British Journal of Applied Science & Technology
18(2): 1-16, 2016; Article no.BJAST.29608
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN ***international***
www.sciencedomain.org

Groundwater Assessment and Aquifer Vulnerability Studies of Emure Ile, Southwestern Nigeria

O. O. Falowo[1*] and O. O. Ojo[1]

[1]Department of Civil Engineering Technology, Faculty of Engineering Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author OOF designed the study. Both authors managed the literature searches and data analyses. Author OOO managed the experimental processes and wrote the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/29608
Editor(s):
(1) Jakub Kostecki, Department of Civil and Environmental Engineering, University of Zielona Góra, Poland.
(2) Harry E. Ruda, Stan Meek Chair Professor in Nanotechnology, University of Toronto, Director, Centre for Advanced Nanotechnology, University of Toronto, Canada.
Reviewers:
(1) Boufekane Abdelmadjid, Higher National School of Hydraulics, Algeria.
(2) Fouepe Takounjou Alain, Hydrological Research Centre, Cameroon.
Complete Peer review History: http://www.sciencedomain.org/review-history/17130

Original Research Article

Received 20th September 2016
Accepted 20th October 2016
Published 5th December 2016

ABSTRACT

Hydrogeological studies and groundwater flow of Emure Ile located in the crystalline basement area of Emure, near Owo, Southwestern Nigeria, has been done. The local geology of the area is predominantly granite-gneiss and migmatite. Hydrogeological measurements were determined from twenty eight existing non-flowing wells across the area. The measurements were used to compute the thickness of the water column/vadose zone, static water level, and hydraulic head of the wells across the area. The hydraulic head measurements were used to develop the groundwater flow model for the area. A total of twenty depth sounding data were acquired using Schlumberger array and presented as sounding curves. The groundwater flow model map shows that groundwater flow is towards the west – east direction representing the central part of the town. The thickness of the water columns/vadose water (average of 2.6 m) and total depth of the wells (average of 5.4 m) are generally low and shallow. The depth to groundwater (water table) ranges from 2.6 m to 4.7 m, with a modal range of 1 – 3 m suggesting a thin vadose zone. Based on DRASTIC index rating, the vadose zone thickness generally fall within high vulnerability rating, aptly suggesting that the aquifer

---

*Corresponding author: E-mail: solageo@yahoo.co.uk;

in the area is significantly vulnerable to contaminants deriving from anthropogenic sources. This result corroborates the deduction from the overburden protective map. The interpreted sounding curves revealed three distinct geoelectric layers overlying the resistive basement, the topsoil, the weathered layer and the partially weathered/fractured basement. The unconfined weathered layer is the main aquifer unit in the area, with resistivity ranging from 7 to 101 Ohm-m suggestive of sandy-clay; and thickness ranging from 2.0 to 84.9 but generally less than 20 m. Therefore combining all the results, the best groundwater development areas with less vulnerability to contamination are found in northwest - southwest parts which constitute for about 30% of the area. However, the groundwater potential of the area is generally low.

Keywords: Flow direction; groundwater; vulnerability; protective capacity; hydrogeological measurement; drastic index.

1. INTRODUCTION

Man greatly depends on water for both domestic and industrial use. It is assumed water covers almost seventy five percent (75%) of the earth's surface. Underground and surface water usually constitute the main sources of water in many hydrological setting. Underground water is held within the pore spaces, fractures and weathered regoliths of rocks. It is believed that this kind of water is protected from contamination primarily because the movement of groundwater through the pore spaces offers a natural sieving mechanism which significantly reduces the quantity of pollutants that the water can carry [1].

However, the availability of quality water resources has always been the primary concern of societies in semi arid and arid regions, even in areas of more abundant rainfall, the problem of obtaining adequate supply of quality water is generally becoming more acute due to ever increasing population and industrialization. As a result of this, surface water cannot be dependable throughout the year, hence, the need to look for other alternatives to supplement surface water.

This makes the world depend on the largest available source of quality fresh water which lies underground and this is referred to as Groundwater. It is the water held in the subsurface within the zone of saturation under hydrostatic pressure below water table [2]. The research for groundwater today has become essential, due to its relative low cost and its chance of obtaining quality water from the bedrock [3].

Therefore, the application of geophysics to the successful exploration of groundwater in the Basement Complex requires a proper understanding of its hydro-geological characteristics. Evidence has shown that geophysical methods are the most reliable and the most accurate means of all surveying method of subsurface structural investigations and rock variation [4,5].

Several methods employed in groundwater exploration include electrical resistivity, gravity, seismic, magnetic, remote sensing, electromagnetic, among others, out of which the resistivity method is the most effective for locating productive well and the Vertical Electrical Sounding (VES) technique can provide information on the vertical variation in the resistivity of the ground with depth and the Constant Separation Traversing (CST) provides a means of determining interval variation in the resistivity of the ground [6,7,8].

The concept of aquifer vulnerability derives from the assumption that the physical geomaterials may provide some level of protection to groundwater, especially with regard to pollutants entering the subsurface [9]. Consequently, the lithologic variations and thickness of the unsaturated zone (vadose zone) which determines the inaccessibility of the underlying aquifer units [10] constitute the focus in aquifer vulnerability assessments.

In view of the above the electrical resistivity method was combined with topography mapping and static water measurement in delineating probable aquiferous zone(s) favourable for groundwater accumulation in Emure-Ile town. The town has become a residential “estate” for many staff of Rufus Giwa Polytechnic, Owo, and Federal Medical Centre, Owo. It is located just 1 km away from Owo metropolis (Fig. 1). Therefore due to recent development taking shape in the town, availability of quality water resources has now become the primary concern of the inhabitants of the town.

2. DESCRIPTION OF THE PROJECT ENVIRONMENT

2.1 Geographic Location, Physiographic Features and Drainage

Emure Ile town, the study area is located within Ondo State (Fig. 1), Southwestern Nigeria. It lies within Latitudes 07° 00' and 07° 30'N and Longitudes 05°15' and 05°45'E. The surrounding topography is gently undulating with gently rising isolated hills attaining heights of over 350 m, whereas the intervening topographic lows are about 300 m (Fig. 2).

Geographically, the area is within the rainforest belt of hot and wet equatorial climatic region, which is characterized by long wet season (April to October) and a short dry season (November to March). The mean temperature range is between 24℃ to 27℃. The range of mean annual rainfall varies from 1000 to 1500 mm [11]. Ajangbasa streams and Aboludo streams which are tributaries of Ogbese river drain the area. Ajangbasa stream flows in southwest direction and Aboludo stream flows zig-zagly in the East – West trend joining Ajangbasa stream.

The area is underlain by mainly migmatites and granite gneiss (Fig. 3) which are mostly concealed by the unconsolidated basement regolith in the area.

The migmatite consist of biotite gneiss, granite, and gneiss as members. The granite is weakly foliated and appears to have resulted from granitization of biotite gneiss and gneiss members. The gneiss in the migmatite has well developed leucocratic/melanocratic banding.

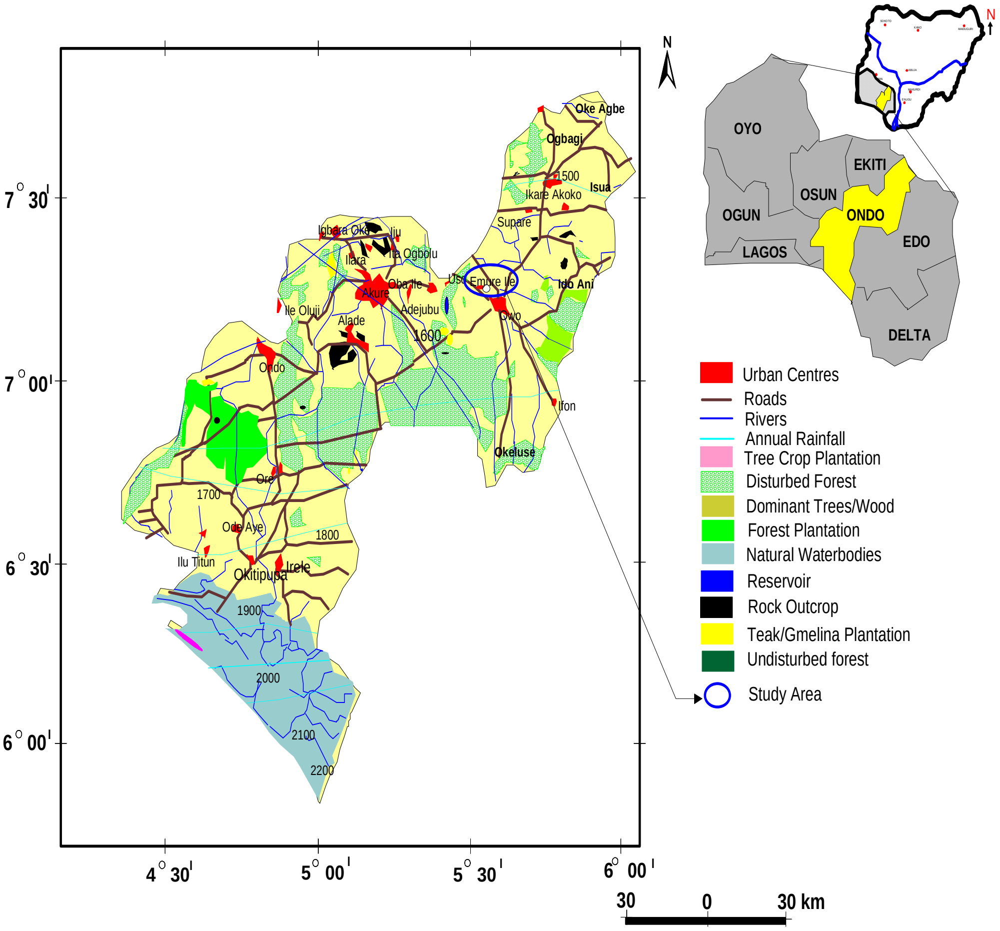


Fig. 1. Land use map of Ondo state showing the study area

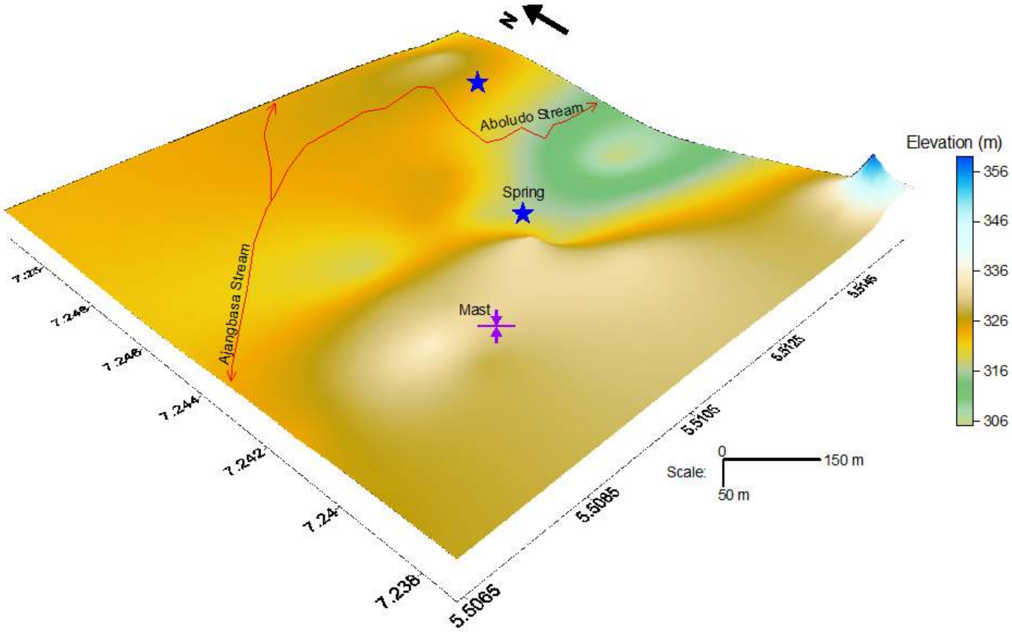


Fig. 2. Topographical map of the study area

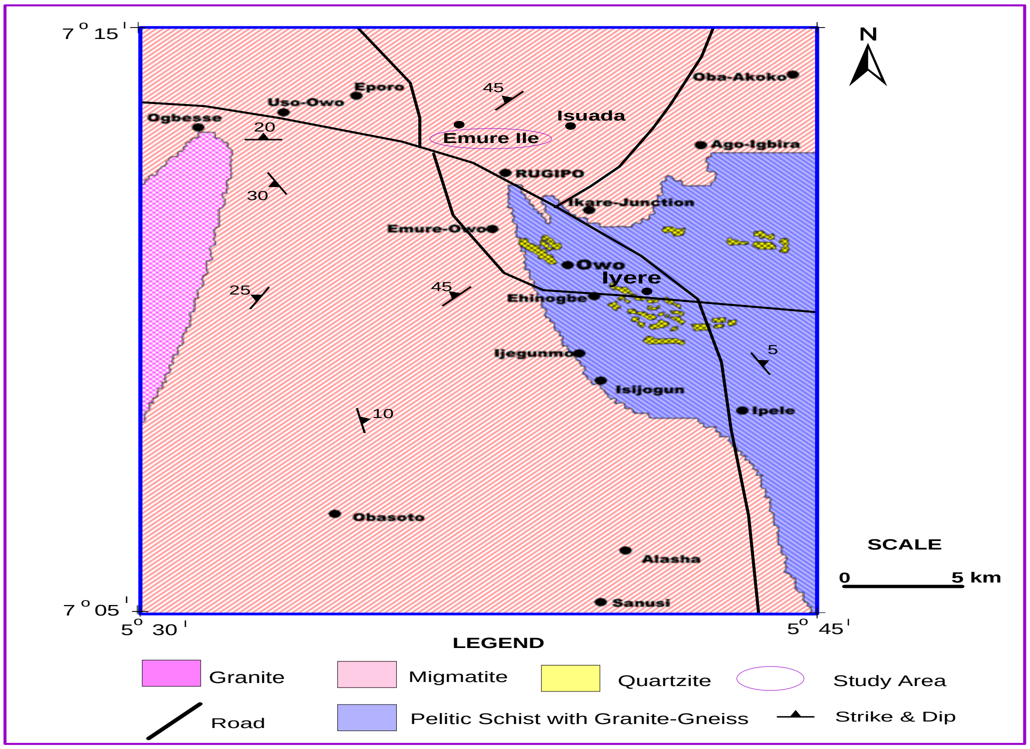


Fig. 3. Geological map of the study area

The vegetation is characterized by thick forest of broad-leaved trees that are ever green. Some of the areas are made farms for cultivation of crops by the peasant farmers.

3. METHODS OF STUDY

The study involved two phases of measurements; the hydrogeologic and geophysical measurements (Fig. 4). The hydrogeologic phase which was conducted during the peak of the dry season (February – March, 2016.involved water level measurements in a total of twenty eight (28) existing non-flowing wells (solar powered/hand pump perennial wells) across the study area. The measurements engaged steel tape whose lower end was marked with carpenter's chalk, as practiced in Moore [12]. This was to enable a reading to be taken from the submerged portion.

To ensure accuracy, two measurements were taken at each well location, and the average values were determined whenever there was contrast. Since the depth to the static water level is considered an approximation of the interface between the vadose and phreatic zones in a non-confined aquifer setting [12]. The measurements were used to compute the thickness of the vadose zone, static water level and hydraulic head of the wells across the area.

The resistivity measurements phase involved the Schlumberger depth sounding [13], [14]. The Ohmega resistivity meter (a product of Allied Associates Geophysical Limited) was used for the data acquisition. A total of twenty (20) depth sounding data were acquired (Fig. 4). Current electrode (AB) separation ranged between 1 m and 150 m. The depth sounding data were presented as sounding curves. The field curves were manually interpreted [14], [15] to determine the geoelectric parameters. The approximate models manually derived were interactively adjusted using the Resist Version 1 software [16] to obtain a better fit in each case.

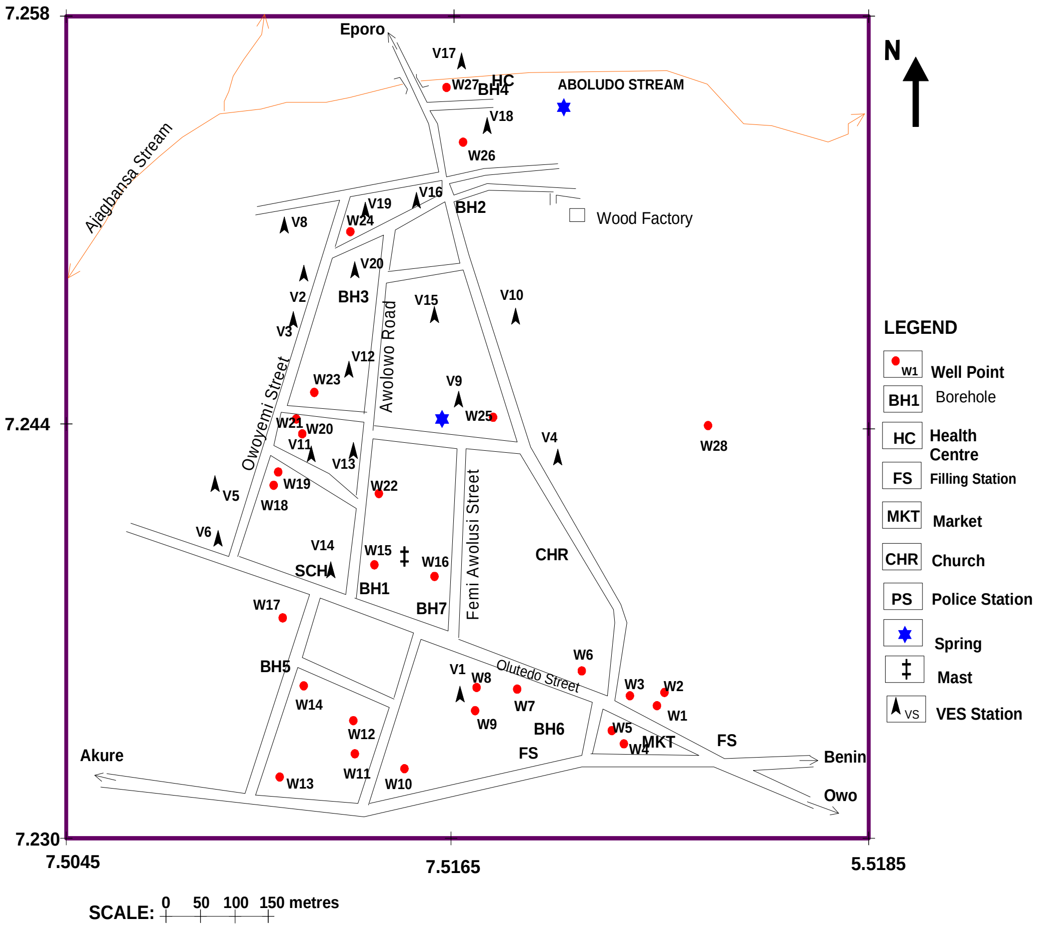


Fig. 4. Base map of the study showing wells, borehole, and VES locations

4. RESULTS AND DISCUSSION

4.1 Hydrogeologic Parameter Consideration

Table 1 gives the summary of all the hydrogeological measurements obtained from the wells. The depth to Static Water Level (water table), an approximation of vadose zone thickness, ranges from 2.6 m to 4.7 m, with a modal range of 1 – 3 m, suggestive of a thin vadose zone. The vadose zone is the unsaturated zone of the subsoil above the water table and plays an important role in percolation of rainfall and surface flow. In general, the deeper the water levels are, the longer pollutant takes to reach the groundwater table. Based on DRASTIC index rating [17] which rates concerning classification of range and rating for depth to groundwater, the vadose zone thickness generally fall within high vulnerability rating [18] corresponding to <4,5 m water depth with a rating of 9, thus suggesting that the surficial aquifers would be very vulnerable to pollution / contaminants derived from anthropogenic sources, because the higher the DRASTIC index value/rating, the greater the groundwater pollution potential and aquifer vulnerability. Although the thickness of the vadose zone is an important consideration in vulnerability assessment [19], [20] the composition of the soil media and the lithologic/physical properties of materials capping the vadose zone also constitute important parameters in vulnerability assessment [17].

Fig. 5 is a map showing spatial variation of hydraulic head thickness across the area; it was calculated by subtracting the well elevation at the surface from static water level. The map shows that central area (trending in East – West direction) have low hydraulic heads. Therefore the topography would facilitate accumulation of groundwater, since depressive areas could serve as groundwater collecting centre, because groundwater always flows in the direction of decreasing head. This was evidenced by generally low piezometric values obtained for Wells located within the central zone, and higher around the northern and southern regions; which also corroborate the surface elevation map in Fig. 2 which shows a topographically-low central.

The total depth of the wells varies between 3.2 m and 7.9 m with an average of 5.4 m, and modal range of 4.0 to 6.0 m. Therefore from these values, the depths of the wells are less than 10 m correlating to shallow wells.

Fig. 6 is a map showing spatial variation of the thickness of water column (W.C.) across the area. The thickness of W.C. ranges between 0.5 m and 5.2 m, with an average of 2.6 m. The modal range is between 0.4 m and 2.4 m corresponding to northwest – southwestern parts of the area. This also accounts for 55 % predominance in the area. However, the northeast – southeast zones have thicker water column between 2.4 m and 6.4 m.

4.2 Geoelectric Parameter Consideration

Fig. 7 shows typical VES curves from the study area. Electrical resistivity methods primarily reflect variation in ground resistivity. The electrical resistivity contrast between discrete geoelectric layers, or lithological sequences [21] in the subsurface are generally adequate to enable the characterization of geoelectric layers. This further assists the delineation and identification of aquiferous or non-aquiferous layers and reliable geological deductions. The five curve types identified in the study area include KH, KHA, H, HA, and QH (Fig. 8). The H and KH signatures are the most predominant accounting for 72 % and 15 % respectively.

The interpreted twenty four sounding curve types (Table 2) indicate four distinct subsurface geologic layers. The layers are the topsoil, the weathered layer, the partly weathered/fractured basement, and the basement. The topsoil has resistivity values ranging from 30 to 3287 Ohm-m, representing clayey sand/sand/laterite topsoil. It has thickness ranging from 0.7 m to 16.5 m. It is underlain by clay-sand / sandy clay weathered layer (which is the main water bearing unit) with resistivity ranging from 7 to 101 Ohm-m and thickness ranging from 2.0 to 84.9 m. The geoelectric basement is at depth ranging from 3.9 m to 101.4 m, with resistivity greater than 1000 Ohm-m. The major aquifer in the area is the unconfined weathered layer.

The thickness and resistivity parameters of unconsolidated materials (over-burden) overlying the basement is important factor in the evaluation of groundwater potential in the crystalline basement area [22]. Fig. 9 shows that the weathered layer is composed of sandy clay / clay-sand. Sandy clay water bearing formation is confined to the southern areas, while clay-sand water unit dominates the northern parts, as they constitute about 60% and 40% respectively of the area. The thickness of the weathered layer is generally less than 20 m (Fig. 10).

Table 1. Summary of the hydrogeological measurement obtained from hand pump/solar powered wells in the study area

Lat.	Long.	Well	SWL (m)	Total depth (m)	Elevation (m)	Water column/vadose water thickness (m)	Hydraulic head (m)
7.2379	5.5155	1	3.41	6.9	361.2	3.5	357.5
7.2379	5.5161	2	1.92	6.2	332.4	4.3	328.1
7.2381	5.5161	3	2.00	4.5	328.1	2.5	325.6
7.2372	5.5150	4	2.22	4.6	332.2	2.4	329.8
7.2374	5.5149	5	1.91	4.4	331.8	2.5	329.3
7.2381	5.5150	6	1.81	6.4	332.4	4.6	327.8
7.2399	5.5123	7	1.94	3.6	331.2	1.7	329.5
7.2403	5.5118	8	2.10	3.6	332.2	1.5	330.7
7.2403	5.5117	9	2.52	4.2	331.9	1.7	330.2
7.2421	5.5112	10	3.81	5.9	332.5	2.1	330.4
7.2418	5.5094	11	3.80	5.7	329.6	1.9	327.7
7.2442	5.5149	12	1.01	6.2	305.3	5.2	300.1
7.2491	5.5133	13	2.52	4.8	325.7	2.3	323.4
7.2449	5.5100	14	4.52	6.8	320.6	2.3	318.3
7.2444	5.5094	15	3.71	4.7	318.1	1.0	317.1
7.2448	5.5115	16	4.74	7.0	324.4	2.3	322.1
7.2456	5.5118	17	2.73	3.2	325.2	0.5	324.7
7.2447	5.5107	18	4.41	7.9	324.5	3.5	321.0
7.2401	5.5088	19	2.91	5.0	328.2	2.1	326.1
7.2409	5.5084	20	2.12	3.5	335.6	1.4	334.2
7.2413	5.5084	21	2.90	4.3	333.3	1.4	331.9
7.2428	5.5089	22	3.01	4.1	327.9	1.1	326.8
7.2441	5.5116	23	2.52	6.1	318.2	3.6	314.6
7.2421	5.5117	24	3.61	7.1	319.1	3.5	315.6
7.2501	5.5146	25	3.24	7.0	330.3	3.8	326.5
7.2516	5.5151	26	1.92	5.4	320.6	3.5	317.1
7.2411	5.5064	27	2.41	5.3	325.8	2.9	322.9
7.2530	5.5120	28	3.10	8.1	308.2	5.0	303.2

The thickness map of the layer above the weathered layer (topsoil) in the area is presented in Fig. 11. The most occurring thickness is in the range of 0.5 m – 5.5 m. However, the southern parts show thicker variation.

Protective near-surface geologic barriers with sufficient thickness and low hydraulic conductivity usually act as efficient groundwater protection media [23]. Clay or silt, characterized by low resistivity (1-100 Ohm-m) and very low permeability, and impervious or semi-impervious materials (laterite and lateritic sand), characterized by high resistivity values (> 400 Ohm-m) constitute protective layers where they cap vadose zones. They are known to effectively slow down contaminants percolation in the vadose zone, thus allowing time for natural degradation. Permeable materials like sand and gravel readily allows access of contaminants.

Therefore using the resistivity of the topsoil which is directly above the weathered layer to evaluate the vulnerability risk of the aquifer to contamination. The topsoil has resistivity ranging from 30 to 3287 Ohm-m with modal range of 200 to 350 ohm-m, indicative of fairly impervious material. This implies that the aquifer units in the area would be fairly protected on the basis of topsoil resistivity. However, the thickness of the topsoil derived from the sounding curves and geoelectric section is also a major factor to be considered in vulnerability potential of the aquiferous units. The average thickness obtained is 3.1 m, indicating a thin layer.

Fig. 12 is the total transverse unit resistance map of the study area. The map shows that the transverse resistance is predominantly between 0 and 1,000 Ωm² suggesting a low groundwater development zone (constitute about 70 % of the area), this resistance values are found around the NNW through the central to the southeast. The medium transverse resistance values (greater than 1,000 Ωm², constitute about 30 % of the area) are found in northwest - southwest parts of study area, these zones are the best area for groundwater development.

Due to the filtering effect of the earth, the total longitudinal unit conductance values were used to evaluate the overburden protective capacity of an area. [24] relates the protective capacity of an overburden overlying an aquifer to its hydraulic conductivity. Using modified [24] classification (Table 3), the overburden protective map of the area (Fig. 13) shows that area falls within the poor to very weak protective capacity. This suggests that the study area has weathering materials of poor/weak protective capacity/ resistance.

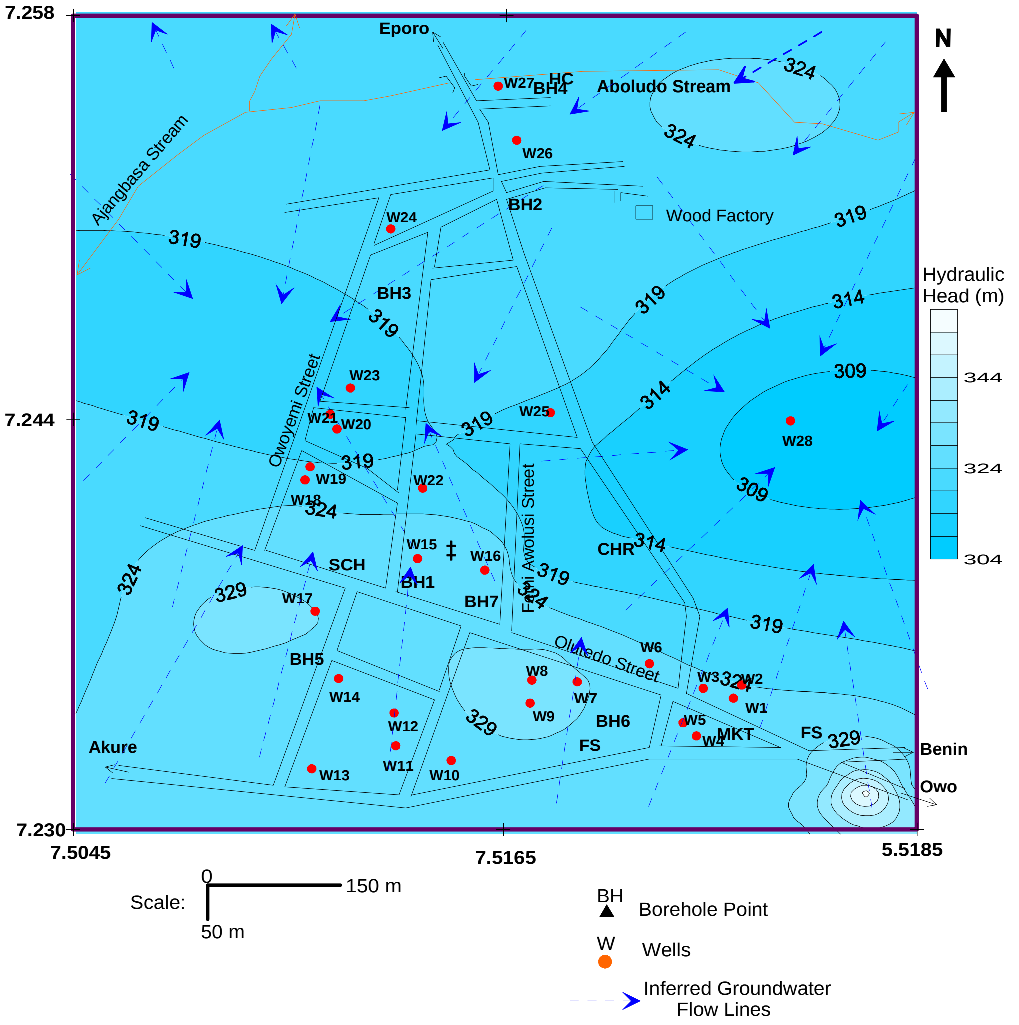


Fig. 5. Piezometric map of the study area

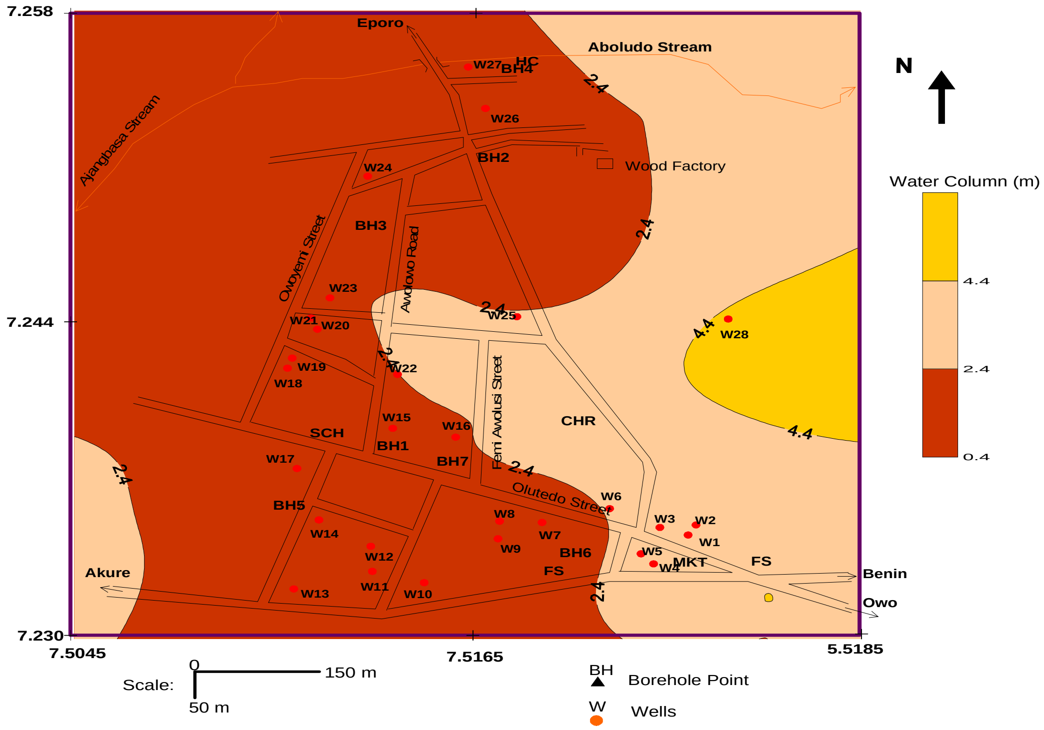
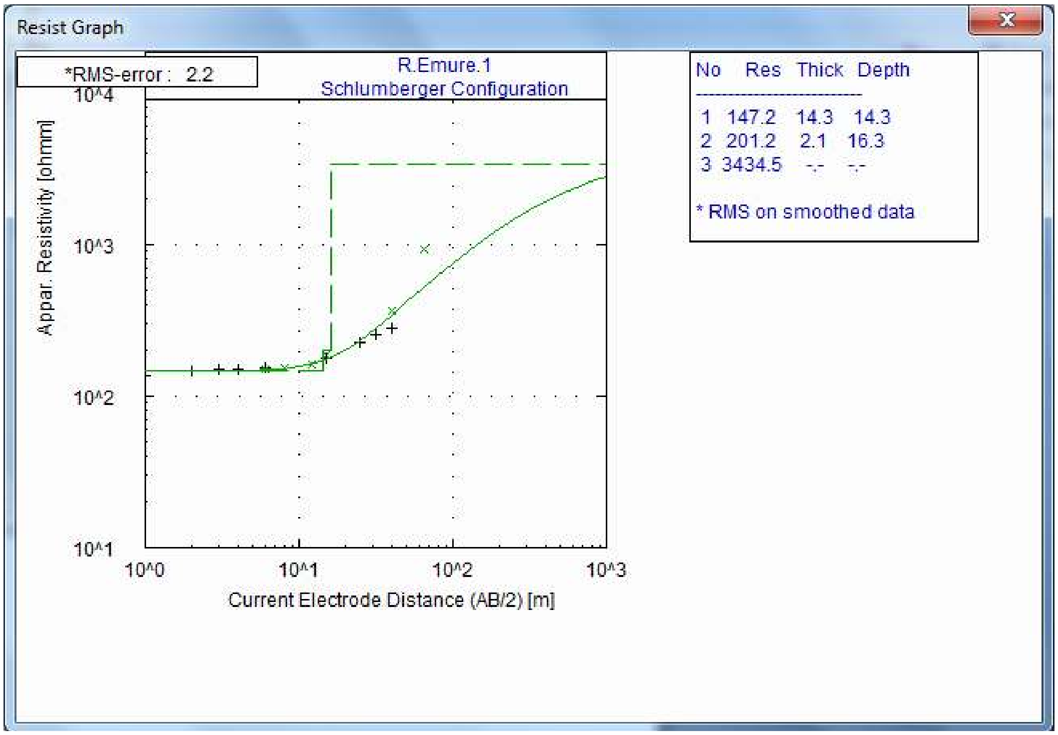


Fig. 6. Map showing vadose water thickness variation across the study area



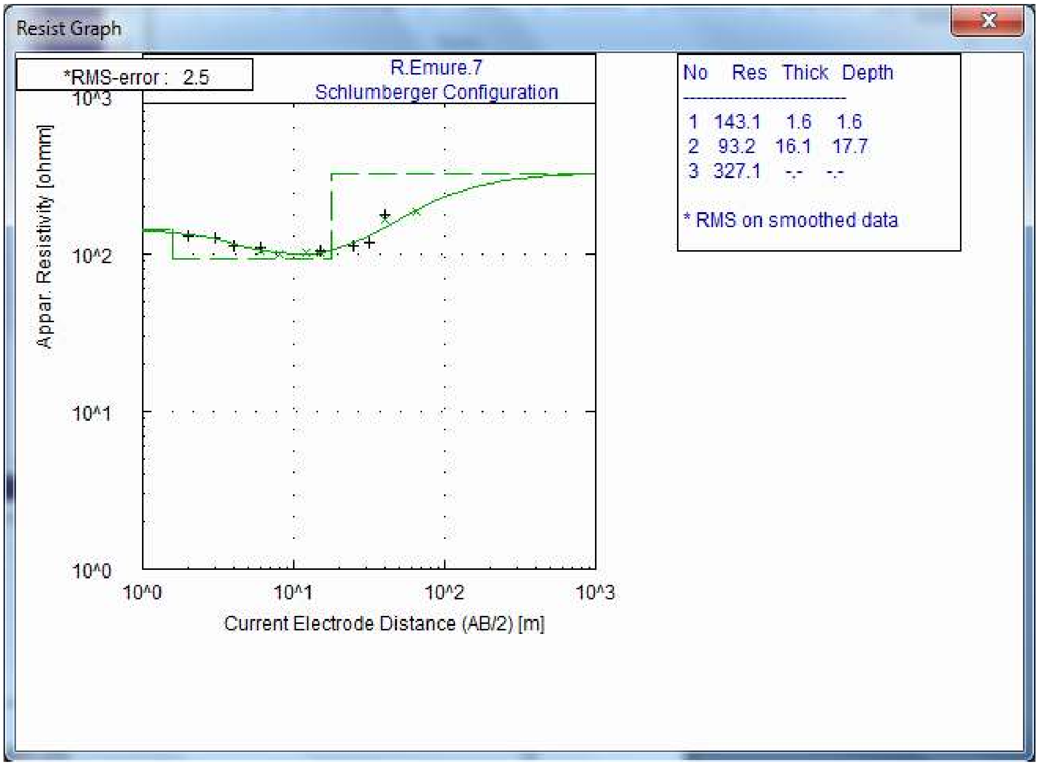
*RMS-error : 2.2

R.Emure.1
Schlumberger Configuration

No	Res	Thick	Depth
1	147.2	14.3	14.3
2	201.2	2.1	16.3
3	3434.5	-.-	-.-

* RMS on smoothed data

(a)



*RMS-error : 2.5

No	Res	Thick	Depth
1	143.1	1.6	1.6
2	93.2	16.1	17.7
3	327.1	-.-	-.-

* RMS on smoothed data

(b)

Fig. 7. Typical depth sounding curves types from Emure Ile: (a) A curve (b) H-curve

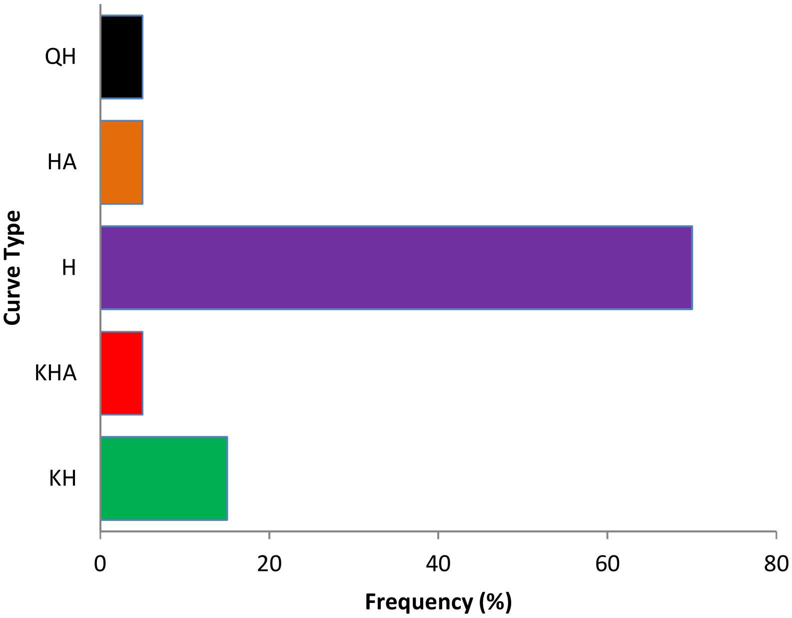


Fig. 8. Bar chart of the sounding curves obtained in the study area showing predominant H-curve

Table 2. Summary of the interpreted vertical electrical sounding curves

Eastings (m)	Northings (m)	VES No.	Resistivity (Ohm-meter)						Thickness (m)					Depth (m)					Curve type
			ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5	d_1	d_2	d_3	d_4	d_5	
777303	801144	1	147	201	3435				14.3	2.1				14.3	16.3				A
776963	801533	2	1146	30	96	505			1.6	4.5	17.2			1.6	6.1	23.2			HA
777031	801590	3	322	3287	18	180	7149		1.1	1.0	5.2	4.9		1.1	2.0	7.3	12.1		KHA
777644	801444	4	201	15	48501				1.8	2.1				1.8	3.9				H
777221	801785	5	399	42	10926				2.9	9.6				2.9	12.4				H
777367	801970	6	273	12	1090				2.5	2.0				2.5	4.5				H
777731	800795	7	143	93	327				1.6	16.1				1.6	17.7				H
777648	802467	8	285	18	512				2.9	2.6				2.9	5.5				H
777686	801987	9	87	34	66166				0.8	18.1				0.8	19				H
777642	801648	10	179	101	502				0.7	11.6				0.7	12.3				H
777248	801372	11	176	53	304				1.6	5.4				1.6	7.0				H
777330	801615	12	240	5220	86	2339			1.8	0.9	5.1			1.8	2.6	7.7			KH
777464	801940	13	229	37	33813				1.2	19.5				1.2	20.8				H
777499	802034	14	191	262	18	31166			0.7	0.1	8.9			0.7	0.8	9.7			KH
777612	801900	15	398	337	7	1359			2.2	0.1	3.4			2.2	2.3	5.7			QH
777431	802183	16	98	241	19	43701			4.7	0.1	6.6			4.7	4.8	11.4			KH
777549	802149	17	50	10	2766				0.7	12.4				0.7	13.1				H
777623	802133	18	64	8	19584				1.4	4.2				1.4	5.6				H
777740	802308	19	202	32	2407				1.1	26.0				1.1	27.1				H
777256	801630	20	287	88	2756				16.5	84.9				16.5	101.4				H

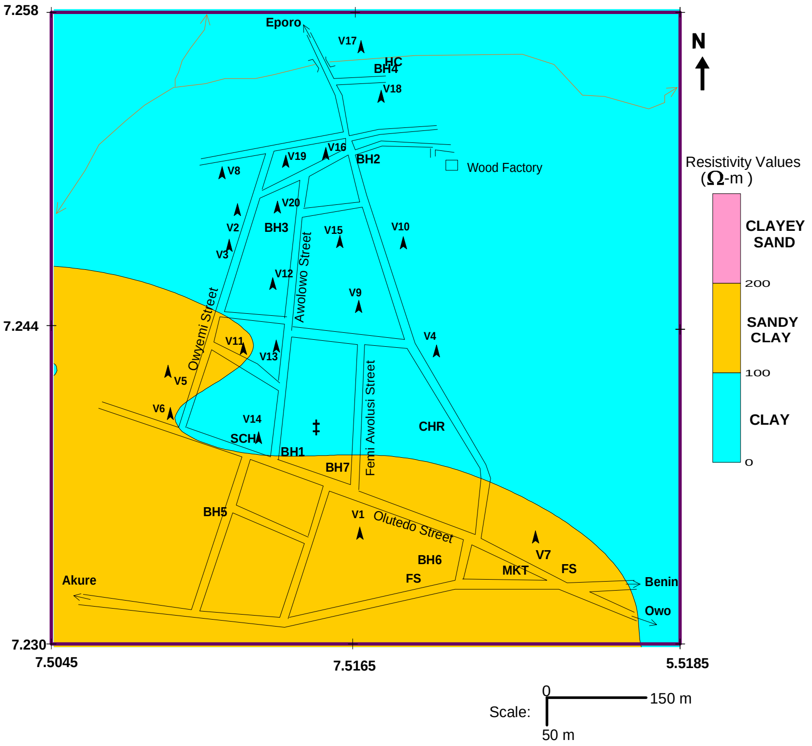


Fig. 9. Contour map of weathered layer resistivity distribution at the study area

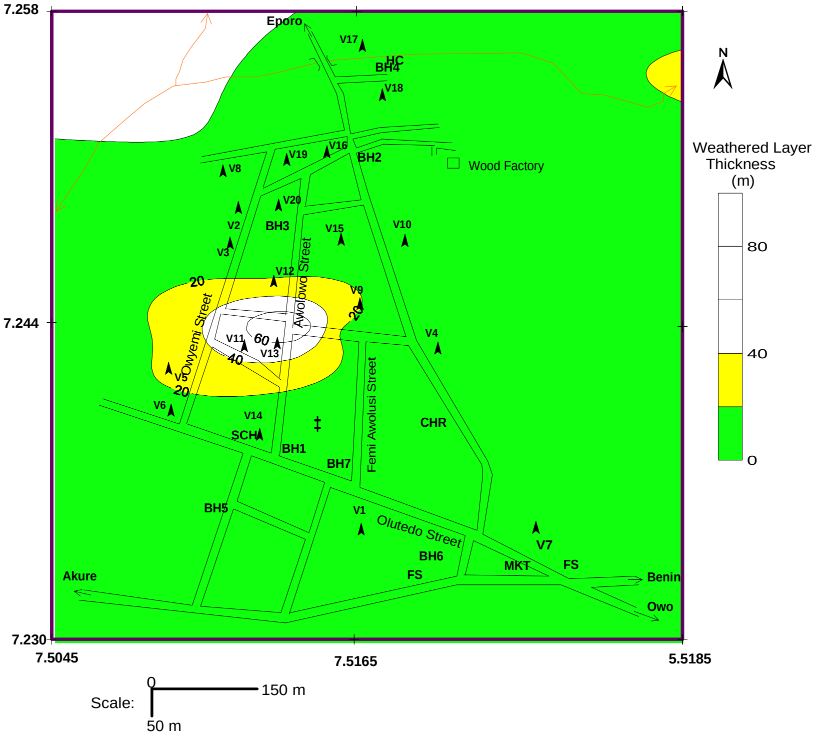


Fig. 10. Contour map of weathered layer thickness distribution at the study area

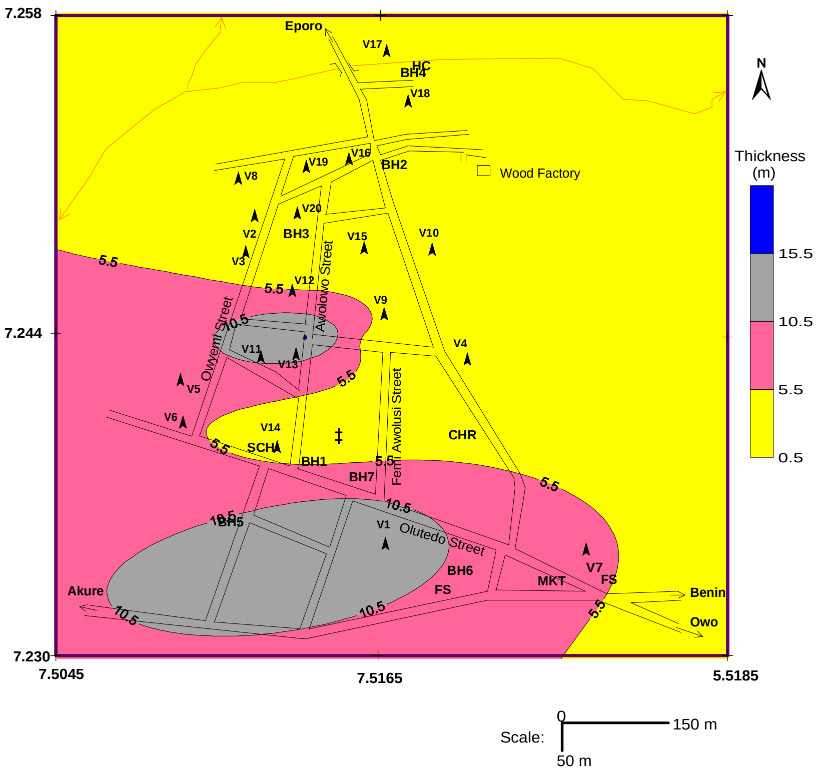


Fig. 11. Thickness map of the layer above the aquifer unit at the study area

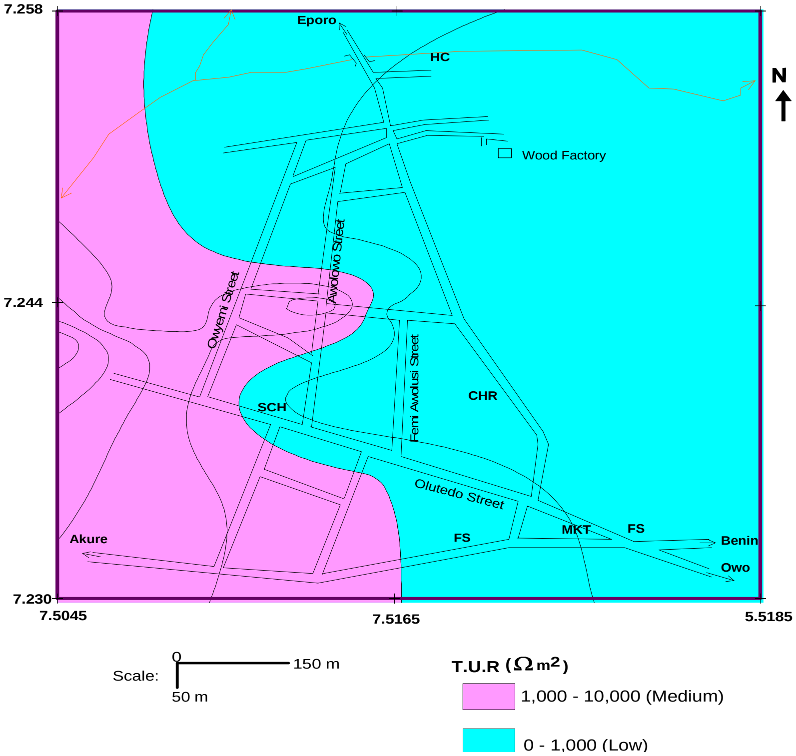


Fig. 12. Traverse resistance map of the study area

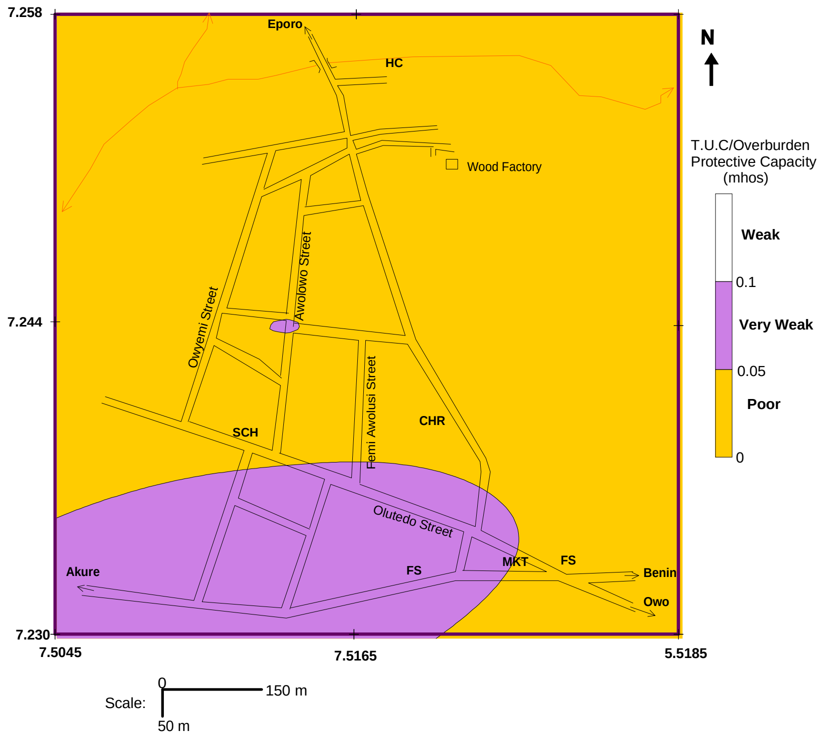


Fig. 13. Total unit conductance/overburden protective map of the study area

Table 3. Modified longitudinal conductance / protective capacity rating

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5 – 10	Very Good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
<0.1	Poor

5. CONCLUSION

The hydrogeological and surface geoelectric measurements conducted at Emure Ile enabled the delineation of aquifer units and assessment of its vulnerability to contamination, and understanding of groundwater flow in the study area. The depth to groundwater (water table) ranges from 2.6 m to 4.7 m, with a modal range of 1 – 3 m in the area, indicative of thin vadose zone. Based on DRASTIC index rating concerning classification of range and rating for depth to groundwater, the vadose zone thickness is generally fall within low vulnerability rating, aptly suggesting that the aquifers in the area are significantly vulnerable to contaminants deriving from anthropogenic sources.

The piezometric map shows that central part of the town (trending in East – West direction) is characterized by low elevations. Therefore this topography facilitates accumulation of groundwater, since depressive areas could serve as groundwater collecting centre. But the thickness of the water columns/vadose water (average of 2.6 m) and total depth of the wells (average of 5.4 m) are generally low and shallow.

The five curve types identified in the study area include KH, KHA, H, HA, and QH. The H and KH signatures are the most predominant accounting for 72% and 15% respectively. The interpreted twenty four sounding curve types indicate four distinct subsurface geologic layers. The layers are the topsoil, the weathered layer, the partly weathered/fractured basement, and the basement. The major water bearing unit identified in the area is the unconfined weathered layer with resistivity ranging from 7 to 101 Ohm-m suggestive of clay-sand/sandy clay and thickness ranging from 2.0 to 84.9 but generally less than 20 m. Consequently the maximum depth to the water bearing formation is between 16.5 to about 20 m. Using the resistivity of the topsoil, which ranges from 30 to 3287 Ohm-m, with modal range of 200 to 350 ohm-m, indicative of fairly impervious material. This implies that the water bearing units in the area would be fairly protected from contamination.

The total transverse unit resistance map shows predominant resistance between 0 and 1,000 Ωm² indicated as low groundwater development zone which constitute about 70 % of the area, and covered the NNW through the Central to Southeast. The medium transverse resistance values (greater than 1,000 Ωm², constitute about 30 % of the area) are found in northwest - southwest parts of study area, these zones are the best area for groundwater development.

Due to the filtering effect of the earth, the total longitudinal unit conductance values were used to evaluate the overburden protective capacity of an area, since there is good relation between protective capacity of overburden overlying water bearing formation and its hydraulic conductivity. The overburden protective map of the area shows that area falls within the poor to very weak protective capacity. This suggests that the study area has weathering materials of poor/weak protective capacity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Olumide BT, Samuel TO and Joseph OA. Groundwater Quality Assessment in Akungba Akoko, Ondo State, Nigeria Research Journal of Environmental and Earth Sciences. 2015;7(1):9-14.
2. Ariyo SO, Banjo AA. Application of electrical resistivity method for groundwater exploration in a sedimentary terrain: A case study of Ilara-Remo, Southwest Nigeria: Continental Journal of Earth Sciences. 2008;3:53–58.
3. Amarachi RA, Ako BD. Groundwater Investigation Using Combined Geophysical Methods. Search and Discovery Article #40914; 2012.
4. Carruthers RM. Review of geophysical techniques for groundwater exploration in crystalline basement terrain: British Geological Survey, Regional Geophysics Research Group, Report. 1985;85/3:30.
5. Emenike EA. Geophysical exploration for groundwater in a Sedimentary Environment: A case study from Nanka over Nanka Formation in Anambra Basin, Southeastern Nigeria: Global Journal of Pure and Applied Sciences. 2001;7/1:1-11.
6. Olayinka AI and Mbachi CNC. A technique for the interpretation of electrical sounding from crystalline basement areas of Nigeria: Journal of Mining and Geology. 1992;27: 63-69.
7. Olorunniwo MA, Olorunfemi MO. Geophysical investigation for groundwater in Precambrian terrain, A case history from Ikare, Southwest Nigeria: Journal of African Earth Sciences. 1987;6:787-796.
8. Ariyo SO. Geoelectrical characterisation of aquifers and Geochemical study of ground waters in the basement complex/ sedimentary transition zone around Ishara, Southwest Nigeria: Unpublished Master’s Thesis, University of Ibadan, Ibadan, Nigeria. 2005;139.
9. Robins NS, Chilton PJ, Cobbing JE. Adapting existing experience with aquifer vulnerability and groundwater protection for Africa. Journal of African Earth Sciences. 2007;47:30-38.
10. Wilson LG. Monitoring in the vadose: Part 3, Groundwater Monitoring Review. 1983; 3(1):155-166.
11. Iloeje NP. A New Geography of Nigeria. Longman Group Ltd; 1981.
12. Moore JE. Field Hydrogeology: A guide for site investigations and report preparation. Lewis Publishers, New York. 2002;182.
13. Zohdy AAR, Eaton GP, Mabey DR. Application of surface geophysics to groundwater investigations: Techniques of water resources investigations of U.S. Geol. Survey. 1974;Book 2. Chapter D1.
14. Patra HP, Nath SK. Schlumberger Geoelectric sounding in Ground Water. Principles, Interpretation and Application. A. A. Balkema Publishers, Brookfield. 1998;183.
15. Koefoed O. Geosounding Principles 1.Resistivity sounding measurements. Elsevier Scientific Publishing Company, Amsterdam. 1979;275.
16. Vander Velpen BPA. Resist Version 1.0. M.Sc. Research Project, ITC, Deft, Netherlands; 1988.
17. Aller L, Bennet T, Lehr JH, Petty RJ, Hackett G. DRASTIC: A standard system for evaluating groundwater pollution potential using hydrogeologic settings.

EPA/600/2-85/018, US Environmental Protection Agency, Ada, Oklahoma. 1987; 455.

18. Samake M, Tang Z, Hlaing W, Mbue IN, Kesereka K, Balogun WO. Groundwater vulnerability assessment in shallow aquifer in Linfen Basin, Shanxi Province, China using DRASTIC Model. Journal of Sustainable Development.2011;4(1):53-71.
19. Osborn NI, Eckenstein E, Koon KQ. Vulnerability assessment of twelve major aquifers in Oklahoma. Oklahoma Water Resources Board Technical report 98; 1998.
20. Harter T. Groundwater quality and groundwater pollution. Publication 8084; 2003. Available:http//:anrcatalog.ucdavis.edu
21. Lashkarripour GR. An investigation of groundwater condition by geoelectrical resistivity method: A case study in Korin Aquifer, Southeast Iran. Journal of Spacial Hydrology. 2003;3(1):1-5.
22. Caruthers RM, Smith IF. The use of ground electrical survey methods for siting water supply boreholes in shallow crystalline basement terrains. In: The Hydrogeology of Crystalline basement Aquifers in Africa. Wright FP, Burgess WC, (eds.). 203-220. Geological Society Special Publication: London, UK; 1992.
23. Lenkey L, Hamori Z, Mihalffy P. Investigating the hydrogeology of a water-supply area using direct-current electrical sounding. Geophy. 2005;70(4): H1-H19.
24. Henriet JP. Direct application of the dar zarrock parameters in groundwater surveys. Geophysical Prospecting. 1976; 24:344-356.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17130