinct conductivity regions were observed along the traverse.

Figure 6d shows the pseudo-section VLF results generated from the interpreted data along with profile 4. The real component varies from -60% to +20%. The conductivity of this section varies between -25 to +10 $mmho/m$. From the section, no distinct conductivity region is delineated. However, the moderate conductivity values between +5 to +10 $mmho/m$ identified along the profile are suggestive of the weathered layer indicated in light yellow color.

Figure 6e shows the pseudo-section VLF results generated from the interpreted data along with profile 5. The real component varies from -60% to +20%. The conductivity of this section varies between -25 to +20 $mmho/m$. From the section, the conductive zones (between +10 to +20 $mmho/m$) identified at lateral distance of 150 to 200 m and 270 to 370 $mmho/m$. These zones are suspected to be weathered and fractured layers from depth of about 20 to 60 m in yellow to red color along with the profile that could favor groundwater exploration.

3.2. Discussion of Results at Wet Season

The lithologic unit as interpreted from the inverted electrical resistivity profile is presented in Table 2 and Figure 7 (a – e) for traverse 1 – 5 respectively. Traverse 1 covered 120 m length

Table 2. Table of geoelectric parameter for electrical resistivity (Dipole – Dipole) of Traverse 1 to 5 during the wet season.

Traverse	Layer	Geoelectric Layer	Relativity (Ωm)	Depth (m)
1	1	Top Soil	28 - 310	0 - 5
	2	Clayey Sand	70 - 300	0 - 20
	3	Sandy Clay	35 - 120	5 - 25
2	1	Top Soil	140 - 500	10 - 25
	2	Clayey Sand	534 - 1400	5 - 25
	3	Sandy Clay	1900 - 23721	5 - 25
3	1	Top Soil	84 - 500	0 - 25
	2	Clayey Sand	500 - 2468	0 - 25
	3	Sandy Clay	370 - 4486	5 - 25
4	1	Top Soil	120 - 450	0 - 10
	2	Clayey Sand	500 - 1200	0 - 25
	3	Sandy Clay	1300 - 4445	5 - 25
5	1	Top Soil	200 - 259	0 - 25
	2	Clayey Sand	50 - 150	5 - 25
	3	Sandy Clay	18 - 42	12 - 25

found at the south-west of the location (Figure 7a). The resistivity value of layer one ranges between 28 and 319 Ωm interpreted as the topsoil with a varying depth of 0 – 5 m. Layer two is inferred as the weathered layer, interpreted as clayey sand has a resistivity ranging from 70 – 300 Ωm with a varying depth of 0 – 20 m. Layer three resistivity value is between 35 and 120 Ωm at 0 – 25 m interpreted as sandy clay.

The traverse line 2 is found in the North-west with a length of 140 m (Figure 7b). Layer one resistivity is between 140 and 500 Ωm at 10 – 25 m depth interpreted as the topsoil. The second layer resistivity is between 534 and 1400 Ωm at 5 – 25 m depth inferred as the weathered layer, with lithology as wet sand. The third layer has resistivity value between 1900 and 23721 Ωm at 5 – 25 m depth interpreted as sand.

The traverse line 3 is 140 m length, located in the north-west (Figure 7c). Layer one has resistivity value ranging 84 – 500 Ωm at 0 – 25 m depth which is the topsoil. The second geoelectric layer inferred as the weathered layer has resistivity values between 500 - 2468 Ωm at 0 – 25 m depth interpreted as wet sand. The third layer, has a resistivity value is between 370 - 4486 Ωm at 5 – 25 m depth interpreted as sand.

The traverse 4 line is 140 m length north-west (Figure 7d). Layer one resistivity is between 120 - 450 Ωm at 0 – 10 m depth interpreted as topsoil. The second geoelectric layer inferred as the weathered layer, interpret as wet sand has a resistivity range of 500 – 1200 Ωm at 0 – 25 m while the third layer, interpreted as sand has a resistivity range of 1300 – 4445 Ωm at 5 – 25 m. The profile line for traverse 5 is 140 m length located in the northeast (Figure 7e). The first layer resistivity values range between 200 – 259 Ωm at 0 – 25 m depth, interpreted as topsoil, the second layer inferred as the weathered layer, clayey

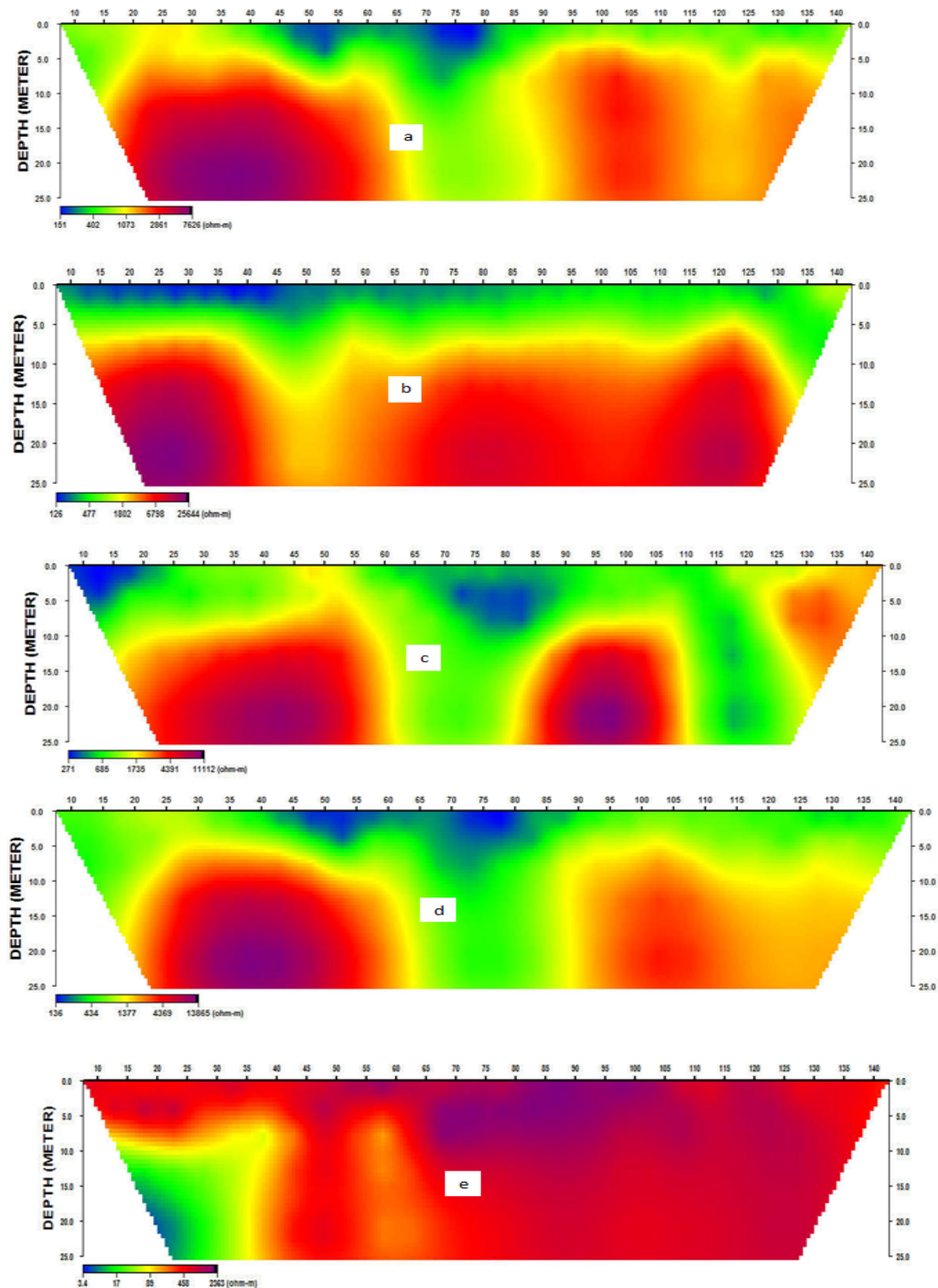


Figure 5. 2D Dipole – Dipole Resistivity profile for Traverses a to e during the Dry Season.

sand with resistivity value ranges between 50 - 150 Ωm while the third layer, interpreted as sandy clay with resistivity value between 18 - 42 Ωm at 12 – 25 m depth.

Figure 8(a - e) shows the pseudo-section VLF results generated from the interpreted data along with profile 1 – 5 during the wet season.

On profile 1 (Figure 8a), the real component varies from -60% to +20%. The section indicates a possible anomalous zone (conductive zone) suspected to be fractured zone at a lateral distance of 290 – 370 m that could favour groundwater exploration. This zone is indicated by highly conductive values between +10 to +30 $mmho/m$ in red colour along with the profile.

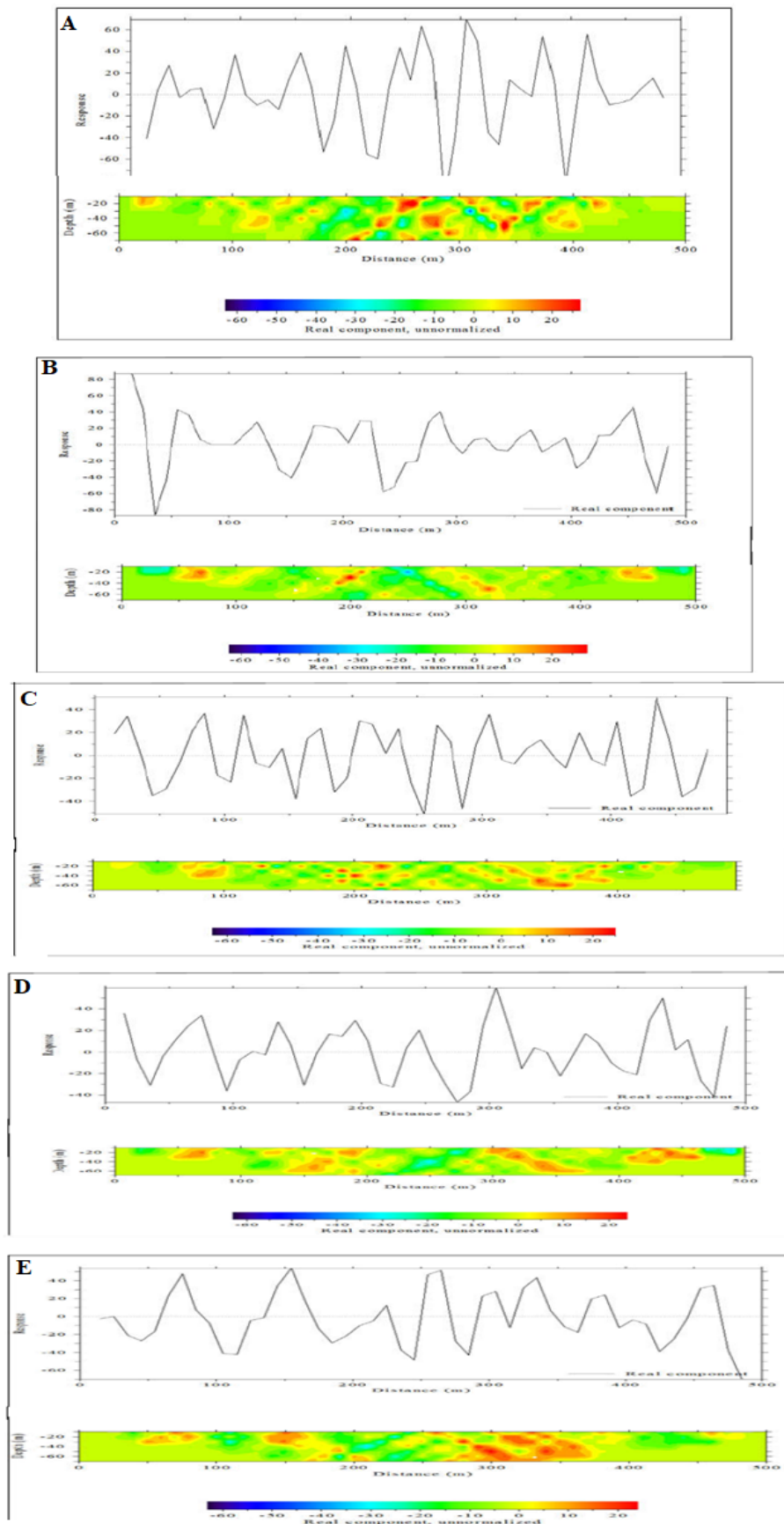


Figure 6. 2D Pseudosection of the VLF along Traverse 1 at Dry Season.

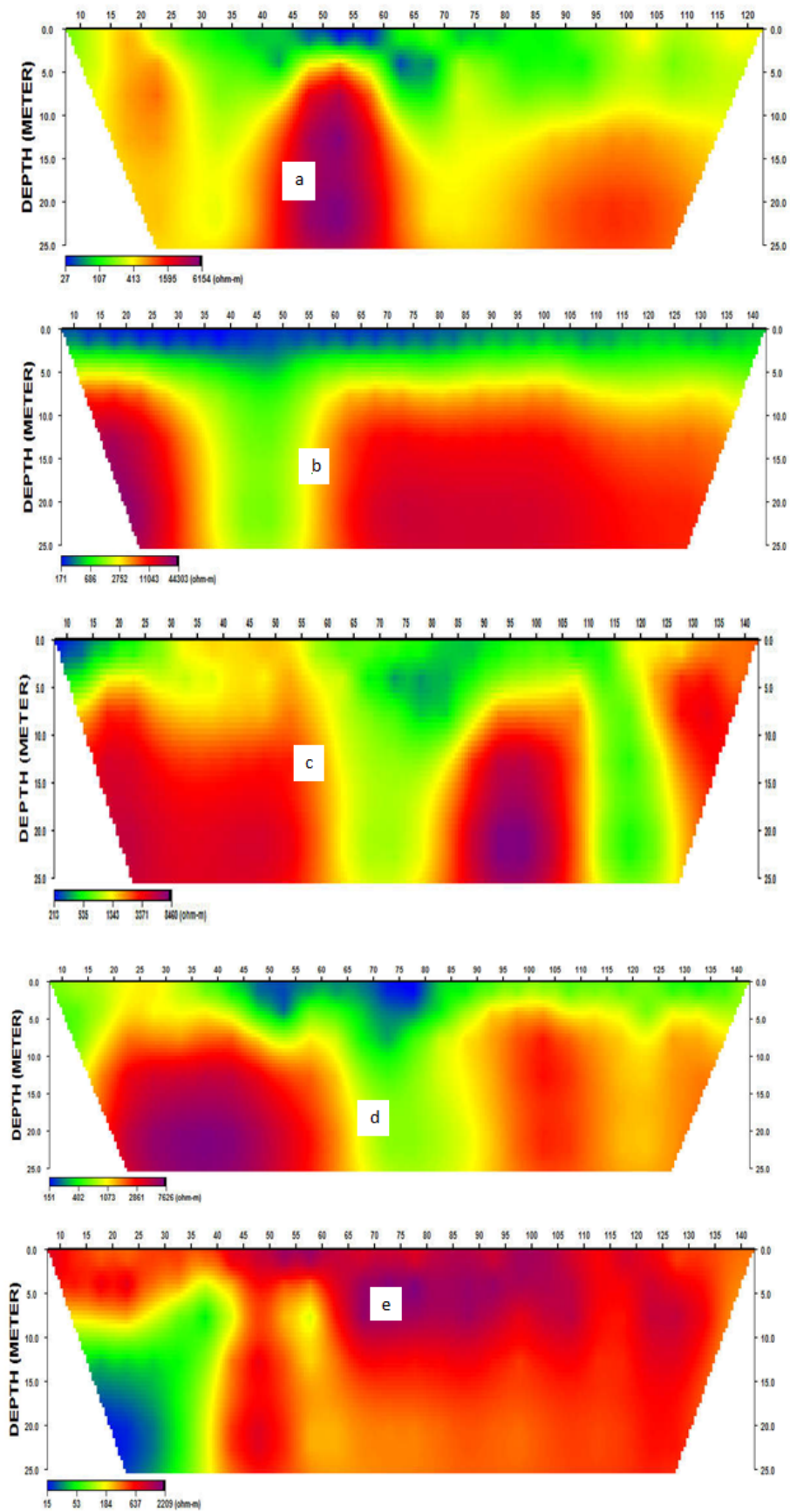


Figure 7. 2D Dipole – Dipole Resistivity Profile for Traverse 1 during Wet Season.

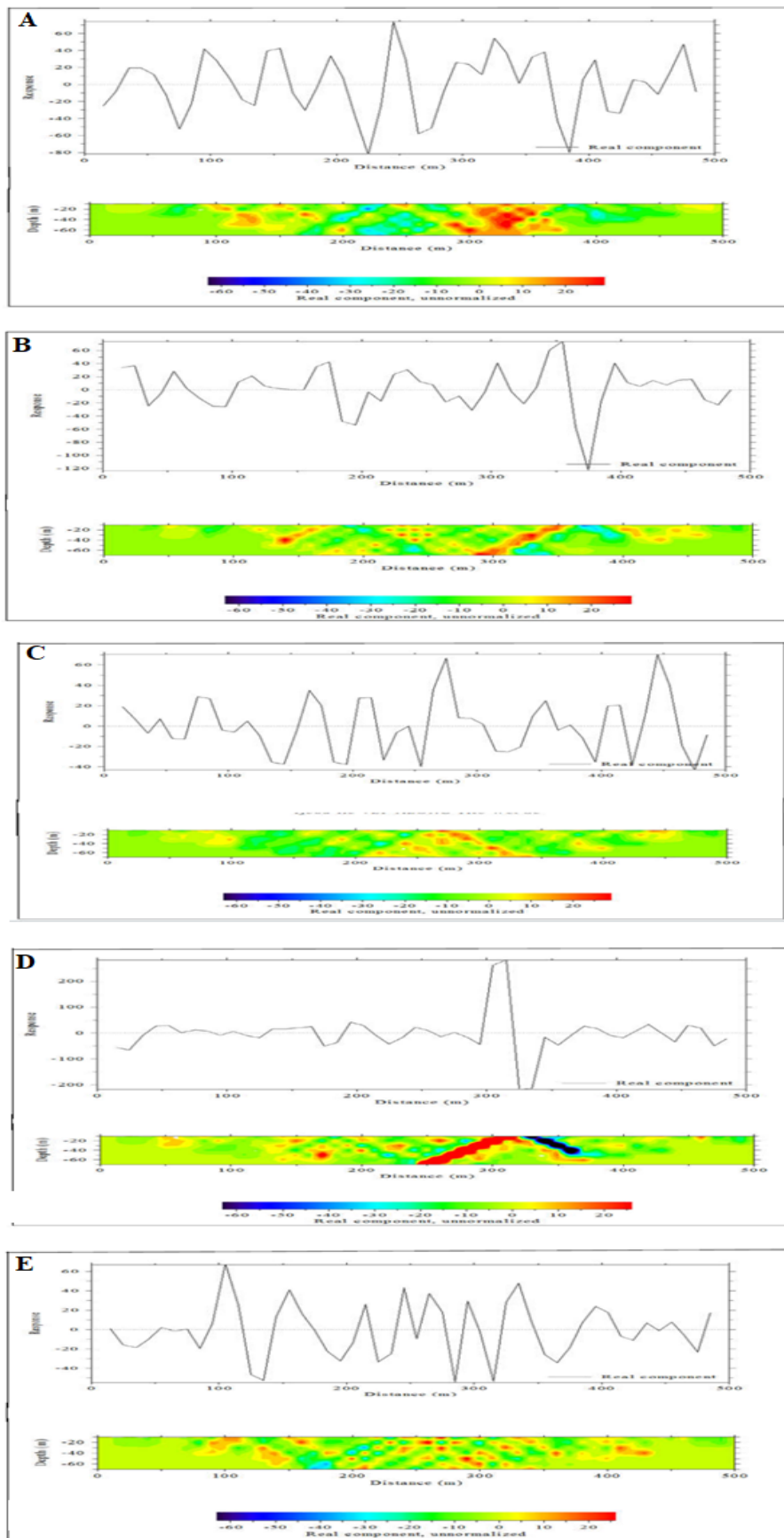


Figure 8. 2D VLF pseudosection along with profile 1 - 5 during wet season.

On profile 2 (Figure 8b), the real component varies from -60% to +20%. The conductivity of this section varies between -25 to +25 *mmho/m*. From the section, the conductive zones (between +15 to +25 *mmho/m*) was identified at a lateral distance of 300 – 350 *m* form a depth of about 20 – 60 *m*. This zone is suspected to be a fractured layer in yellow to red colour along with the profile that could favour groundwater exploration.

On profile 3 (Figure 8c), the real component varies from -60% to +20%. The conductivity of this section varies between -20 to +15 *mmho/m*. From the section, a conductive zone is identified at a lateral distance of 210 – 340 *m* that could favour groundwater exploration. This zone is indicated by high conductive values between +10 to +15 *mmho/m* suspected to be a fractured layer from a depth of about 20 to 60 *m* in yellow to light red colour along with the profile.

Along with profile 4 (Figure 8d), the real component varies from -60% to +20%. The section indicates a possible anomalous zone (conductive zone) suspected to be a fractured zone at lateral distance of 250 – 350 *m* that could favour groundwater exploration. This zone is indicated by the highly conductive value in red colour along with the profile.

On profile 5 (Figure 8e), the real component varies from -60% to +20%. From the section, the subsurface is indicative of conductivity values that range from -10 to +15 *mmho/m*. However, no distinct conductivity regions were observed along the traverse.

3.3. Correlation of Results for Dry and Wet Season along Profiles 1 to 5

The comparison of the layer resistivity of Table 1 and Table 2 with Figures 5 to 7 reveals the following:

On profile 1, the resistivity values are higher in the dry season than the wet season. Hence, the aquifer thickness of layer 2 in the wet season (Figure 7a) is 20 *m* higher than that of the dry season which is 11 *m* (Figure 5a).

On profile 2, the resistivity values are higher in the dry season than the wet season. Hence, the aquifer thickness for layer 2 in the wet season (Figure 7b) is 25 *m* higher than that of the dry season which is 7 *m* (Figure 5b).

On profile 3, the resistivity values are higher in the dry season than the wet season. Hence, the aquifer thickness for (layer 2) in the wet season (Figure 7c) is 25 *m* higher than that of the dry season which is 11 *m* (Figure 5c).

On profile 4, the resistivity values are higher in the dry season than the wet season. Hence, the aquifer thickness of layer 2 in the wet season (Figure 7d) is 25 *m* higher than that of the dry season which is 10 *m* (Figure 5d). The layers resistivity values for the dry season is higher than that of the wet season.

On layer 5, the resistivity values are higher in the dry season than the wet season. Hence, the aquifer thickness of layer 2 in the wet season (Figure 7e) is 25 *m* higher than the dry season which is 11 *m* (Figure 5e).

4. Conclusion

In Ijebu-Ife during the dry and wet seasons; the study reveals high resistivity values for all layers with low depth and corresponding low conductivity during the dry season. The study also reveals low resistivity values for all layers with high depth and corresponding high conductivity during the wet season.

During the dry season, the resistivity value of the second layer in Ijebu-Ife is high (292 Ωm – 3258 Ωm) maximum and (85 Ωm – 774 Ωm) minimum compared with that of the wet season (500 Ωm – 2468 Ωm) maximum and (50 – 150 Ωm) minimum. The thickness of the aquifer is low during the dry season (3–11 *m*) maximum depth and (3–7 *m*) minimum depth compared with during the wet season (0 – 25 *m*) maximum and (0–20 *m*). According to Coker *et al.* [5] during the wet season, high depth and low resistivity values were recorded which could be a result of the influence of pore water.

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