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GIS Integrated Geomorphological, Geological and Geoelectrical Assessment of the Groundwater Potential of Akure Metropolis, Southwest Nigeria

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Abstract

Landsat EMT+ surface reflectance images of 2002 of the Akure Metropolis were processed to generate geomorphological and lineament maps. Five Hundred and thirteen Schlumberger Vertical Electrical Sounding (VES) data set were quantitatively interpreted using the partial curve matching and computer assisted 1-D forward modeling. Four geomorphological units which include residual hills, pediments, low land pediments and etchplain were delineated. Satellite- imagery-delineated lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations with subsidiary NW-SE and W-E trends. The VES interpretation results delineate four main subsurface geologic units. These include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement bedrock. Two major aquifer units - the weathered basement and the partly weathered/fractured basement were delineated. Thematic maps of geology, geomorphology, hydro-lineament density, aquifer thickness, and electrical coefficient of anisotropy were integrated to classify the Akure Metropolis into very low, low, moderate and high groundwater potential zones.

Keywords: Geomorphology, Geology, Geoelectrical characteristics, Groundwater potential

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1 Introduction

Akure, the Ondo State capital, has witnessed rapid housing and estate development, establishment of new industries and expansion of older ones. Population explosion, exacerbated by rural-urban migration has been accompanied by increase in demand for portable water for human consumption, industrial and agricultural needs. However, access to potable water has remained inadequate because of limited water supply from the Ondo State water corporation. The limited water supply is poorly distributed and the distribution networks are poorly maintained. This has led some inhabitants of the metropolis to resort to rainwater harvesting, surface water sources such as streams and rivers and digging of shallow wells. Rivers, streams and shallow hand dug well waters are highly susceptible to contamination through anthropogenic sources. Groundwater is less prone to pollution, requires limited or no treatment and can be developed close to the point of need (Olorunfemi, 2009). This makes groundwater development through borehole drilling a viable and alternative source of potable water. This must have informed the decision of Ondo state Government through the Ondo State Water Corporation and the UNICEF Assisted Water Supply and Sanitation Agency (WATSAN) to engage in borehole drilling within the metropolis as a viable supplement to her inadequate surface water supply scheme.

However, groundwater development in Basement Complex environment, as is the case in Akure Metropolis, through borehole drilling has been characterized by spate of failures. Basement aquifers are discontinuous and limited both in lateral and vertical extent (Satpathy and Kanungo, 1976). It is the poor understanding of this hydrogeological characteristics of the Basement Complex environment that is significantly responsible for borehole failures. Secondly, detailed regional assessment of the groundwater potential of the study area has not been undertaken. There is therefore the need to assess the groundwater potential of Akure Metropolis using remote sensing, geomorphological, geological, geoelectrical and existing borehole information. The research deliverable – a groundwater potential map, will be useful for short and long term planning of groundwater development programme for the study area.

The hydro-geophysical evaluation of the groundwater potential of Akure Metropolis was carried out by Olorunfemi et al., 1999, using lineament, static water level analysis, limited groundwater yield data and geoelectrical parameters. The metropolis was broadly classified into low, medium and high groundwater potential zones. The constraint of this study was that sampling points were located based on available topographic map (not georeferenced) and hence may have been subjected to significant spatial error. The data points were limited, so also were the thematic maps. Sampling points in the present study will be properly geo-referenced and the spatial distribution enhanced. Several thematic maps will be synthesized in a GIS environment for the development of the groundwater potential map.

1.1 Description and Physiography

Akure Metropolis lies within Latitudes 7° 09' and 7° 19'N and Longitudes 5° 07' and 5° 17'E (Northings 790820 – 809277 mN and Eastings 733726 – 752139 mE, UTM Minna Zone 31) (Figure 1). The metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs. Topographic elevations vary between 260 and 470 m above sea level (Owoyemi, 1996). The metropolis is drained by several streams and rivers. The major ones are Rivers Ala, Ogburugburu and Elegbin and their tributaries.

1.2 Geology and Hydrogeology

The area around the Akure Metropolis is underlain by four of the six petrological units of the Basement Complex of southwestern Nigeria as identified by Rahaman (1988). These are the Migmatite-Gneiss-Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and Unmetamorphosed dolerite dykes (Figure 2). The study area exhibits varieties of structures such as foliation, schistosity, folds, faults, joints and fractures. Generally, the structural trends in the study area are NNW-SSE and NNE-SSW. Numerous small and long fractures, joints and fissure zones which generally trend north-south are common. These structural trends fall within the principal basement complex fracture direction identified by Oluyide, 1988. Lineaments extracted from aerial photographs, satellite imageries and Side Looking Airborne Radar (RADAR) imageries over Akure area showed that the lineaments predominantly trend in the ENE-WSW direction (Owoyemi, 1996; Odeyemi et al., 1999). The lineament map generated by Owoyemi, 1996 showed high density of lineament and lineament intersections in the eastern, southwestern and north central part of the metropolis underlain by granites and migmatite gneiss while the north central part underlain by charnockites has very low lineament density. The groundwater, in a typical basement complex area like the Akure Metropolis, is contained in two major aquifer units, namely weathered and fractured basement aquifers (Ako and Olorunfemi, 1989; Aniya and Schoeneick, 1992; Olorunfemi and Fasuyi, 1993; Afolayan et al., 2004 and Bayode et al., 2006). The former is derived from chemical alteration processes while the latter is the product of tectonic activities. The Basement Complex rocks are mostly concealed by a sequence of unconsolidated superficial deposits and basement regolith produced by prolonged weathering of the parent rock. Rocks dominated by unstable ferromagnesian minerals tend to weather into clay, sometimes, micaceous impermeable poor water discharging rock formations while those rocks rich in quartz and other stable minerals will disintegrate into porous and permeable water bearing gravelly or sandy medium (Offodile, 2002).

The weathered layer aquifer may occur singly or in combination with the fractured aquifer. Olorunfemi and Fasuyi (1993) identified the aquifer combinations in the basement complex area as weathered layer aquifer; weathered/fractured (unconfined) aquifer; weathered/fractured (confined) aquifer; weathered/fractured (unconfined)/fractured (confined) aquifer and the fractured confined aquifer. Porosity and permeability determine the storativity and the groundwater yielding capacity of rocks and these characteristics depend on texture and mineralogy of rocks. In fresh, non-fractured crystalline rocks, the porosity is often less than 3% and the permeability is virtually nil. However, the porosity and permeability are increased considerably by weathering and fracturing (Offodile, 2002). Aquifers in the basement rocks are highly limited in lateral and depth extent (Satpathy and Kanungo, 1976).

2 Methodology

2.1 Geomorphological and Structural (lineament) Mapping

In this study therefore, rock and soil units, topographic profile, streams, rivers and other features were identified and delineated from digital satellite scenes using appropriate software-supported techniques. Subset Topographic map, Aster DEM, Landsat EMT+ surface reflectance image of 2002 of the study area were pre-processed for geometric correction, haze reduction and re-sampling. Optimum index factor and covariance analysis were carried out in order to determine the least correlated bands and these bands were subjected to convolution filters, texture analysis at 3X3 window size, histogram equalization, de-correlation stretch, principal component analysis (PCA) and the Aster DEM to topographic analysis such as sink fill and shielded relief to generate classified land cover map, geomorphological map and lineament map.

2.2 Geophysical Investigation

The geophysical investigation involved the electrical resistivity method. The Vertical Electrical Sounding (VES) technique adopting a Schlumberger array was used. The half current electrode spacing (AB/2) was varied from 1 m to a maximum of 100 m .The choice of the VES stations was constrained by the geology, structure (lineament) map, terrain, accessibility and representativeness of the spread of the stations. Every VES station was appropriately geo-referenced. Secondary information on existing VES data and borehole records (logs, yield etc.) were assessed re-processed and incorporated. Four Hundred and two (402) Vertical Electrical Sounding (VES) data from 114 localities were sourced and collated. Twenty five (25) sets of borehole data were also sourced. Additional one hundred and eleven (111) primary VES data were collected from Aule and Ilupeju areas of Akure Metropolis where the secondary data were not representative or non-existent. In all, five hundred and thirteen (513) VES data set from 116 localities were acquired. A GPS generated base map with sample locations are shown in Figure 3. The VES data were presented as depth sounding curves and interpreted quantitatively using the partial curve matching technique and computer assisted 1-D forward modeling with W-Geosoft software. The interpretation results (layer resistivities and thicknesses) were used for geoelectrical characterization and computation of electrical coefficient of anisotropy (Olorunfemi et al., 1991).

3 Results and Discussion

3.1 Geomorphology and Structures (Lineaments)

Figure 4 shows the geomorphological map of the study area. The geomorphological units include residual hills with elevations of 353 – 470 m above sea level (a.s.l.) located at the northern, south central and western flank of the metropolis. The pediments are located at the foot of the residual hills with elevations in the range of 328 – 353 m a.s.l. Both relatively high elevation geomorphological units constitute the water shed for the numerous streams and rivers. The low lands pediments (307 – 328 m a.s.l) and the etchplain (260 – 307 m a.s.l.) fall within and around the stream/river channels and are located at the western/southwestern, southern and eastern flank. The satellite imagery delineated lineaments are shown in Figure 5. The lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations and subsidiary NW-SE and W-E trends that are typical of the Basement Complex region of Nigeria (Oluyide, 1988, Owoyemi, 1996 and Odeyemi et al., 1999).

3.2 Geophysical Investigation

3.2.1 Characteristics of the VES Curves

The VES type curves range from 2-layer to three-layer H; four-layer AA, HA, KH and QH; five-layer AKH, HAK, KHA, KQH and QHA and six-layer HKHA, HKQH, KHKH, KQHA and QHKH type (Figure 6). The KH and H type curves predominate with frequencies of 26% and 24% respectively while the HA and HKH type follow with frequencies of 13% and 11% respectively. The four type curves account for 74% of the total.

3.2.2 Subsurface Geoelectric/Geologic Sequence

The VES interpretation results delineate four main subsurface geologic units. These include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement bedrock. The topsoil is the uppermost layer which, at some localities, is underlain by a lateritic layer. The layer resistivity values vary widely between 13 ohm-m and 7133 ohm-m (Figure 7) with the highest frequency of occurrence between 13 and 300 ohm-m. The wide variation in layer resistivity depicts variations in composition degree of fluid saturation (or moisture content) and degree of compaction. The low resistivity (< 300 ohm-m) end of the resistivity spectrum is typical of clay and sandy clay while the high/very high resistivity end (> 300 ohm-m) is diagnostic of clayey sand, sand and laterite. The topsoil thicknesses range in value from 0.3 m to 5.2 m but are generally less than 1.5 m (Figure 8). The topsoil becomes thicker when it is underlain by a lateritic layer or merges, in resistivity, with the underlying weathered basement.

The weathered layer underlies the topsoil directly in most places unless where the fresh basement rock occurs at shallow depth (nearly outcropping) and it merges with the topsoil or is outcropping. The layer resistivity values range between 6 ohm-m and 727 ohm-m with the highest frequency in the 6-150 ohm-m range (Figure 9). The weathered layer varies in resistivity and composition depending on the parent rock – typically clayey with low layer resistivity values (< 100 ohm-m) over basic charnockite and sandy/clayey sand (> 100 ohm-m) on fine-coarse grained granitic/gneissic rocks. The weathered layer thicknesses vary between 0.3 m and 106 m (Figure 10).

The partly weathered/fractured basement column sometime underlie the weathered layer directly (as unconfined fractured basement) (Olorunfemi and Fasuyi, 1993) or occurs within fresh basement rock (as confined fractured basement). This geologic layer was only delineated beneath some VES stations. The layer resistivity values range from 17 ohm-m to 985 ohm-m with the highest frequency in the 17-300 ohm-m range (Figure 11). The thickness of this horizon varies from 0.2 m to 108 m but is generally less than 25.0 m (Figure 12).

The fresh basement rock is typically characterized by layer resistivity values greater than 1000 ohm-m. Lower resistivity values (< 1000 ohm-m) were obtained at locations where the overlying layer is very conductive leading to a screening effect and an underestimation of the resistivity of the expectedly infinitely resistive basement rock.

3.2.3 Basement Structures

Basement structures such as fractures and faults are often discernable from VES curves and usually manifest as inflections on the rising segment of the VES curves (Olorunfemi and Fasuyi, 1993, Olorunfemi, 2009, Ademilua and Olorunfemi, 2011, Ojo and Olorunfemi 2013a&b). Using the above characteristics to interpret the VES curves, partially weathered/fractured basement columns were delineated in 233 (45.5%) of the 512 VES curves processed. The frequency of occurrence of such basement fractures is however controlled by the geology – much higher in quartzitic and migmatitic gneiss rocks than in charnockite and granite.

3.2.4 Aquifer Types

Two major aquifer units were delineated in the study area. These include the weathered basement and the partly weathered/fractured basement. The two aquifer units occur in five combinations as observed by Olorunfemi and Fasuyi, 1993. The weathered layer however remains the main aquifer unit.

3.3 Groundwater Potential Map

In basement complex terrain, groundwater occurs in weathered and or fractured basement columns (olorunfemi and Olorunniwo, 1985; Olorunfemi and Fasuyi, 1993). The effective porosity of these two aquifer units determines the storage capacity whereas the connectivity of the pore spaces and hence the aquifer permeability, determines the groundwater yield. Although the weathered layer is porous, its permeability and hence the groundwater yielding capacity is limited by the clayey nature of the aquifer unit. Fractured basement porosity and permeability are enhanced by fractures and network of joints and shear zones which assist groundwater flow. Basement complex profile with both weathered and fractured basement aquifers usually have characteristically high groundwater yield (Olorunfemi et al., 1993; Olorunfemi, 2008). However, the nature of the weathered basement and the intensity of fracturing is determined by the geology. For example migmatitic and quartzitic rocks have tendency for higher degree of fracturing than metasediments (schist) and charnockitic rocks (Olorunfemi and Olorunniwo, 1985 and Olorunfemi and Fasuyi, 1993). Most areas underlain by crystalline rocks are characterized by high relief with high run-off and low infiltration (or recharge) rates, making geomorphology a factor in groundwater potential evaluation (Ariyo and Adeyemi, 2009).

Aquifer permeability constitutes the most important hydrogeological parameter in groundwater yield and hence groundwater potential assessment. In basement complex terrain, permeability is aided by faults, fractures and network of joints and shear zones. One of the established means of determining faults, fractures and joints is through lineament mapping from topographical maps, satellite imageries and other remotely sensed imageries. Such generalized lineaments are further processed for hydro-lineaments (lineaments that are hydrogeologically relevant). The degree of fracturing or inhomogeneity can also be established through the determination of electrical coefficient of anisotropy (λ) which has been found to be related to groundwater yield (Olorunfemi et al., 1991).

In this study, thematic maps of geology, geomorphology, hydro-lineament density, aquifer thickness, and electrical coefficient of anisotropy were integrated to generate the groundwater potential map of Akure metropolis. The maps were imported into the GIS for storage followed by the allocation of weight to each layer and different score to each attribute within the layers (Table 1) using reclassification and buffer generation methods. The groundwater potential map was finally composed using overlay function to combine all the layers.

Figure 13 shows the generated groundwater potential map for the Akure Metropolis. The map classified the study area into very low, low, moderate and high groundwater potential zones based on Carruthers and Smith, 1992 and Akinluyi, 2013 groundwater yield-potential classification in a typical basement complex environment. The map was validated using twenty five geo-referenced borehole groundwater yield data with a 76% correlation between the borehole yield rating and the groundwater potential map rating (Table 2). 3.2% of the survey area (comprising parts of Araromi, Igbatoro, Army Barrack and Ondo Road) falls within the very low groundwater potential zone with groundwater yield of < 0.5 l/s; 75.8% of the study area comprising Road Block area, Obele, parts of Shagari Estate, Odudu, Fanibi, Akure Stadium, Owena Motel area, Igbatoro, Oshinle, Ijoka, parts of Oke Aro, Adofule, Pelebe Ilekun, School of Agriculture and parts of Benin Garage) falls within the low groundwater potential zone with groundwater yield of 0.5 – 0.99 l/s while 21% 9 comprising of parts of FUTA, Benin Owena River Basin area, Alagbaka, Idita, parts of Obele Estate, north of Adofule, Ijapo Estate etc) falls within the moderate groundwater potential zone with yield of 1.0 – 1.49 l/s and a tiny fraction or 0.03% falls within the high groundwater potential zone (> 1.5 l/s) in the northeastern and south central part.

Table 1: Multi-criteria evaluation (MCE) parameters for the generation of groundwater potential map.

S/N	Thematic Map (Layer)	Attribute	Rating	Weightage (%)
1	Hydro-lineament , Density	0 – 0.17	1	40
		0.17 – 0.47	3	
		0.47 – 0.81	4	
		0.81 – 1.179	5	
2	Geology (Lithology)	Charnockite	1	40
		Biotite Granite	2	
		Migmatite Gneiss	3	
		Porphyritic Granite	5	
3	Hydro- Geomorphology	Rsidual Hill	1	15
		Pediment	2	
		Pediplain	3	
		Etchplain	4	
4	Aquifer Thickness (m)	0-10	1	10
		10-20	2	
		20-40	3	
		40-176	4	
5	Coefficient of Anisotropy	1.0-1.12	1	10
		1.12-1.19	2	
		1.19-1.30	3	
		1.30-2.00	4	

Table 2: Validation parameters for the groundwater potential map

S/N	Borehole Geographic Co-ordinate		Groundwater Yield/Potential Rating	Rating from Groundwater Potential Map
	Northings (m)	Eastings (m)		
1	792741.455	738424.948	0.93 (L)	L
2	793126.481	739276.377	1.20(M)	M
3	796356.600	742643.191	1.20(M)	M
4	796867.706	744129.232	1.20(M)	M
5	799067.926	744782.074	0.75(L)	L
6	799522.853	740356.969	1.26(M)	L
7	800294.798	741141.960	1.12(M)	L
8	800618.881	747747.666	1.00(M)	L
9	801511.182	744858.545	0.50(L)	L
10	801780.404	743353.525	0.75(L)	L
11	801810.684	743261.315	1.14(M)	M
12	801967.971	740836.250	0.50(M)	L
13	802357.591	748260.774	1.23(M)	M
14	802725.064	741722.525	1.26(M)	L
15	803236.542	739458.474	0.90(L)	L
16	803654.278	749481.846	0.89(M)	L
17	804140.884	748466.734	1.10(M)	M
18	804160.351	739874.441	1.10(M)	L
19	804240.518	743740.482	0.80(L)	L
20	806054.374	737564.021	0.80(L)	L
21	806085.246	737594.558	0.20(VL)	L
22	806392.947	737685.142	0.80(L)	L
23	807085.737	747439.448	0.60(L)	L
24	807113.114	746764.238	1.00(M)	M
25	807487.338	747867.042	0.82(L)	L

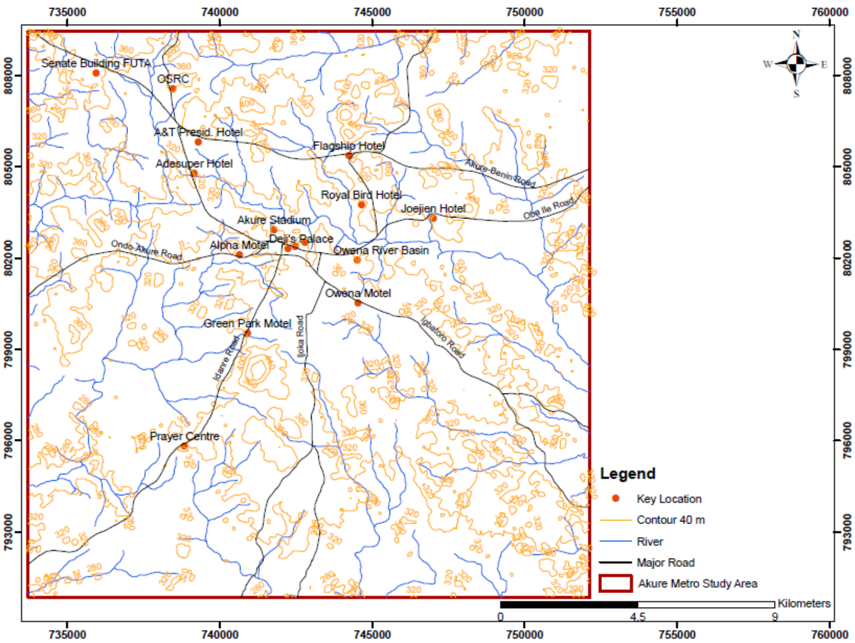

Figure 1: Map of Akure Metropolis – the study area, showing the topographic Variations

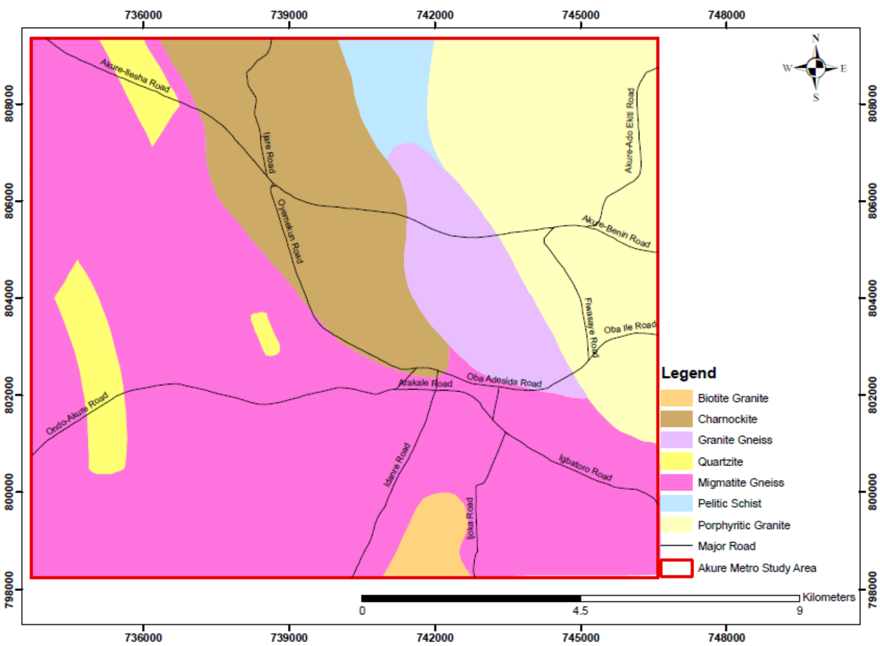

Figure 2: Geological map of Akure Metropolis (after Owoyemi, 1996)

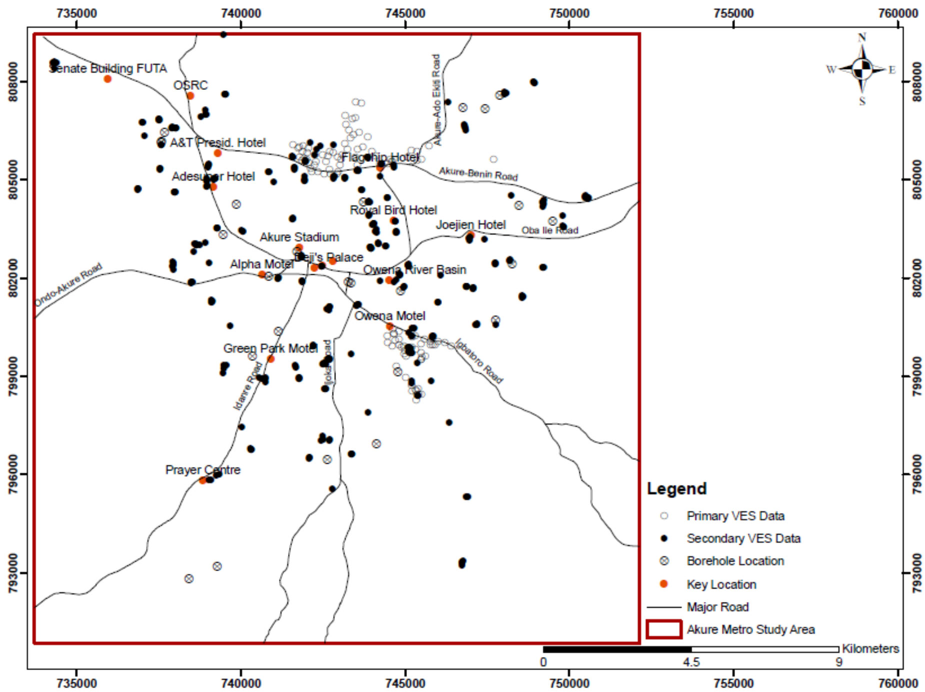

Figure 3: Geophysical (VES) and borehole data acquisition map

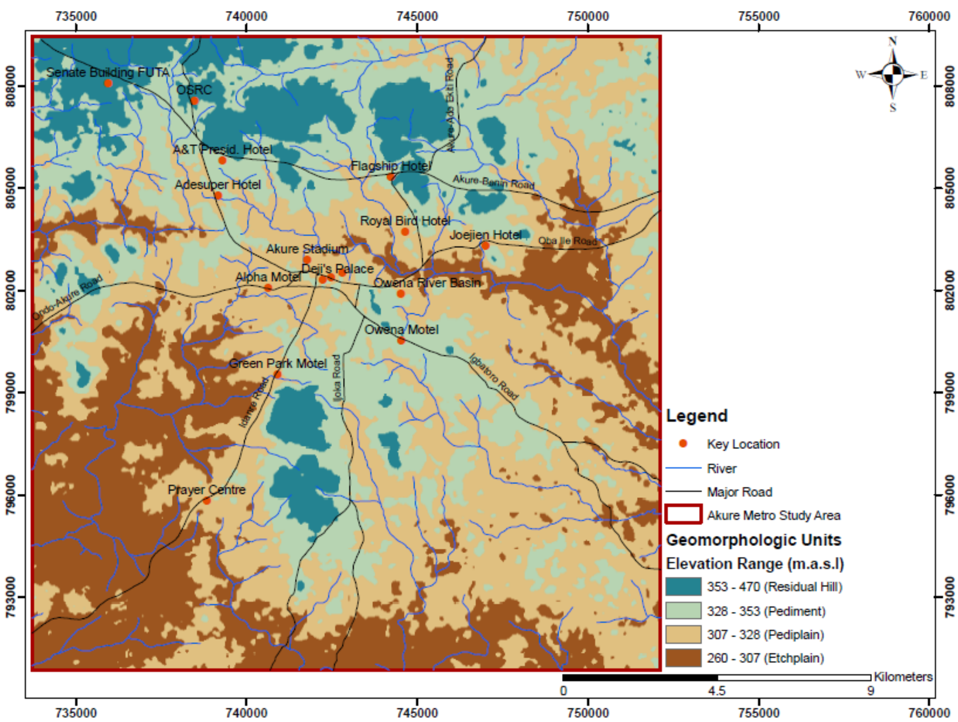

Figure 4: Geomorphological map of Akure Metropolis

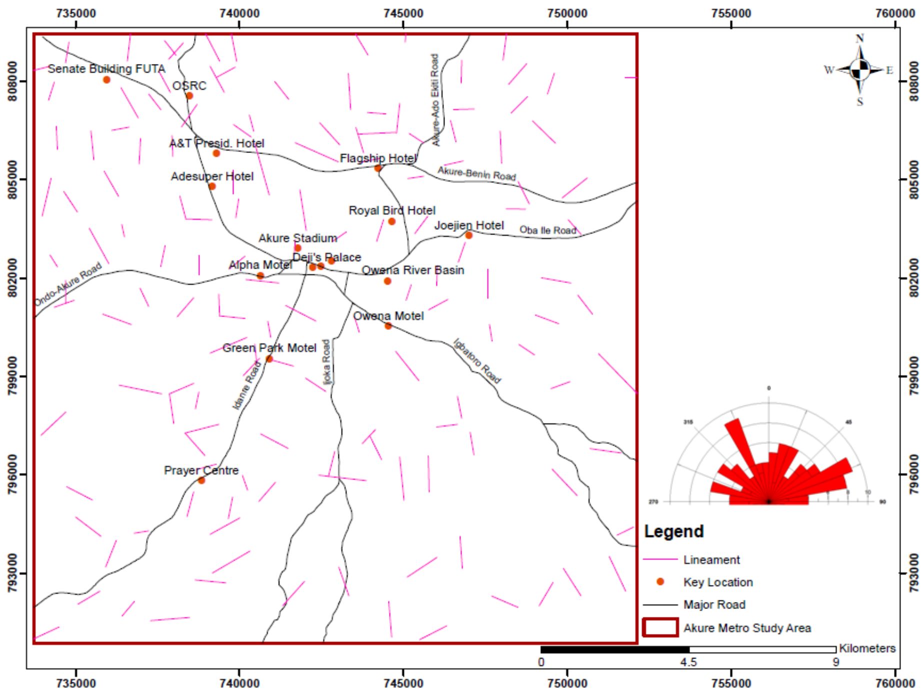

Figure 5: Lineament map of Akure Metropolis

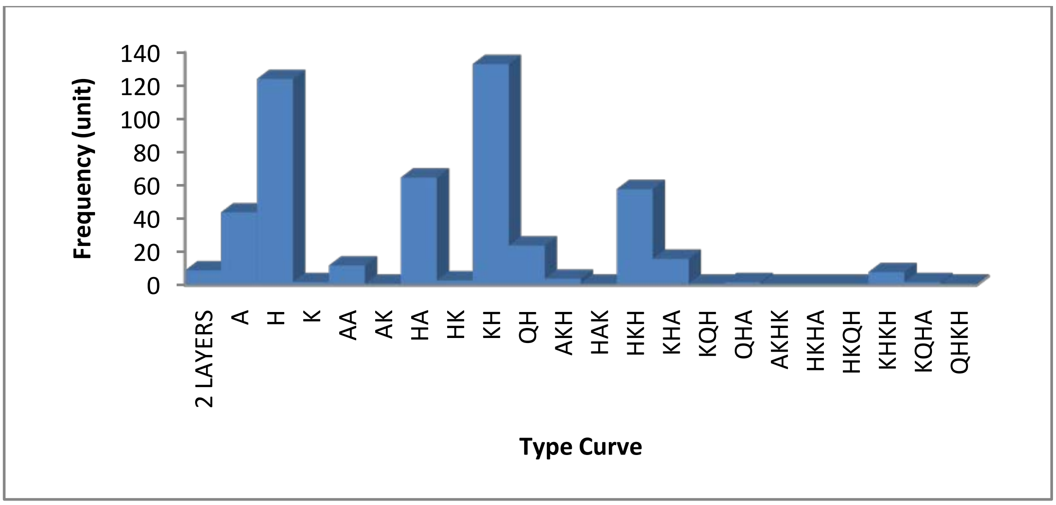

Figure 6: Histogram of the VES type curves.

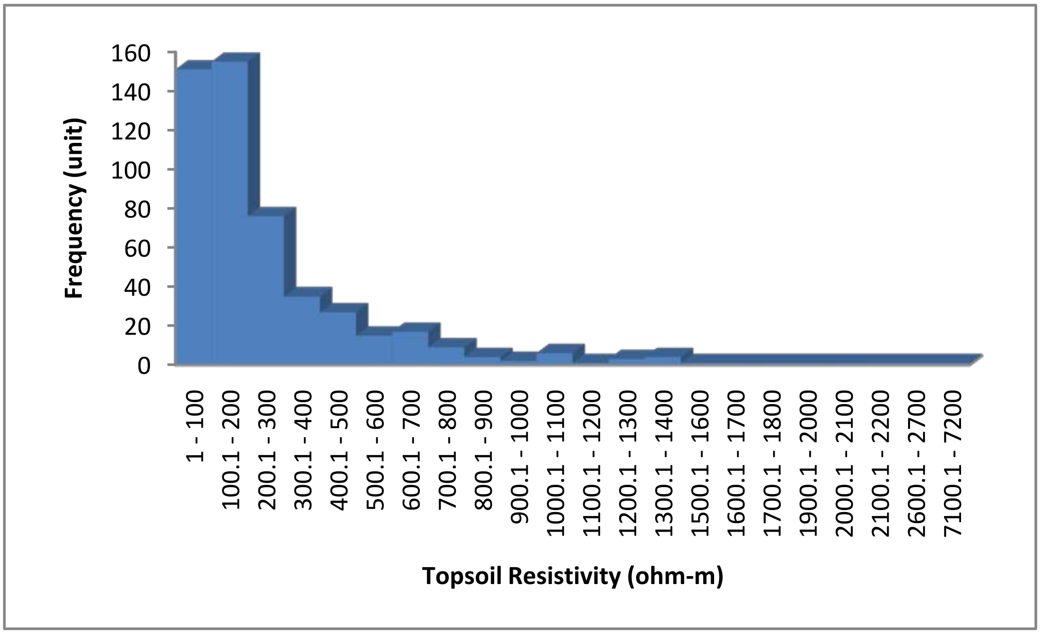

Figure 7: Histogram of the topsoil resistivity.

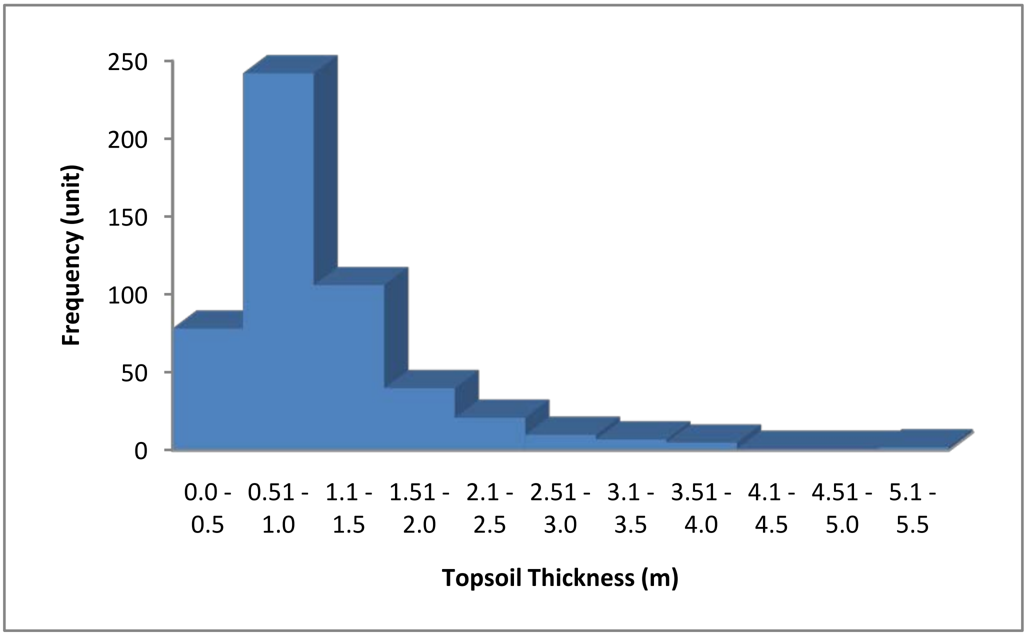

Figure 8: Histogram of topsoil thickness.

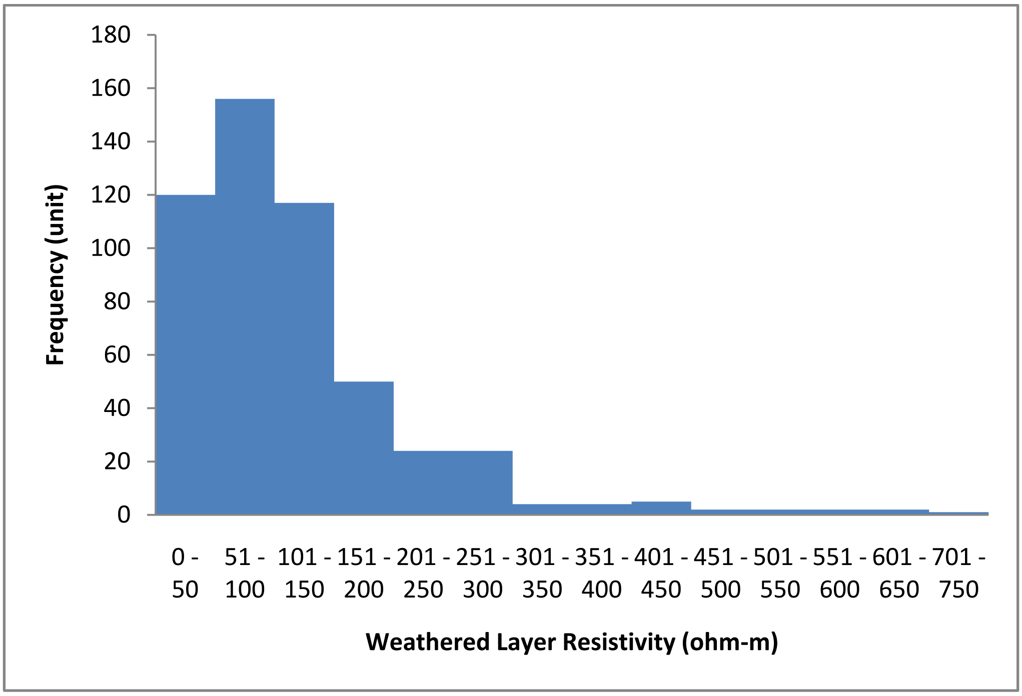

Figure 9: Histogram of weathered layer resistivity.

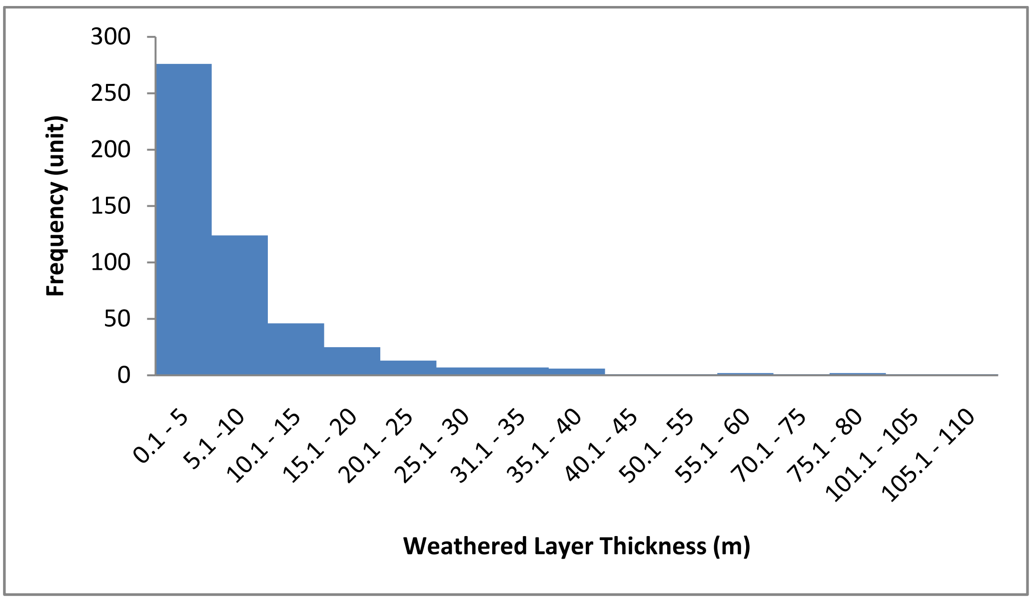

Figure 10: Histogram of weathered layer thickness.

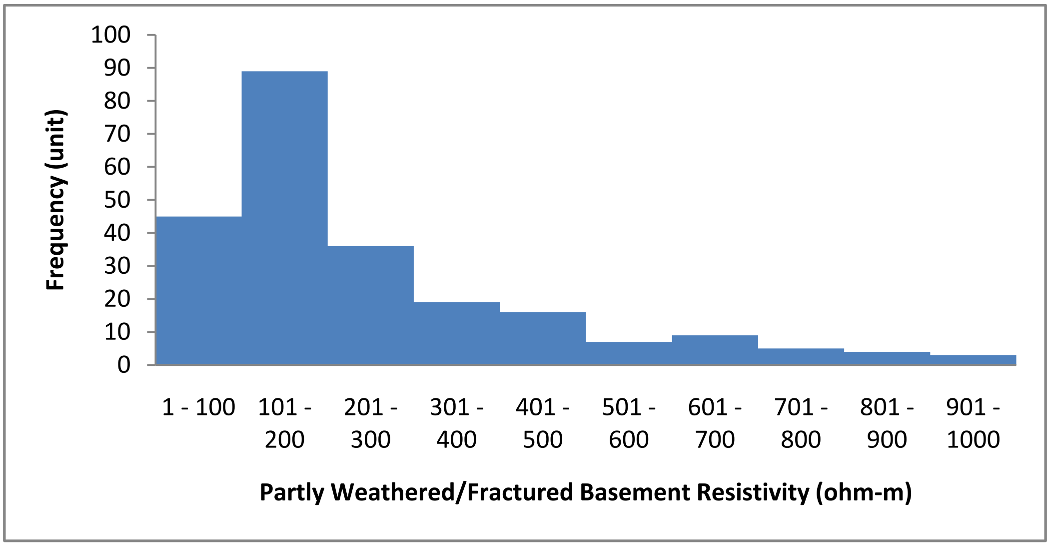

Figure 11: Histogram of partly weathered/fractured basement resistivity.

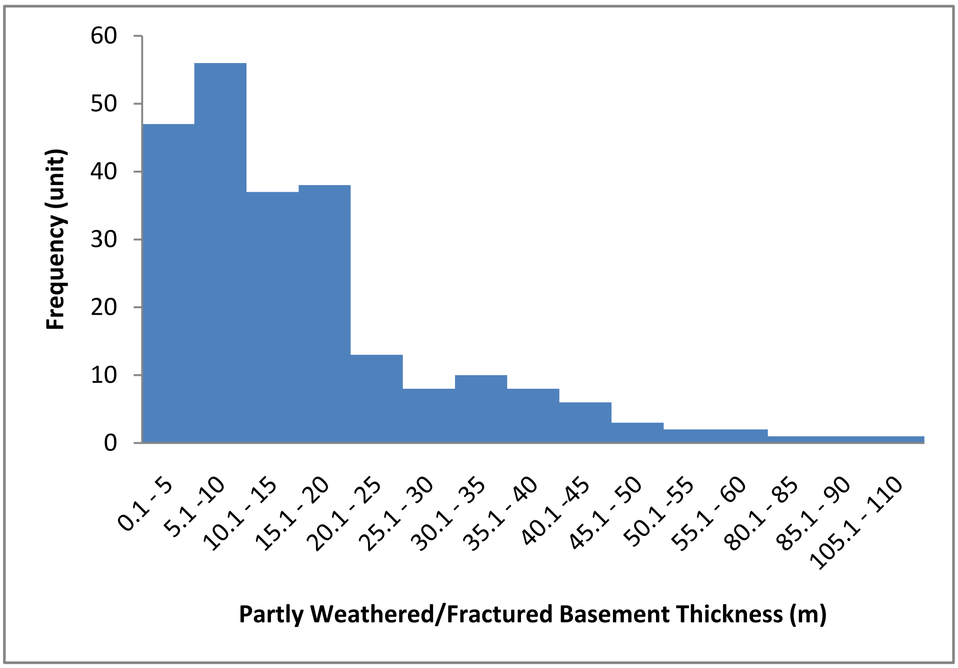

Figure 12: Histogram of the partly weathered/fractured basement thickness.

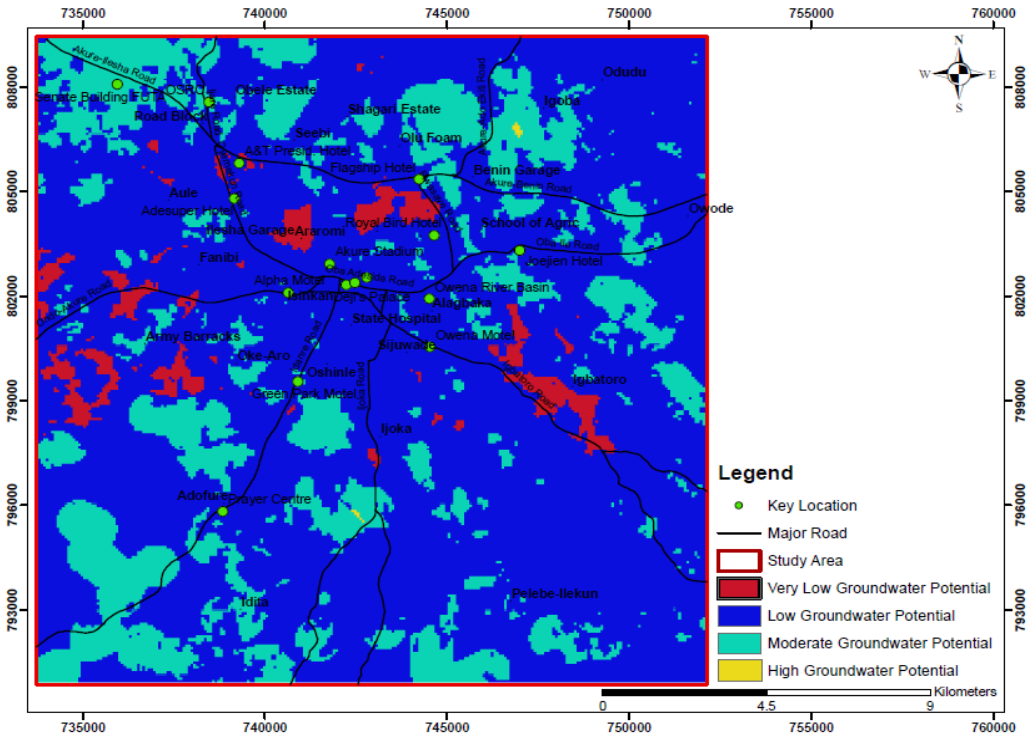

Figure 13: Groundwater potential map of Akure Metropolis

4 Conclusion

Geomorphological, geological and geoelectrical data were integrated in the GIS environment to assess the groundwater potential of the Akure Metropolis. The study area is underlain by the Migmatite-Gneiss-Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and Unmetamorphosed dolerite dykes.

Subset Topographic map, Aster DEM, Landsat EMT+ surface reflectance image of 2002 of the study area were used to generate geomorphological map and lineament map of the Akure Metropolis. The identified geomorphological units include residual hills, pediments, low land pediments and etch plain. The satellite-imagery-delineated lineaments predominantly trend NNW-SSE, ENE-WSW and NNE-SSW. Five hundred and thirteen (513) VES data set from 116 localities were acquired (primary and secondary), processed and interpreted quantitatively using the partial curve matching technique and computer assisted 1-D forward modeling with W-Geosoft software.

The VES type curves range from 2-layer to three-layer H; four-layer AA, HA, KH and QH; five-layer AKH, HAK, KHA, KQH and QHA and six-layer HKHA, HKQH, KHKH, KQHA and QHKH type. The KH and H type curves predominate with frequencies of 26% and 24% respectively. The VES interpretation results delineate four main subsurface geologic units. These include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement bedrock. Two major aquifer units were delineated in the study area. These include the weathered basement and the partly weathered/fractured basement. The two aquifer units occur in five combinations as observed by Olorunfemi and Fasuyi, 1993. The weathered layer however remains the main aquifer unit.

Thematic maps of geology, geomorphology, hydro-lineament density, aquifer thickness, and electrical coefficient of anisotropy were integrated to generate the groundwater potential map of Akure Metropolis.
The generated groundwater potential map of the area shows that most parts (79%) of the metropolis have very low to low groundwater potential rating (yield of 0.0 - 0.99 l/s) and that the groundwater potential rating is at best of moderate level rating (yield of 1.0-1.49 l/s). The high groundwater potential zones are isolated and very limited.

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