Assessment of groundwater yield potential in Ekiti East Local Government Area, Southwestern Nigeria

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Received: 11 January 2020 / Accepted: 28 May 2020 / Published online: 6 June 2020
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Abstract

This study presents the categorization of Ekiti East Local Government Area into different groundwater potential zones with a view to reducing incessant boreholes failures and providing sufficient water to meet domestic and agricultural requirements of people in the area. To achieve this objective, 35 locations were sounded using the Schlumberger electrode array. Data obtained from the vertical electrical soundings (VES) were interpreted quantitatively by partial curve matching and 1-D computer iteration to facilitate the selection of an appropriate boreholes location. Thirty-five boreholes were subsequently drilled, and their yields were obtained during pumping test. Synthesizing the geo-electric parameters with the yields of the boreholes, the yield potential map was produced using Surfer 12 software. The VES survey revealed six geo-electric layers including the topsoil (44–1024 Ωm , 0.3–1.7 m), clay (26–494 Ωm , 0.9–30.8 m), laterites (353–1782 Ωm , 0.7–7.7 m), weathered zone–clayey soil (8.9–260 Ωm , 1.4–24.8 m), fractured layer (5.2–929 Ωm , 4.6–11.8 m) and fresh basement with resistivity that ranges from 474 to 77,144 Ωm and undeterminable depth. The bulk of groundwater was localized in the weathered and fractured layers due to availability of pores spaces arising from weathering and fracturing. Long-range in resistivity values especially in the topsoil was due to variation in soil's composition and differential response to lithification. Two main rock units (migmatite gneiss and fine-grained granite) played major role in the groundwater occurrence of the study area. Thick weathered overburden developed more easily on migmatite gneiss than fine-grained granite. Aquifer yield map classified the study area into low (Eda Ile-Ekiti and Isinbode-Ekiti), medium (Omoo Oke-Ekiti) and high (Ilasa-Ekiti, Ikun/Araromi-Ekiti, Omoo-Ekiti and Kota-Ekiti) yield groundwater potential zones. Low to high groundwater zones cut across migmatite gneiss terrain with about 60% representation of high groundwater potential, indicating the mixed character of the rock. Fine-grained granite had only low groundwater potential coverage. Thus, lithology played a major role in the groundwater occurrence of the study area with terrain covered by fine-grained granite mainly in the low groundwater potential zone. The zones with high yield potential have been deciphered to serve as possible area for the future groundwater development and for choosing the drilling sites.

Keywords Boreholes · Geo-electric layers · Yield · Lithology · Fresh basement

1 Introduction

Ekiti East Local Government is one of the most populous local governments in Ekiti State Nigeria. Surface water and groundwater are the two main sources of water for domestic and agricultural activities in the area. The surface water often dries off during dry season putting people in the

study area into difficulty with respect to water especially for domestic uses. In addition, the surface water when available is prone to contamination from anthropogenic activities. People have to seek for alternative source(s) of water in which groundwater is readily represented. Groundwater is comparatively safer since it is located in the subsurface of the earth, and there is no direct contact

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with surface activities. However, the available fresh water in form of groundwater useful for drinking and agricultural activities is limited in quantity.

Ekiti East Local Government Area is located on basement terrain which generally has problems of groundwater supply due to the crystalline nature of the underlying rocks which lack primary porosity and permeability. Such rocks can only serve as aquifer when fractured and/or deeply weathered [1]. Groundwater occurrence in the study area is complex and erratic. Groundwater development in form of boreholes/wells requires pre-drilling sound scientific geophysical and hydrogeological investigations to avoid boreholes failure which is prevalent in the area [2]. Therefore, there is the need to categorize the area into different groundwater potential zones to guide future drillers and researchers that may want to work in the area. Groundwater yield and hydrodynamic activities in basement areas depend on depth of weathering and intensity of fracturing of the underlying rocks. The discontinuous nature of the basement aquifer systems makes detailed knowledge and application of the geological, hydrogeological and geophysical investigations inevitable in the search for groundwater [3–6]. Many researchers [7–12] have contributed significantly to groundwater potential evaluations in basement terrains. Study carried out at the basement terrain of Challenge and Oluyole in Ibadan Southwestern Nigeria with the aim of delineating the area into different groundwater potential zones using resistivity depth soundings [13] revealed that the areas with thick overburden are priority areas for possible groundwater development. Also, research work on the investigation of the influence of lineaments, lineament intersections and geology on groundwater yield in the basement complex terrain of Ondo State, Southwestern Nigeria [12] concluded that borehole data located on or near lineaments or at intersection of lineaments gave higher yields more than those located before lineaments or outside lineaments, while quartz schist and quartzite exhibited the highest average groundwater yield of all the lithological units. Research by [14] on the “Groundwater Potential of Basement Aquifers in Part of Southwestern Nigeria” revealed that groundwater development is most promising in areas where thick overburden is complemented with the presence of fractures.

Data acquired during groundwater exploration have been useful with respect to subsequent planning and management of groundwater [15, 16]. In addition, well yield parameters have been employed in groundwater potential characterization [17, 18]. The evaluation of groundwater productivity is largely based on the availability of well yield parameters [19, 20]. Groundwater being one of the most valuable natural resources vital for the sustenance of life on earth, it becomes expedient to explore

for its occurrence in the complex rocks of the earth. To make a reliable prediction of where groundwater occurs, a number of techniques have been applied [21–23]. Among the geophysical techniques (seismic, gravity, ground penetrating radar, electrical resistivity), the electrical resistivity method has been found to be most useful/effective and economical in deciphering groundwater occurrence into groundwater potential zones [24]. The method has been employed to determine the thickness of bedrock, clay aquitards, the vertical extent of certain types of soil and the spread of groundwater contamination [25, 26].

Aquifer parameters (yield, transmissivity, storability and hydraulic conductivity) are usually obtained during borehole pumping test. Such parameters can be synthesized to obtain useful decisions concerning aquifers [27]. Main focus of exploration for groundwater is to guarantee good sustainable groundwater development. To achieve this goal, integration of aquifer parameters determined from vertical electrical soundings and pumping test is essential. Subsurface lithologies, their resistivities, thicknesses and structures are highlighted from the geophysical survey. Pumping test involves pumping water from a test well at a constant rate and measuring the water depth over a given time. Yield of aquiferous layer is estimated during this test [28, 29].

There is no functional scheme for water supply by government, and there is little or no information with regard to scientific-based exploration for groundwater in the study area. This study, therefore aimed at categorizing Ekiti East Local Government Area into different groundwater potential zones by synthesizing aquifer parameters obtained from electrical resistivity survey with yields obtained from drilled boreholes. The categorization will reduce the rate of borehole failures and provides a guide for sustainable groundwater development in the area.

2 Location/geology and hydrogeology of the study area

The study was carried out in Ekiti East Local Government Area, Southwestern Nigeria. The area is located within latitude 7°40'58" N, 7°48'10" N and longitudes 5°37'32" E, 5°45'12" E (Fig. 1). Existing road network and interconnected minor roads and footpaths provide access to towns and villages within the study area. The area witnesses two major seasons (rainy and dry) yearly. The rainy season covers a period that commences in March and ends in November, while the dry season is between ending of November and early March. The area has an annual rainfall of 1500 mm, high relative humidity (70–85%) and an average annual temperature of 28 °C. Geologically, the study area is an Archean–Early Proterozoic basement complex

The figure is a geological map of Ekiti State, Nigeria. It includes an inset map of Nigeria showing the location of Ekiti State. The main map shows the state's boundary in red. The legend indicates:

- Borehole Location: Red diamond with a number.
- Town: Black square.
- Migmatite gneiss: Tan color.
- Fine grain granite: Light green color.
- Inferred geologic boundary: Dashed line.

 The map shows several towns: Ilasa-Ekiti, Ikun/Araromi-Ekiti, Kota-Ekiti, Omuo Oke-Ekiti, Omuo_Ekiti, Eda Ile_Ekiti, and Isinbode-Ekiti. Numerous borehole locations are marked with numbers (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35). The map also shows a dashed line representing an inferred geologic boundary and a scale bar from 0 to 1100 M. A north arrow is present in the bottom right corner.

Vertical electrical sounding (VES) was carried out in 35 locations using the Schlumberger electrode array. The VES technique was used because of its appropriateness in searching for groundwater occurrence [36]. Moreover, the method is simpler and more economical than other

geophysical methods. It reveals the general geological subsurface structure and bedrock topography [37]. At each location, geographical positions (coordinates) were measured using Magellan eXplorist Hand held GPS. An ABEM SAS 1000 Terrameter was used to obtain the apparent resistivity at each VES location. Field data obtained from the survey were plotted on the log–log paper manually and subsequently subjected to partial curve matching. The model obtained from the partial curve matching was employed for computer aided iteration to obtain the true resistivity and thickness of the subsurface layers. Geo-electric sections were plotted employing traverses A–A', B–B', C–C', D–D', E–E' and F–F' (Fig. 1). Pumping tests were carried out in 35 boreholes drilled in the sounding locations using the single well pumping test approach. The focus here is to obtain the yield of each borehole. Therefore, a container of known volume was used to collect the pumped water. Subsequently, water discharge (Q) was calculated with respect to time. Specifically, in this study, yield of each borehole was calculated using a calibrated 20-L container. The 20-L container was filled with water during pumping with time required to fill it noted. The specific yield was subsequently estimated by dividing the volume of water in the container by the time. The container was filled with water three times at different intervals of 60 min, 120 min and 180 min. Average yield was subsequently computed. The aquifer yield potential map of the area was subsequently produced by synthesizing obtained geo-electric parameters with the yields of the boreholes using Surfer 12 software.

4 Results

Result of the geographical coordinates of the 35 sounding locations/drilled boreholes in this study is presented in Table 1. The elevation ranged from 450 to 573 m with an average of 530 m indicating a fairly high area. Other results are presented in form of geo-electric table (Table 2), representative resistivity curves (Fig. 2) and geo-electric sections (Figs. 3, 4, 5, 6, 7).

4.1 Geo-electric sections

The 2-D geo-electric sections (GES) across the VES points were developed from the resistivity curves and thickness parameters generated from the depth sounding curves which correlated to the sounding points within the study area. Six (6) GES were generated including GES A–A' (Ilasa-Ekiti), GES B–B' (Omulo Oke-Ekiti), GES C–C' (Kota-Ekiti), GES D–D' (Omulo-Ekiti), GES E–E' (Eda Ile-Ekiti), and GES F–F' (Isinbode-Ekiti) (Table 2, Figs. 3, 4, 5, 6, 7, 8).

4.1.1 Geo-electric section A–A' (Ilasa-Ekiti)

The geo-electric section A–A' (Ilasa-Ekiti) (Fig. 3) revealed six subsurface layers; topsoil, clay, laterite, weathered, fractured basement and fresh basement. The topsoil thickness is relatively thin along these sections. The range of resistivity and thickness values for the topsoil are 118–396 Ω m and 0.8–1 m, respectively, which indicate that the predominant composition of the topsoil is loamy soil. Clay was encountered in VES 1 and 33. The resistivity ranged from 250 to 331 Ω m, while the thickness ranged between 20 and 3.2 m. Laterite was encountered only in VES1 and the resistivity and thickness values were 1782 Ω m and 0.7 m, respectively. Naturally, soils of different types have different resistivity values due to variation in composition, structure, water content and temperature. Electrical conductivity of laterite increases with moisture content [38]. The high resistivity noted in this study is due to lateralization process during which the soil is leached leaving only oxides of iron and aluminum which harden when exposed to air.

Weathered basement was encountered in VES31 and 33. The resistivity and thickness values for the weathered basement ranged from 62.2 to 89.0 Ω m and 11.8–10 m, respectively, indicative of aquiferous layer. Fracture basement was revealed in VES33 with resistivity values of 142–94 Ω m and thickness of 1.7 m. The differences in degree of fracturing resulted into varied resistivity values. Fresh Basement was observed in VES1 and 31 with high resistivity values that ranged from 3216 to 1960 Ω m indicating dry layer zone.

4.1.2 Geo-electric section B–B' (Omulo Oke-Ekiti)

The geo-electric section along traverse B–B' (Omulo Oke-Ekiti) is presented in Fig. 4. The resistivity values of topsoil ranged from 67–307 Ω m, while thickness was between 0.2 and 1 m in this section. The resistivity values revealed that the predominant compositions of the topsoil are clay and loamy soil. The variations in the composition of topsoil resulted to wide variation of resistivity values. Clay was encountered in VES 5, 6, 7 and 9. The range of the resistivity and thickness values for the clay were 126–313 Ω m and 13 m–1.2 m, respectively. The variation in resistivity values is as a result of differences in water content of the porous media. The layer is porous but not permeable enough and serves as aquitard.

Laterite was encountered in VES 5 and 6 in this section, and the range of resistivity and thickness values were 859–1750 Ω m and 1.3–7.7 m with high resistivity values as a result of leaching during lateralization. The layer is an aquiclude with little or no groundwater occurrence.

Table 1 Boreholes location/yields

Borehole VES/No	Locations	Northing	Easting	Elev. (m)	Yield (L/s)	Overburden thickness (m)
BH1/VES1	St John Ang. Pry Sch, Ilasa-Ekiti	7.8007	5.6881	514	1.43	21.1
BH2/VES2	St Anthony Cath. Pry Sch., Ilasa-Ekiti	7.8028	5.6820	498	1.14	23.7
BH3/VES3	Basic Health Center, Kota- Ekiti	7.7663	5.7221	521	1.22	35
BH4/VES4	A.U.D Pry Sch, Kota-Ekiti	7.7696	5.7200	540	1.2	23.7
BH5/VES5	Methodist Pry Sch, Kota-Ekiti	7.7584	5.7260	557	1.28	15
BH6/VES6	Comprehensive Health Center, Kota-Ekiti	7.7609	5.7334	553	1.3	22.2
BH7/VES7	A.U.D Pry Sch, Omuo Oke-Ekiti	7.7674	5.7423	553	1.08	22.1
BH8/VES8	St Paul's Ang Pry Sch, Omuo Oke-Ekiti	7.7653	5.7466	544	1.04	24.3
BH9/VES9	Muslim Comm Pry Sch, Omuo Oke-Ekiti	7.7714	5.7535	543	0.72	16.7
BH10/VES10	ECWA Pry Sch, Omuo Oke-Ekiti	7.7708	5.7466	539	0.81	14.6
BH11/VES11	St Anthony Pry Sch, Omuo Oke-Ekiti	7.7624	5.7420	546	1.12	21.2
BH12/VES12	C.A.C Pry Sch, Ilisa-Qtrs, Omuo-Ekiti	7.7335	5.7251	559	1.13	14.1
BH13/VES13	Comprehensive Health Center, Ilisa-Qtrs. Omuo-Ekiti	7.7329	5.7258	558	1.18	18.4
BH14/VES14	Methodist Pry Sch, Ilisa-Qtrs, Omuo-Ekiti	7.7299	5.7226	573	0.96	13
BH15/VES15	Moses Orimolade Pry Sch, Ilisa-Qtrs, Omuo- Ekiti	7.7312	5.7262	562	0.98	7.0
BH16/VES16	Westley United Pry Sch, Iworo-Qtrs. Omuo-Ekiti	7.7311	5.7261	561	0.44	23.1
BH17/VES17	Basic Health Center, Iworo-Qtrs, Omuo-Ekiti	7.7223	5.7218	559	0.67	9.4
BH18/VES18	Comm. Pry Sch, Iworo-Qtrs, Omuo-Ekiti	7.7221	5.7205	533	0.39	3.5
BH19/VES19	A.U.D Pry Sch, Iludofin-Qtrs, Omuo-Ekiti	7.7410	5.7195	558	1.1	8.3
BH20/VES20	St Mary Pry Sch, Iludofin-Qtrs, Omuo-Ekiti	7.7365	5.7210	540	1.05	28.5
BH21/VES21	St Andrew Pry Sch, Iludofin-Qtrs, Omuo-Ekiti	7.7377	5.7163	567	0.97	11.9
BH22/VES22	Basic Health Center, Eda-Ile	7.7420	5.6423	547	0.81	9.9
BH23/VES23	Basic Health Center, Isinbode-Ekiti	7.6826	5.6256	450	0.41	11.3
BH24/VES24	Comprehensive Health Center, Isinbode-Ekiti	7.6844	5.6301	451	0.63	17
BH25/VES25	Ireopodun C/S Pry.Sch. Isinbode-Ekiti	7.6861	5.6265	487	0.40	4.7
BH26/VES26	St Anthony Cath Pry Sch. Isinbode-Ekiti	7.6886	5.6314	498	0.38	13.2
BH27/VES27	AUD Pry Sch. Isinbode-Ekiti	7.6869	5.6408	482	0.39	12.6
BH28/VES28	St Paul Ang Pry. Sch. Eda Ile-Ekiti	7.7506	5.6433	557	0.7	10.6
BH29/VES29	St Augustine Cath Church. Eda-Ile	7.7519	5.6408	556	0.41	5.4
BH30/VES30	St Luke Ang.Pry Sch. Ikun/Araromi	7.7936	5.7228	489	1.06	32.5
BH31/VES31	St Phillip Pry Sch. Ilasa	7.8033	5.6858	496	1.11	14.4
BH32/VES32	Amos Ayeni Memorial Pry Sch	7.8144	5.6847	485	1.11	16.4
BH33/VES33	Market Square	7.8053	5.6850	487	1.05	17.3
BH34/VES34	St pilot pry sch Kota-Ekiti	7.7637	5.7259	553	1.06	28.2
BH35/VES35	Comm. Pry sch Oke Bola, Omuo Oke	7.7728	5.7367	551	0.94	36.5

Sand/clay was encountered in VES 7 and 9 and the range of resistivity and thickness values were 236–260 Ω m and 15–20 m, respectively. It is characterized as good aquiferous layer because it was highly saturated with water. Variation in porosity and permeability of the layer resulted to different values of resistivity.

Weathered layer was encountered in this geo-electric section in VES31 and 33. Resistivity and thickness values for the weathered basement being 10–78 Ω m and 16.8 m, respectively. Variation in resistivity values was due to differential weathering and variation in water

content of the layer with low resistivity indicating high degree of water saturation, while high resistivity value implies low degree of water saturation. This zone constitutes the aquiferous layer with relatively high degree of water saturation.

Fractured basement was delineated in this section in VES6 with the resistivity value of 494 Ω m and thickness of 11 m. The fractures served as conduit for passage of water. Fresh basement was shown in VES9 with the high resistivity value of 755 Ω m which indicated dry layer.

Table 2 Geo-electric sections' data from the study area

Borehole	Topsoil		Clay		Laterite		Sandy clay		Weathered Layer		Fracture Layer		Fresh basement
	Ωm	m	Ωm	m	Ωm	m	Ωm	m	Ωm	m	Ωm	m	Ωm
<i>Geo-electric section A–A' (Ilasa-Ekiti)</i>													
BH1	117.8	0.8	250	20	1781.5	0.7	–	–	–	–	–	–	3216
BH31	396	1	331	3.2	–	–	–	–	89.1	10	–	–	1960
BH33	125	0.3	–	–	–	–	–	–	62.4	3.5	142	–	–
									66.2	11.8	194	1.7	
<i>Geo-electric section B–B' (Omuo Oke-Ekiti)</i>													
BH5	307	0.8	313	13	1750	1.3	–	–	78	–	–	–	–
BH6	185	1	77	2.7	859	7.7	–	–	62	–	494	11	–
BH7	67	0.2	148	2	–	–	236	20	10	–	–	–	–
BH9	298	0.5	126	1.2	–	–	260	15	–	–	–	–	755
<i>Geo-electric section C–C' (Kota-Ekiti)</i>													
BH34	80	0.4	280	3.4	–	–	–	–	60	20	–	–	–
			150	4.6					23	–			
BH3	61	0.5	136	6.3	768	1.8	–	–	48	26	–	–	–
									5	–			
BH4	55	0.9	42	6	–	–	–	–	33	17	139	–	–
<i>Geo-electric section D–D' (Omuo-Ekiti)</i>													
BH15	83	0.5	212	1.4	857	6			66	5	–	–	5651
BH12	143	0.7	282	4	–	–			62	9	494	11	–
BH20	–	–	226	0.6	–	–			58	20	159	8	
BH19	44	0.4	369	0.9	–	–			29	1.7	–	–	3513
									41	5			
<i>Geo-electric Section E–E' (Eda Ile-Ekiti)</i>													
BH29	–	–	265	0.6	539	2			16.9	2.8	–	–	662.3
BH28	44	0.5	–	–	–	–			19	2	–	–	1215
									87	9			
BH22	56	0.5	–	–	–	–			26	3	352	6	
									5		221	8	
<i>Geo-electric Section F–F' (Isinbode-Ekiti)</i>													
BH23	99	0.4	–	–	–	–	–	–	–	–	929	–	9765
BH25	174	0.5	52	3	–	–	–	–	9	1.4	476	–	
BH26	–	–	265	4.1	702	0.5	289	1.3	156	7.4			1533

4.1.3 Geo-electric section C–C' (Kota-Ekiti)

Figure 5 reveals the variations in resistivity and thickness values of the layers across the geo-electric section C–C' (Kota-Ekiti). The observed subsurface layers were topsoil, clay, laterite, weathered and fractured basement. The thickness of the topsoil is relatively thin along this section. The resistivity and thickness values of the topsoil are 55–80 Ωm and 0.4–0.9 m, respectively. The predominant composition of the topsoil is sand. This zone does not support groundwater accumulation due to low thickness value. Clay was encountered in VES 34, 3 and 4. The range of the resistivity and thickness values for the clay were 42–280 Ωm and 3.4–6.3 m, respectively. This

layer was porous but partially permeable. The differential hardness resulted to numerous resistivity values.

Laterite was encountered only in VES3 in this section. The resistivity and thickness values were 768 Ωm and 1.8 m, respectively. The high resistivity value occurred due to hardness of the layer after the soil has been leached which resulted to poor support for groundwater occurrence.

Weathered basement was encountered in this geo-electric section in VES34; VES3 and VES4 with resistivity and thickness values of 5–60 Ωm and 17–26 m, respectively. Differential weathering and variation in water contents account for varied resistivity values where low resistivity values imply high degree of weathering, while

Fig. 2 Samples of geo-electric curves from the study area

Fig. 3 Geo-electric section A–A' (Ilasa-Ekiti)

Fig. 4 Geo-electric section B–B' (Omuo Oke-Ekiti)

Fig. 5 Geo-electric section C–C' (Kota-Ekiti)

high resistivity values imply low degree of weathering. Fracture basement was revealed in VES4 with resistivity value of 139 Ω m while thickness could not be delineated in the geo-electric section. The thickness could not be delineated because of limited spread of the Schlumberger array.

4.1.4 Geo-electric section D–D' (Omuo-Ekiti)

Figure 6 shows the range of variations of resistivity and thickness values of layers within the depth penetrated in this geo-electric section (Omuo-Ekiti). Generally, the section revealed six subsurface layers: topsoil, clay, laterite,

Fig. 6 Geo-electric section D–D' (Omuo-Ekiti) **Fig. 7** Geo-electric section E–E' (Eda Ile-Ekiti) **Fig. 8** Geo-electric Section F–F' (Isinbode-Ekiti)

weathered, fractured basement and the presumed fresh basement. The topsoil was predominantly loamy soil with resistivity and thickness values that ranged from 44 to 143 Ω m and 0.4–0.7 m, respectively. Clay was encountered in VES 15, 12, 20 and 19. The range of the resistivity and thickness values for the clay were 212–389 Ω m and 0.6–4 m, respectively.

Laterite was encountered only in VES15, and it has resistivity and thickness values of 857 Ω m and 6 m. High hardness of the laterite was responsible for high resistivity value of the layer.

Weathered layer was encountered across this section in VES 15, 12, 20 and 19 with the range of resistivity and thickness values of 29–66 Ω m and 5–20 m, respectively. Fractured basement was revealed in this section in VES12 and 20 with the range of resistivity values of 159–494 Ω m and thickness of 8–11 m, respectively.

Fresh basement was shown in all the VES stations across this geo-electric section with high range of resistivity values of 3513–5651 Ω m which signified dry layer.

4.1.5 Geo-electric section E–E' (Eda Ile-Ekiti)

Figure 7 represents geo-electric section E–E' (Eda Ile-Ekiti). The subsurface layers were topsoil, clay, laterite, weathered, fractured basement and the fresh basement. The topsoil is predominantly loamy soil with resistivity and thickness values of 44–56 Ωm and 0.4–0.7 m, respectively. Clay was encountered in VES5 28 and 29. The resistivity of the clay was 265 Ωm , while the thickness ranged from 0.5 to 4 m. Laterite was only encountered in VES29, and it has resistivity and thickness values of 539 Ωm and 2 m.

The weathered layer revealed in VES 22, 28 and 29 had resistivity and thickness values that ranged from 5 to 87 Ωm and 2–9 m, respectively. The water content of this layer is slightly high because it is porous. Fracture basement was revealed in this section in VES22 with the range of resistivity values of 221–352 Ωm and thickness of 6–8 m, respectively. Variation of fracturing resulted to varied water content and subsequently different resistivity values. Fresh basement was shown in VES28 and 29 with the high range of resistivity values of 1215–6623 Ωm which indicated dry layer.

4.1.6 Geo-electric section F–F' (Isinbode-Ekiti)

Figure 8 is the geo-electric section F–F' (Isinbode-Ekiti) that delineated six subsurface layers; topsoil, clay, sandy clay, weathered, fractured basement and the fresh basement. The topsoil layer is not thick in this section. Resistivity and thickness values for the topsoil ranged from 99 to 174 Ωm and 0.4–0.5 m, respectively, indicating predominantly loamy and sandy soil. Clay, with resistivity that ranged from 52 to 265 Ωm and thickness of 3–4.1 m, respectively, was encountered in VES23, 25 and 26.

Sandy clay with distinct resistivity of 289 Ωm and thickness of 1.3 m was encountered in VES 26. Weathered layer that has resistivity and thickness values of 9 to 156 Ωm and 1.4–7.4 m, respectively, was encountered in VES 25 and 26. This layer was the aquiferous layer, and its viability was enhanced by the overlying sandy clay layer that serves as aquiclude.

Fractured basement was revealed in VES23 and 25. The resistivity of the fractured basement ranged from 476 to 929 Ωm . The layer may be aquiferous in view of the fractures that serve as conduits to recharge water from rainfall. Fresh basement with high resistivity that ranged from 1533 to 9765 Ωm was revealed in VES23 and 26, respectively. This layer serves as aquifuge as it was non porous and non permeable.

Geo-electric sections of the Ekiti East Local Government Area were produced to show possible aquiferous layers in the study area. In addition, resistivity and thickness values were integrated to predict groundwater occurrence of the

study area. Generally, all topsoils in the geo-electric sections had varied resistivity values due to variation in soil composition and moisture content, while varied resistivity in weathered zones was due to differential weathering and varied water saturation of the layer in response to geology of the sounding locations.

4.2 Characterization of the study area into different groundwater potential zones

It is necessary to understand the different yield potential of geologic formations in order to categorize their groundwater occurrence. Yield signifies an aquifer's ability to release groundwater, and it is the volume of water released from storage during pumping. The yield represents the amount of dewatered material in a cone of depression during pumping test [39].

The yield of an aquifer is less than its porosity due to capillary retention as not all water drains from the pore spaces during abstraction. The retained water is referred to as specific retention. Estimated yield for each of the borehole is presented in Table 2. The yield map (Fig. 9) classified the study area into low yield zone (0–0.64 L/s), medium yield (0.65–0.94 L/s) and high yield zone (0.95–1.45 L/s). The yield map designates Ilasa-Ekiti, Ikun/Araromi-Ekiti, Omuo-Ekiti and Kota-Ekiti as the high groundwater potential zones, while Omuo Oke-Ekiti is in the medium groundwater yield. The low yield zone comprises Eda Ile-Ekiti and Isinbode-Ekiti areas.

5 Discussion

Two major rock units (migmatite gneiss and fine grain granite) cover the study area. The two rocks respond to weathering differently, and this has resulted in the uneven topography with varied elevations. Fine grain granite (intrusive igneous rock) is harder than migmatite gneiss that has been metamorphosed and subjected to different thermo-tectonic events. Thus, it becomes obvious that area covered by the fine-grained granite may have low groundwater occurrence. Furthermore, 4–6 geo-electric layers were observed in the study area. The first geo-electric layer representing the topsoil is very thin in most of the sections.

Thin layer of this type is prone to contamination from anthropogenic activity and dangerous to groundwater quality [34, 39]. The wide range of resistivity values (44–396 Ωm) of topsoil in this study occurred as a result of variation in soil composition and its moisture content. The research of [40] revealed that only topsoils with resistivity values in excess of 200 Ωm are practically non-corrosive which support the assertion that the soil in this study is

Fig. 9 Groundwater yield map of the study area

corrosive as over 80% of the topsoil layers have resistivity $< 200 \Omega\text{m}$. The geo-electric sections succinctly revealed the weathered layer and fractured zone as the main aquifer in the study area.

This submission is in agreement with some previous research work on basement terrains [5, 8, 17]. By visual inspection, the aquifer yield classification map (Fig. 9) showed that Isinbode-Ekiti (fine-grained granite terrain) and Eda Ile-Ekiti (migmatite gneiss terrain) covering 30% of the study had low groundwater potential compared to the high groundwater potential zone (Kota-Ekiti, Ilasa-Ekiti, Ikun/Araromi-Ekiti, Omuo-Ekiti) with 60% representation located on migmatite gneiss terrain. The remaining 10% (Omuo Oke-Ekiti) still on migmatite gneiss terrain belongs to the medium groundwater potential zone. The erratic occurrence of groundwater in the study area is due mostly to distribution of rocks in the area. However, migmatite gneiss being a mixed rock (heterogeneous rock

composing of intermingled metamorphic and igneous components) exhibits unpredictable characteristics which explains why all the three groundwater potential zones occur on migmatite gneiss terrain. The fine grain granite at Isinbode-Ekiti had only low groundwater potential.

6 Conclusion

Thirty-five sounding locations as well as drilled boreholes were occupied to assess subsurface hydrogeological conditions with a view to categorizing Ekiti East Local Government Area into different groundwater potential zones.

The quantitative computer assisted VES interpretation as well as the geo-electric sections revealed six layers in the subsurface including topsoil, clay, laterite, weathered layer, fractured layer and fresh basement with different resistivity and thickness values. Lithological variations/

differential weathering and fracturing of the layers are responsible for the wide variation of resistivity values. Topsoil, clay and laterite delineated across the study area have non to limited groundwater occurrence. Bulk of groundwater resides in the weathered and fractured layers. Fresh basement layer constitutes an aquifuge with high resistivity values. The aquifer yield classification map categorized the area into low, medium and high yield groundwater potential zones. Ilesa-Ekiti, Ikun/Araromi-Ekiti, Omuo-Ekiti and Kota-Ekiti were categorized as the high groundwater potential zones, while Omuo Oke-Ekiti is in the medium groundwater yield. The low yield zone comprises Eda Ile-Ekiti and Isinbode-Ekiti areas.

Lithology played a major role in the groundwater occurrence of the study area with areas covered by fine-grained granite mainly in low groundwater potential zone. The zones with high yield potential have been deciphered to serve as possible area for the future groundwater development and for choosing the drilling sites.

Acknowledgements We acknowledge with thanks; Mr. Ojo, Abayomi Amos, who participated in the data acquisition of this manuscript.

Compliance with ethical standards

Conflict of interest We the authors hereby declare that we have no conflict of interest.

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