Research article

Geo-investigation on groundwater control in some parts of Ogun state using data from Shuttle Radar Topography Mission and vertical electrical soundings

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ABSTRACT

Groundwater is a vital natural resource that plays a significant function in sustainability of living things on earth. Its exploration requires special skill for optimum exploitation. Shuttle Radar Topography Mission (SRTM)and Vertical Electrical Sounding (VES) were used to detectthe stratigraphy and subsurface structures controlling the groundwater system around Iju – Ota, Ogun State, Southwestern Nigeria. Nineteen (19) VES points were carried out where there were dense concentrations of lineaments and interconnected to establish the connection of the observed lineaments with groundwater occurrence in the study area using Schlumberger array, with electrode spacing of AB/2 varying from 180 to 320 m. The analysis of SRTM data revealedthe dominating structural NE-SW and NW-SE trends, which control aquifer structure. The geoelectrical parameters from the VES results were used to map the stratigraphic sequences in the study area. Six (6) units that comprisethe topsoil, lateritic clay, clayey sand, mudstone, sand (main aquifer), and shale or clay were identified in the study area. The aquiferous unit around Iju – Ota axis ranged from 30 to 80 m. Theextracted from the hill shaded SRTM data and the result of VES revealed that the thickness of the aquifer is as a result of interconnectivity of the lineaments observed in the SRTM data suggesting that the groundwater occurrence in the study area is chiefly controlled by these fractures.

1. Introduction

It has been established that civilization and development of any nations (communities inclusive) have flourished due to reliable water supplies and have suffered setback as the water supplies failed (Troften, 1973; Olasehinde, 2010). Water is an inevitable tool for life survival on earth (Chaplin, 2001; Jequier and Constant, 2010; Hanslmeier, 2011; Oladejo et al., 2013; Adagunodo et al., 2018; Adejumo et al., 2018; SDG6, 2018; Westall and Brack, 2018). It occurs in three forms: as rain, surface flow and subsurface flow. In Nigeria, rain and surface water are easily contaminated due to negligence of the regulatory bodies on water conservation and treatment for its sustainability (Adagunodo et al., 2018; Joel et al. 2019a, b). As a result of this, groundwater is the major source of water for drinking (Adagunodo, 2017) and domestic usages (Olafisoye

et al., 2012; Oladejo et al., 2015). Groundwater is cheap, safe, constant in quality and quantity, and abundant to man when properly explored (Umar et al., 2017). It is however essential to understand the stratigraphic structures of a terrain before its groundwater resource can be optimally harnessed, either through dug wells or boreholes (Olasehinde, 2010). Various methods have been employed in groundwater exploration globally, ranging from traditional methods such as fracture trace method and borehole drilling (Lattman and Parizek, 1964; Acharya et al., 2012) to the use of geophysical methods such as electrical resistivity, magnetics, electromagnetics, seismic, radiometric techniques and so on (McNeill, 1991; Bernard and Legchenko, 2003; Goldman and Neubauer, 1994; Hewaidy et al., 2015; Shishaye and Abdi, 2016; Helaly, 2017; Muhammad and Khalid, 2017; Muthamilselvan et al., 2017; Poongothai and Sridhar, 2017; Umar et al., 2017; Gao et al., 2018). In addition, Sunmonu

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et al. (2016), Adagunodo et al. (2018) and Joel et al. (2019a) had established that geophysical methods are capable to map the depth togroundwater table. Groundwater has been successfully investigated on sedimentary and basement terrains using resistivity technique by number of researchers (Okereke et al., 1998; Nwankwoet al., 2004; Singh et al., 2006; Ariyo and Adeyemi, 2009; Al-Amoush, 2010; Nwankwo, 2011; Zarroca et al., 2011; Ikhane et al., 2012; Molli et al., 2015; Omeje et al., 2013; Omeje et al., 2014; Rotimi et al., 2014; Sunmonu et al., 2015; Aizebeokhai et al., 2016; Sunmonu et al., 2016; Joel et al., 2016; Muhammad and Khalid, 2017; Poongothai and Sridhar, 2017; Umar et al., 2017).

The application of Shuttle Radar Topography Mission (SRTM), a remotely-sensed data for hydro-geophysical investigation is increasingly becoming well known most importantly in areas where orthodox method such as resistivity technique is inadequate. This is used for subjective estimation of ground-water resources through the extraction and studying of geological features, surface-morphology and their hydrogeological attributes. In addition, better observation and systematic examination invariedgeomorphic units, lineaments structure and land-forms which oversee the condition of presence of water underneath the earth-surface are provided. Employed remote-sensing and GIS techniques to identify potential areas for groundwater in the Musi-basin by the use of various maps (these include hydro-geomorphological, structural, geological, slope, drainage, land use or land cover and slope. Other investigators that have used remotely-sensed data to carry out groundwater investigations either as stand-alone or as integrated techniquewith other geophysical techniques include Edet et al. (1994), Batalan and De Smedt (2000), Valeriano et al. (2006), Wright et al.(2006), Grohmann et al. (2007) and Sultan et al. (2017). The use of remotely sensed data in hydrogeological investigation has been able to provide complementary information about the subsurface of an area before borehole can be drilled (Goki et al. 2010; Anudu et al. 2011; Omeje et al., 2014; Sultan et al., 2017).

Due to the influx of people into study area (Iju – Ota community area of Ado-Odo/Ota Local Government Area, Ogun State),basic necessities of life (such as water) has been a concern as a result of uneven distribution of water in this zone. Inadequate water supply to the communities has been epileptic due to the inability of the government to meet demand of water resources needed by this ever-growing community as a result of absolute reliance on surface water. Therefore, the search for groundwater resource as a complimentary is needed in the community in order to meet the demand of water resources for domestic purposes and other related usages. Application of both Vertical Electrical Sounding (VES) and Shuttle Radar Topography Mission (SRTM) on this terrain will aid the mapping of groundwater potential system inIju – Ota community, which will be insightful for borehole drilling. In addition, extracted lineaments from satellite imagery will aid the choice of VES point selection within the study area, such that these fracture traces will be the prospects for hydrogeophysical mapping in Iju – Ota community. Although some studies have reported significant deviations between the traced lineaments and the major fracture systems in some regions (Acharya et al., 2012; Acharya and Mallik, 2011; De'gnan and Clark, 2002), integration of geophysical method (such as electrical resistivity method) with satellite imagery for groundwater exploration will assist one to locate the correct point that is suitable for groundwater exploitation (Omeje et al., 2014; Dafalla et al., 2015; Anbazhagan and Jothibasu, 2016). This present study, therefore, employed the integration ofSRTM and VES with the aim to accurately investigate groundwater potential zones in an inter-bedded area (conglomerates of sedimentary and shallow basement rocks) such as Iju – Ota community in Ogun State, in order to address the inadequate water supply being experienced in the area.

2. Geological and hydrogeology settings of the study area

The study region is generally a gently sloping low-lying area. It falls within the eastern Dahomey (or Benin) Basin of southwestern Nigeria which stretches along the continental margin of the Gulf of Guinea. The groundwater occurrence, movement and accumulation are chiefly controlled by geology. The geologic factors that control the groundwater system are stratigraphy, petrography, thickness, geomorphology and structure (Adagunodo, 2017). The local geology of Iju – Ota axis lies within the sedimentary rock sequence of Dahomey Basin which extends from the eastern part of Ghana through Togo and Benin Republic to the western margin of the Niger Delta (Onuoha, 1999) (Figure 1). The sequence arrangement of the local geology underlain by the study area is as follows: Recent Alluvium (Quaternary age) which trends towards south-east, east south and central part of the study area and formed a boundary with Coastal Plain Sands in the west. This formation is followed by Coastal Plain Sands (Tertiary age – Pliocene) which is located in the west, south-west and eastern part of the study area and also formed boundary with Ilaro Formation in the north-west. Ilaro Formation (Tertiary age - Eocene) overlays both Coastal Plain Sands and Recent Alluvium and formed boundary with Ewekoro Formation/OshosunFormation/Akinbo Formation. This formation cut across north-west to north-east of the study area. This geological formation is followed by Ewekoro Formation/Oshosun Formation/Akinbo Formation (Cretaceous – Paleocene). It cutsacross north-north to north-east trend. The last geological formation which underliesEwekoro Formation is Abeokuta Formation which is Cretaceous age (Senonia) and this formation formed boundary with Basement Complex in the north and Ewekoro Formation in the north-east (Omatsola and Adegoke, 1981). The Hydrogeology of Dahomey basin comprises Ogun River and Owena basin. The tectonic structure of the basin is simple, forming a monocline against the basement outcrop to the North, with only little evidence of faulting (Joel et al., 2019b). The area is characterized by two major climatic seasons, namely:dry season spanning from November to March and rainy (or wet) season between April and October. Occasional rainfalls are usually witnessed within the dry season, particularly along the region adjoining the coast. Mean annual rainfall is greater than 2000 mm and forms the major source of groundwater recharge in the area.

3. Material and methods

3.1. Shuttle Radar Topography Mission (SRTM)

The Shuttle Radar Topography Mission (SRTM) is an international research effort that obtains digital elevation models on a near-global scale from 56°S to 60°N to generate the most complete high-resolution digital topographic database of the Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during the 11-day STS-99 mission in February 2000 using older Space-borne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR). To acquire topographic data, the SRTM payload was outfitted with two radar antennas. One antenna was located in the Shuttle's payload bay, the other – a critical change from the SIR-C/X-SAR, allowing single-pass interferometry – on the end of a 60-meter (200-foot) mast that extended from the payload bay once the Shuttle was in space. The technique employed is known as interferometric synthetic aperture radar. The elevation models are arranged into tiles, each covering one degree of latitude and one degree of longitude, named according to their southwestern corners. The resolution of the raw data is one arcsecond (30 m along the equator) and coverage includes Africa, Europe, North America, South America, Asia, and Australia. The elevation models derived from the SRTM data are used in geographic information systems and can tell how the surface of Earth changes due to the actions of glaciers, rivers and the processes.

The SRTM, a pass of single interferometer mission flown on February 2000, with generated Digital Elevation Model (DEM) data at 90 m of resolution, which is 80% of surface of the earth in C-band is presented in Figure 2. The shuttle radar topography mission digital elevation model data were obtained from the archives of United State Geological Survey Agency (http://www.cgiar-csi. Org/data/srtm-90m-digital-elevation-database-v4-1). The extracted data are within the longitude 3° 00′ to
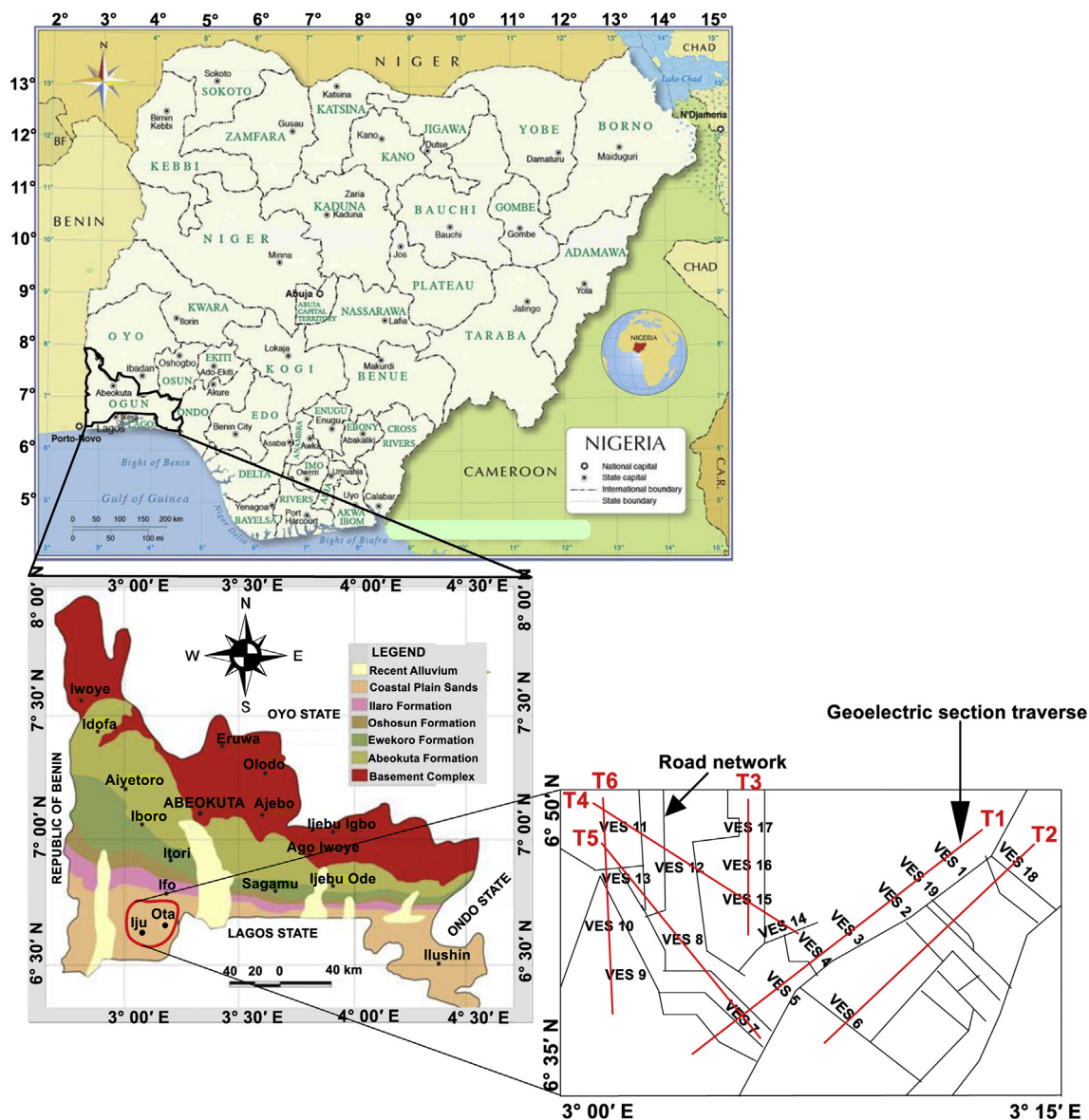
Figure 1. Map of Nigeria showing the geological map, base map and VES points in Iju – Ota axis.

3° 30′ E and latitude 6° 30′ to 7° 00′ N. These data were subjected to hill-shading using Idrisi 32 software to enhance the linear features that could be the major regional fractures (Valeriano et al., 2006). The analytical hill shaded result was used to create the hill-shadingimage with the Sun azimuth angle set to 315° (NW) and the Sun elevation angle set at 30° as reported inAnudu et al. (2011) and Omeje et al. (2014). The lineaments and its orientations were digitized on-screen using GEOrient 9.5.0 software.

3.2. Vertical Electrical Sounding

In this investigative study, nineteen (19) resistivity soundings were carried out both in NE –SW and NW – SE orientations, where lineaments were concentrated and interconnected (Lattman and Parizek, 1964; Acharya et al., 2012) as shown in Figures 5a and b. ABEM 4000 series equipment was used and this computes and displays mean apparent resistivity for the electrode configurations of choice. As adopted by other authors (Sunmonu et al., 2012; Adagunodo et al. 2017, 2018; Oyeyemi et al., 2018),Schlumberger Array was used for
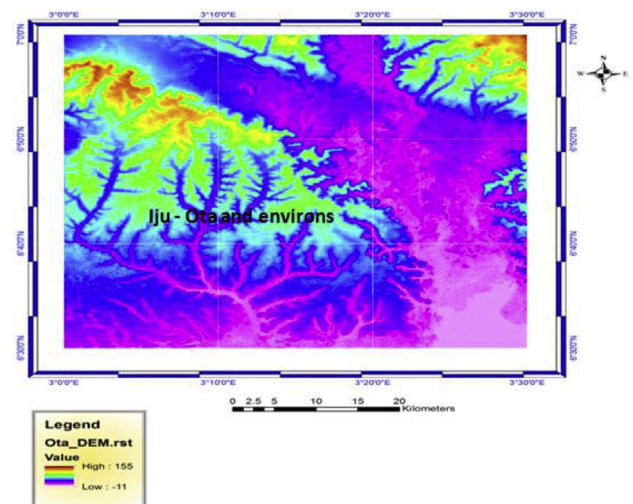

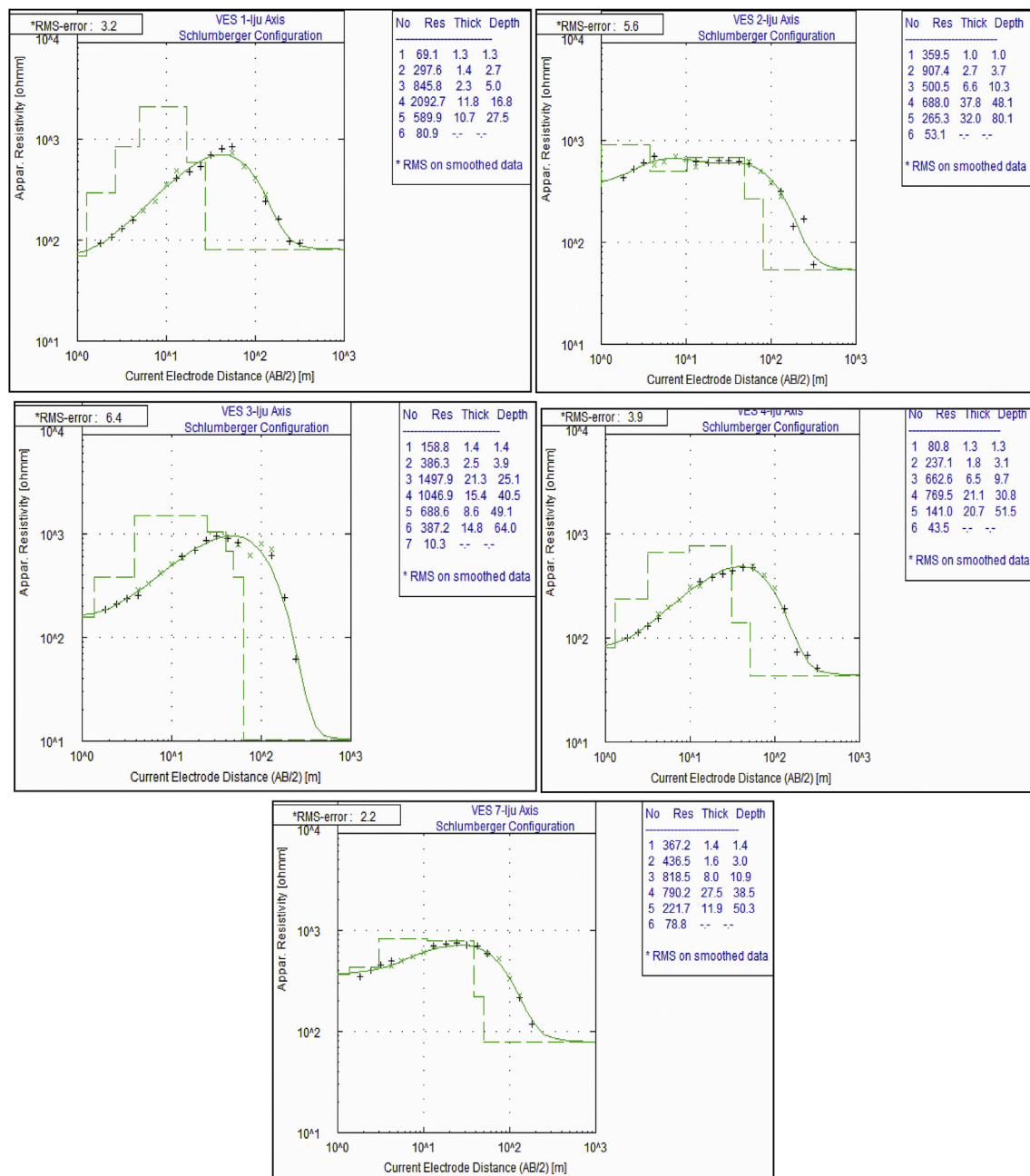**Figure 2.** Digital Elevation Model showing the watershed of Iju area.

Figure 3. Some of the VES curve types obtained in Iju – Ota axis (VESs 1 to 4 and VES 7).

the present study with current electrode spacing that ranged from 180 to 320 m.

The obtained data were manually plotted using log-log graph. An automated iterative program (1D inversion algorithm) known as Win-Resist version 1.0 software was used to model the partial curve matching results (Aizebeokhai and Oyebanjo, 2013; Adagunodo et al., 2015), which greatly minimized the interpretation errors (Sunmonu et al. 2012, 2016; Adagunodo et al., 2017). The major VES curve types obtained in this study are presented in Figure 3.

4. Results and discussions

4.1. Interpretation of SRTM (digital elevation model) data

The SRTM data extracted from Hill shaded digital elevation model and Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) software was used to infer the detailed hydrogeological features that control the groundwater system in the area. The purpose of using SRTM is to acquire possible knowledge of surficial features such as topographic information and/or lineaments, which could have originated as a result of joints, foliation, fractures, faults and other subsurface features (Wright et al., 2006; Anudu et al., 2011) in some parts of the study area. Understanding of these surficial features prior to localized geophysical survey(s) could enhance proper identification of suitable site for development of productive wells, corresponding to the zones of deformation in the subsurface (Akinluyi et al., 2018). Figure 2 presents the hydrogeological near-surface feature (in watershed form) of the study area. The watershed presented on the DEM is capable of revealing shallow underground tributaries, based on the relationship between the surficial and subsurface features (Valeriano et al., 2006; Zandbergen, 2008). The total numbers of lineaments extracted and digitized were fifty-eight (58) as revealed in Figure 4. The lineament map is presented in Figure 5a, while the map revealing the lineaments and the VES points is presented in Figure 5b. By comparing Figures 2,5a and b, the lineaments
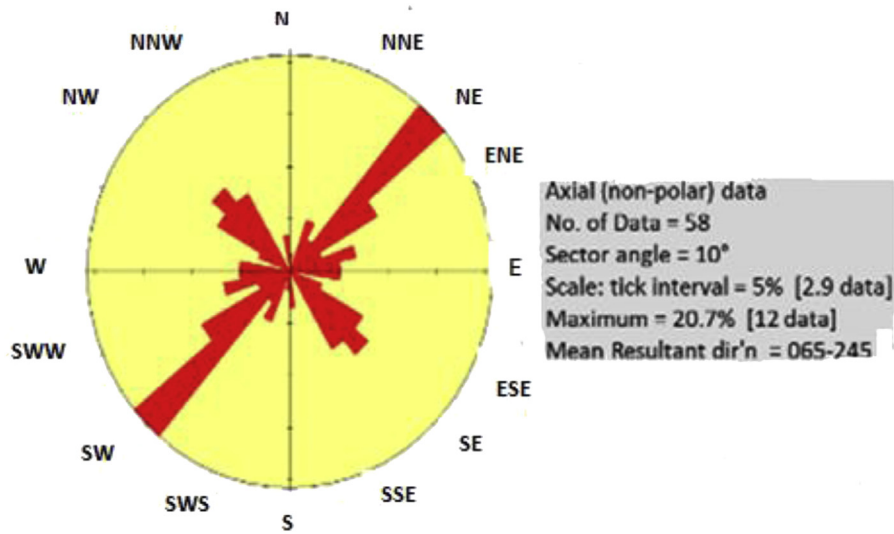
Figure 4. Lineament orientation with strikes in NE – SW and NW – SE directions.
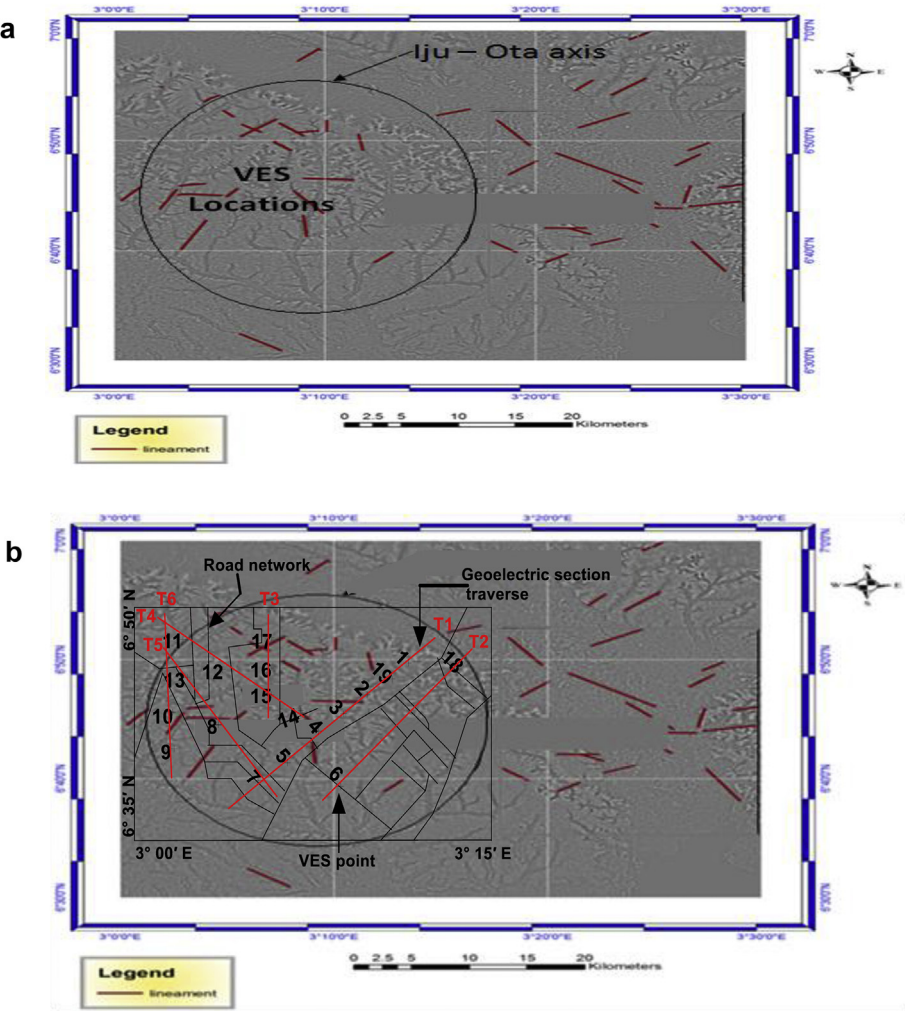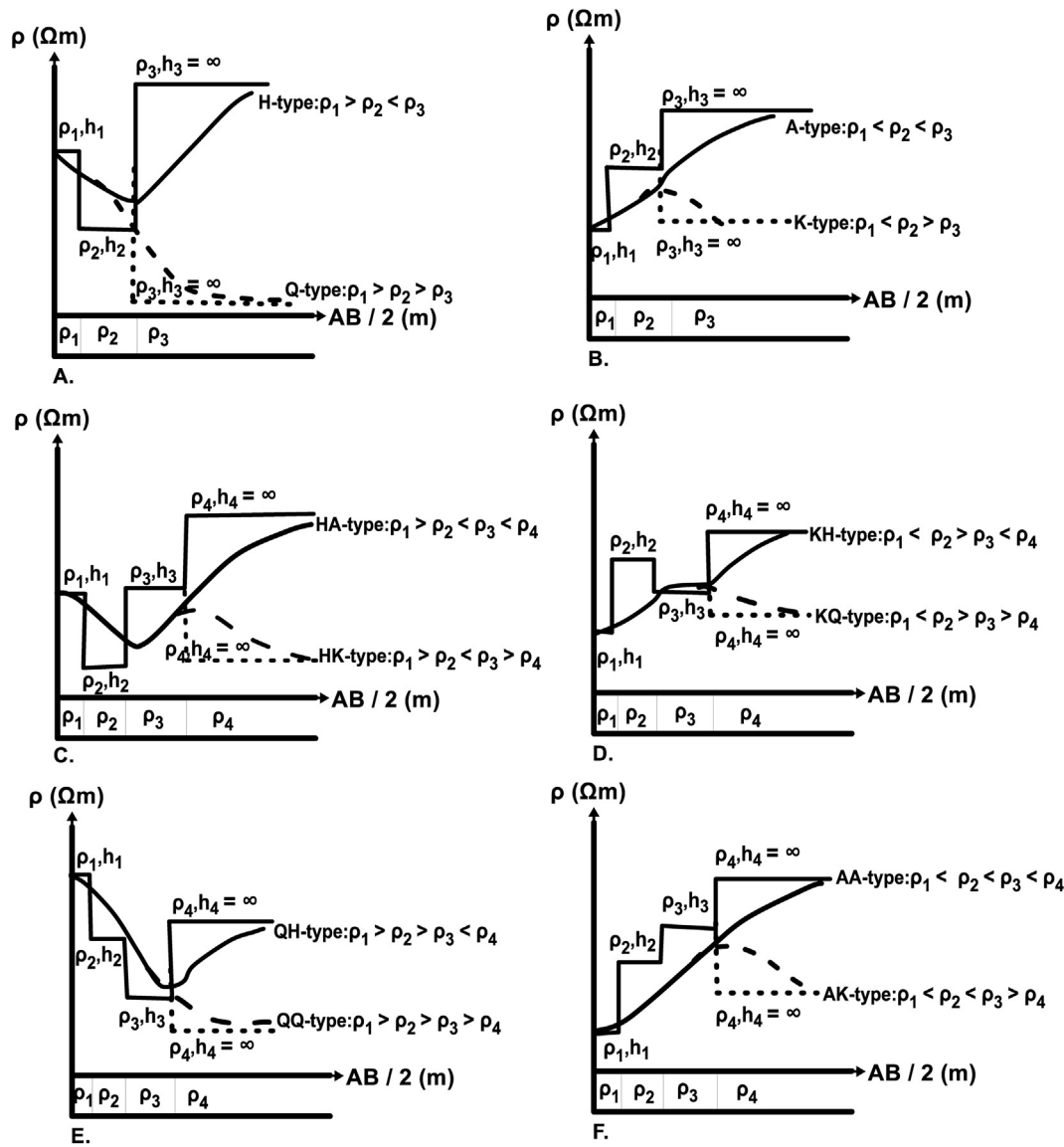

Figure 5. a: Lineament map of the study area. b: Map of lineaments with VES points.

Figure 6. VES curve types. (A) H- and Q-type. (B) A- and K-type. (C) HA- and HK-type. (D) QH- and QQ-type. (E) KH- and KQ-type. (F) AA-and AK-type. Source: Sunmonu et al. (2015).

are concentrated and interconnected both at the eastern and the westernparts of the study area. It was observed further that some of the lineaments wereinterconnected; signifying that the groundwater system inIju – Ota is chiefly controlled by fractures (Edet et al., 1994). In the western and eastern parts of the study area, a dominance of groundwater channels reflects the high concentration of lineaments which suggests the zones of high groundwater potential (Grohmann et al., 2007; Anudu et al., 2011; Omeje et al., 2014). The extracted lineaments were used to produce the lineaments' orientations, which are presented in Figure 4. The orientations of the lineaments trend inNE – SW and NW – SE directions. This suggests that groundwater potential could be very high along thelineaments (Edet et al., 1994; Valeriano et al., 2006; Wright et al., 2006; Omeje et al., 2014).

4.2. Vertical Electrical Sounding (VES) data interpretation

The lithological layers were named and classified based on the resistivity contrasts among the layers, as classified by Keller and Frischnecht (1970), Sunmonu et al. (2015), Sunmonu et al. (2016), and Kure

et al. (2017). The most common and basic classification of the resistivity curve in Precambrian basement terrain belongs to the three-layer type. This type reveals that three (3) different resistivity values (ρ_1, ρ_2 and ρ_3) correspond to three lithological variation in the subsurface. Three-layer geo-sounding curves are fundamentally grouped into four (4) categories:

   i. Minimum type: When $\rho_1 > \rho_2 < \rho_3$. This is referred to as H-type (associated with the name of Hummel).

   ii. Double-ascending type: When $\rho_1 < \rho_2 < \rho_3$. This is also known as A-type (corresponding to term anisotropy).

   iii. Maximum type: When $\rho_1 < \rho_2 > \rho_3$. This is known as K-type or is sometimes referred to as DA-type (meaning displaced or modified anisotropy).

   iv. Double descending type: When $\rho_1 > \rho_2 > \rho_3$. This is known as Q-type and is sometimes referred to as DH-type (meaning displaced Hummel or modified Hummel). Figures 6a and b showed the diagrammatical representations of all these type curves for the three-layer cases.

Table 1. Resistivity sounding classifications.

| Curve type	VES point	Curve frequency	Curve model	Model percentage
AAKQ	1, 4 and 5	3	$\rho_1 < \rho_2 < \rho_3 < \rho_4 > \rho_5 > \rho_6$	15.8%
KHKQ	2, 8, 10, 12 and 18	5	$\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 > \rho_6$	26.3%
AKQQ	3, 6, 9, 14, 15, 16, 17 and 19	8	$\rho_1 < \rho_2 < \rho_3 > \rho_4 > \rho_5 > \rho_6$	42.1%
KHAK	7 and 11	2	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5 > \rho_6$	10.5%
QHKQ	13	1	$\rho_1 > \rho_2 > \rho_3 < \rho_4 > \rho_5 > \rho_6$	5.3%

Table 2. Lithological characterization of Iju –Ota axis.

Layers	1			2			3			4			5			Shale/Clay
Lith.	Topsoil			Lateritic clay			Clayey sand			Mudstone			Sand (main aquifer)			
VES	Res. (Ωm)	h (m)	D (m)	Res. (Ωm)	h (m)	D (m)	Res. (Ωm)	h (m)	D (m)	Res. (Ωm)	h (m)	D (m)	Res. (Ωm)	h (m)	D (m)	Res. (Ωm)
1	69.1	1.3	1.3	297.6	1.4	2.7	845.8	2.3	5.0	2092.7	11.8	16.8	589.9	10.7	27.5	80.9
2	359.5	1.0	1.0	907.4	2.7	3.7	500.5	6.6	10.3	688.0	37.8	48.1	265.3	32.0	80.1	53.1
3	158.8	1.4	1.4	386.3	2.5	3.9	1497.9	21.3	25.1	1046.9	15.4	40.5	688.6	8.6	49.1	387.2
4	80.8	1.3	1.3	237.1	1.8	3.1	662.6	6.5	9.7	769.5	21.1	30.8	141.0	20.7	51.5	43.5
5	304.7	1.1	1.1	602.7	4.6	5.7	637.3	3.0	8.8	2203.9	15.8	24.6	172.0	19.6	44.2	27.9
6	367.2	1.4	1.4	436.6	1.6	3.0	818.5	8.0	10.9	790.2	27.5	38.5	221.7	11.9	50.3	78.8
7	54.8	0.9	0.9	443.4	2.1	3.0	263.7	6.8	9.8	762.6	11.3	21.1	1250.8	18.7	39.7	463.1
8	514.2	1.6	1.6	764.4	2.5	4.1	417.0	7.1	11.2	1194.8	25.7	36.9	241.7	15.9	52.8	7.3
9	93.1	1.1	1.1	483.2	2.0	3.1	660.5	5.7	8.7	574.7	30.8	39.5	218.7	24.7	64.2	42.1
10	191.5	1.1	1.1	783.0	2.6	3.7	404.8	7.2	11.0	1849.1	22.5	33.4	438.3	16.1	49.5	30.9
11	195.3	1.2	1.2	597.9	2.4	3.6	312.3	4.7	8.2	595.4	6.3	14.6	1931.6	23.2	37.8	504.2
12	237.3	1.5	1.5	482.5	3.3	4.8	453.8	6.6	11.4	888.6	29.5	40.9	837.7	22.7	63.5	107.4
13	636.0	1.5	1.5	510.7	3.4	5.0	496.1	1.8	6.8	1183.5	5.1	11.9	1786.3	25.7	37.6	53.9
14	166.4	1.5	1.5	194.9	2.5	4.1	893.6	6.7	10.7	763.9	18.5	29.2	505.8	19.5	48.6	77.2
15	302.1	1.7	1.7	506.7	3.1	4.8	743.9	8.8	13.6	556.6	36.9	50.5	530.1	26.9	77.4	7.6
16	126.8	1.1	1.1	522.0	2.1	3.2	1244.5	15.9	19.1	447.4	15.5	34.6	186.6	15.5	50.1	83.6
17	79.5	1.0	1.0	526.3	7.4	8.6	1317.5	19.7	28.2	561.6	8.7	37.0	251.2	14.2	51.2	19.6
18	273.1	1.0	1.0	925.5	2.9	4.0	908.3	4.9	8.9	1902.9	14.1	23.0	234.2	14.3	37.4	53.1
19	224.1	1.3	1.3	1375.4	6.6	7.9	1564.4	14.2	22.1	582.4	15.3	37.4	192.1	17.1	54.5	28.8

Note: Lith. = Lithology, Res. = Resistivity, h = Thickness, D = Depth.

However, in sedimentary basin, more than three-layered lithological settings (such as four, five-layer curves and so on) corresponding to multiple curve types could be achievable. For example, in order to classify a 4-layered resistivity curve, its classification can be done by analyzing the first 3 resistivity values (ρ_1, ρ_2 and ρ_3) and the last three resistivity values (ρ_2, ρ_3 and ρ_4), such that eight (8) categories of four-layered curves (that is, HA, HK, AA, AK, KH, KQ, QH, and QQ) are possible as shown in Figures 6c, d, e, f. Further classifications can be done using this basic approach as documented by Patra and Nath (1999) and Sunmonu et al. (2015). Five (5) different curve types were identified in the study area, which are AAKQ-curve, KHKQ-curve, AKQQ-curve, KHAK-curve, and QHKQ-curve types (Table 1). The percentage distribution of the curve types in the order of appearance from the curve types are as follow: 15.8% are of AAKQ-type, 26.3% are of KHKQ-type, 42.1% are of AKQQ-type, 10.5% are of KHAK-type, and 5.3% are of QHKQ-type respectively. Classification of the VESs to their respective types, curve models and their frequencies are summarized in Table 1. The interpretation of geoelectrical results revealed six lithological layers in the study area such as topsoil, lateritic clay, clayey sand, mudstone, sand (main aquifer) and shale or clay as shown in Table 2 in accordance to the interpretation of Oyeyemi et al. (2018). Because of the unavailability of borehole data due to the practising system of groundwater withdrawal (hand-dug well) in the study area, these lithological distribution was inferred based on the comparison with the local geology of Iju and Ota respectively. The first layer which is topsoil has resistivity values ranging from 69.1 to 636.0 Ωm with mean value of 233.4 Ωm, while the thickness varies from 0.9 to 1.7 m. Most times, the resistivity value of first layer always depends on the volume of clay content of the moisture and its compaction degree level (Aizebeokhai et al., 2016). The layer underlain by topsoil is lateritic clay, with resistivity values ranging from 237.1 to 1375.4 Ωm with average value of 550.4 Ωm and varying thickness of about 1.4–6.6 m. Beneaththe lateritic clay is clayey sand with mean value of 770.7 Ωm which is continuous laterally from second layer. The resistivity value of this layer ranges from 263.7 to 1564.4 Ωm, with a thickness of about 2.3–19.7 m. Both second and third layers have different degree of water saturation and compaction, which are impermeable, most especially area where percolation are poor as a result of compaction. These layers once a while always form parched aquifer and as a result the areas experience flooding (Aizebeokhai et al., 2016). Fourth layer is underlain by mudstone and is highly resistive. This was delineated to have resistivity value that ranged from 447.4 to 2203.9 Ωm, with average value of 1023.9 Ωm and thickness that varies from 5.1 to 37.8 m. High resistivity value was observed in this layer and could be attributed to intercalation of phosphate of metamorphic and magmatic flow. Underneath this layer is sand which is found to be the main aquifer with resistivity value that ranges from 141.0 to 1931.6 Ωm and mean value of 562.3 Ωm while the thickness varies from 8.6 to 26.9 m, respectively. The fifth layer delineated is the main aquifer that consists of unconsolidated grain sand, which is coarse in nature. Underneath the aquifer layer is shale or clay with resistivity values that fluctuated from 7.3 to 504. 2 Ωm.
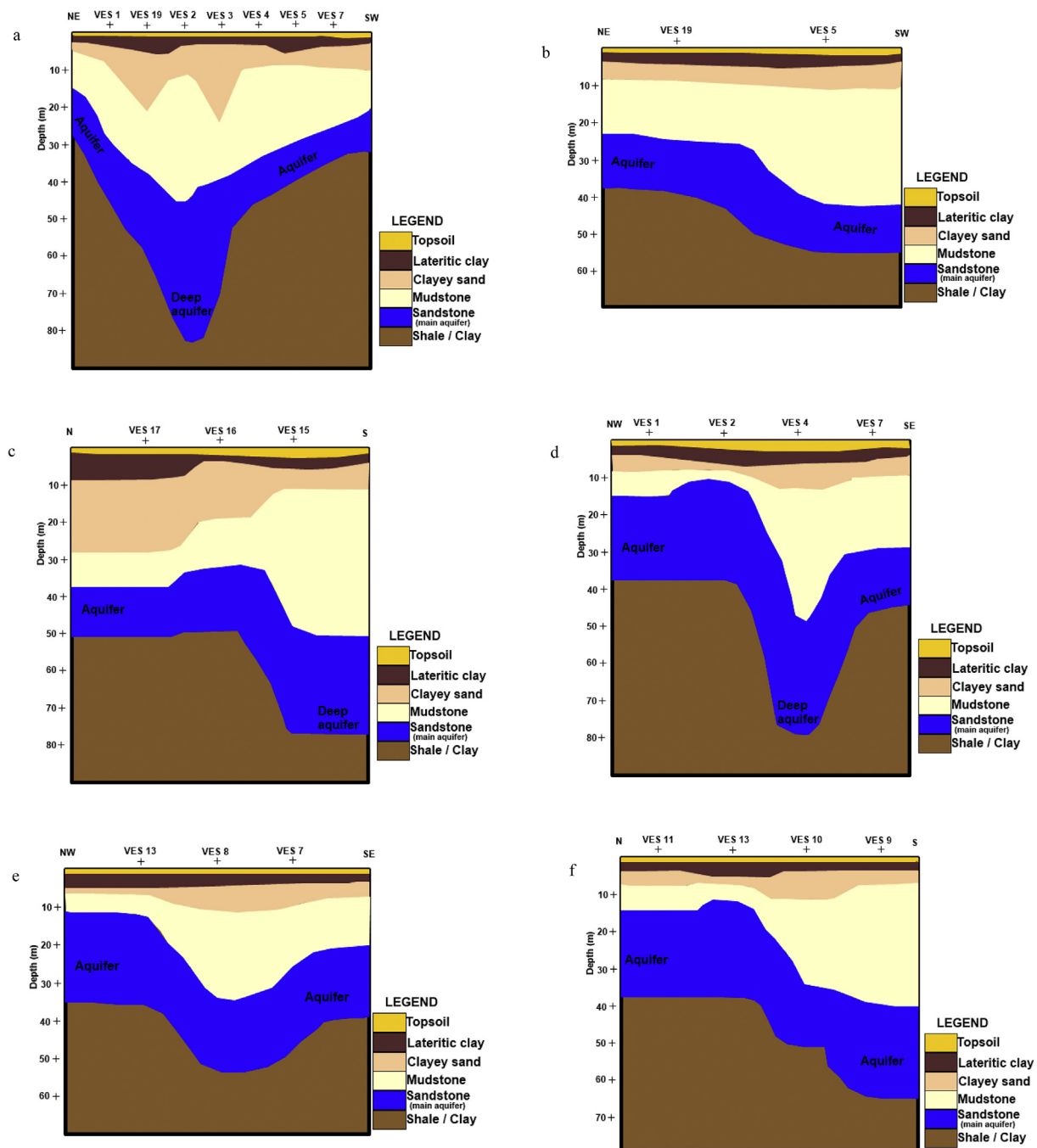
Figure 7. a. Geoelectric section of traverse 1. b. Geoelectric section of traverse 2. c. Geoelectric section of traverse 3. d. Geoelectric section of traverse 4. e. Geoelectric section of traverse 5. f. Geoelectric section of traverse 6.

4.2.1. Geoelectric section

The result presented showed the geospatial features of the subsurface layers according to their depths and stations. The geoelectric sections of six traverses, as revealed on Figures 1 and 5b were plotted in order to map the depth to the main aquifer (Figures 7a, b, c, d, e, f). The importance of geoelectric sections is to map the variations of geoelectrical parameters along a linear path (Adagunodo et al. 2015, 2017; Sunmonu et al., 2015, 2016; Raji and Adeoye, 2017). The six traverses were grouped as follow: traverse 1 contained VESs 1, 19, 2, 3, 4, 5 and 7 in NE – SW direction, traverse 2 contained VESs 18 and 6 in NE – SW direction, traverse 3 contained VESs 17, 16 and 15 in N – S direction, traverse 4 contained VESs 11, 13, 15 and 14 in NW – SE direction, traverse 5

contained VESs 13, 8 and 7 in NW – SE direction, and traverse 6 contained VESs 11, 13, 10 and 9 in NS direction. Each traverse was chosen according to how the two-dimensional (2D) signatures of the subsurface variations can be imaged conveniently (Adagunodo et al., 2017). The 2D imaging is also capable of revealing both lateral and vertical variations within the subsurface. The top of the main aquifer in the study area fluctuates from 11.9 to 50.5 m while the aquifer bottom fluctuates from 27.5 to 80.1 m. This reveals that the depth to the main aquifer in Iju and Ota is approximately 25.0 m. The aquifer thickness varies from point to point with minimum thickness of about 8.6 m and maximum thickness of 32.0 m. The thickness of the aquifer in Iju and Ota community is a result

of the fractures (lineaments) that are interconnected, which will definitely result to good yield at this depth.

Traverse 1 revealed that aquifer may be reached at depth of 28.0 m for VES 1, for VES 19 the depth to the aquifer ranged between 35.0 m and 55.0 m, as well as VES 3. But at VES 2, the depth to the aquifer is between 50.0 m and 80.0 m while is 40.0 m at VES 4 and VES 5 and 35.0 m at VES 7 respectively in the NE-SW direction (Figure 7a)Transverse 2 showed the variations in the aquifer to be between 28.0 m and 50.0 m in NE-SW direction (Figure 7b). Transverse 3 in the N–S direction further revealed the thickness of aquifer towards the southern part of the study area to be approximately 30.0 m thick and the depth to reach the aquifer in thatorientationranged between 40.0 m and 80.0 m (Figure 7c). Transverse 4 in the NW-SE direction unfolds the depth to the aquifer that ranged between 20.0 m and 80.0 m with deep aquifer observed at VES 4 (Figure 7d) while transverse 5 revealed similar trend but at the depth to the aquifer that ranged between 20.0 m and 50.0 m with observed thick overburden (Figure 7e). Also transverse 6 discloses the trend of the aquifer to be N-S direction at the depth thatvaried between 20.0 m and 60.0 m at VES 11, VES 13, VES 10 and VES 9 respectively (Figure 7f).

5. Conclusions

The lineaments and the production of the rose diagram indicate the trend of the structural features that control the groundwater system in the area which invariably suggests high groundwater potential of the study area, where water can be tapped and served for long period of time. Resistivity technique (geoelectric section) revealed good aquiferous features with variation in depths of about 25.0 m–80 m for a good yield in the study area. The use of resistivity technique and SRTM for hydrogeological investigation revealed significant subsurface features of a better groundwater characterization in the study area. Significantly, the combinations of these two techniques serve a better scientific idea for undisclosed nature of groundwater featuresin sedimentary terrain where fractures are buried in the subsurface. It is therefore recommended that thickness of aquifers should be determined from geo-electric studies before recommending the drilling locations in the study area.

Declarations

Author contribution statement

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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