A Further Comprehensive Approach To Assessing The Groundwater Potential Of The Basement Complex Terrain Of Ekiti State, Southwestern Nigeria.

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ABSTRACT: Hydrogeophysical investigation as well as analyses of hydrogeomorphological, geologic/hydrogeologic, electrical resistivity and borehole data has been carried out in the Basement Complex terrain of Ekiti State, Southwestern Nigeria. This is a second and further step to validate and consolidate on the results from the earlier preliminary approach of Bayowa et'al (2014b) with a view to identifying the hydrogeologic/geoelectric characteristics of the area and classifying the area into different groundwater potential zones. The VES interpretation results were used for aquifers identification; aquifers geoelectric parameter determination and for the calculation of the overburden coefficient of anisotropy for each of the parametric VES. Hydrogeomorphological, lineament density, lineament intersection density and overburden coefficient of anisotropy thematic maps were produced and integrated for the classification of the study area into different groundwater potential zones. The reliability of the groundwater potential map was checked with the existing groundwater yield data. The groundwater yields of boreholes located on quartzitic rocks had a mean of 1.56 l/s while the mean groundwater yield from metasediment (schist) was 1.14 l/s. The study area was characterized into five different groundwater potential zones which are very low, low, moderate, high and very high. Ijelu-Ekiti, Ayede, Ipao, Ikole, Oye. Ayegbaju, Ofale-Ijero and Omuo-Ekiti were classified by very low groundwater potential while low groundwater potential was established in Ijesa-Isu, Iludofin, Iyemero, Esure, Otun, Osi, Iropora, Ifaki, Ikun, Ijero, Ado, Emure and Ise/Orun. Igbara-Odo, Ilawe, Ikogosi, Ido, Ipole-Iloro, Ipere, Ayetoro, Ikoro, Ifisin, Ilogbo, Isinbode, Erinmope and Iwaro fall within moderate groundwater potential zones. High groundwater potential was recorded in Ijan, Okemesi, Aramoko, Ilemeso, Ikere, Etisun and Itawure. Efon-Alaaye and Ilumoba fall within very high groundwater potential zone. The groundwater potential of Ekiti State is generally of very low –moderate level rating. There are however few areas with high to very high groundwater potential.

Keywords: overburden, transmissivity, hydrogeophysical, groundwater, aquifer

1. INTRODUCTION

There has been a progressive increase in the population of Ekiti State with the attendant increase in the demand of potable water for both domestic and industrial usages. The gross inadequacy of public water supply necessitated a detailed study involving borehole, geomorphological, hydrogeological and geophysical assessments. Bayowa et al.(2014b) and Olorunfemi et'al (1991) carried out investigations on the electrical anisotropy and groundwater yield in the basement complex area of the southwestern Nigeria. Their findings include amongst others that the groundwater yield in the basement complex area of the southwestern Nigeria generally increases with increase in the overburden coefficient of anisotropy. Teme,. and Oni (1991) used remote sensing techniques to detect groundwater flow in fractured media in hard rock terrain. They were able to use aerial photograph and radar imagery to adequately locate and delineate the extent and frequency of these fractured systems thus making it possible for the siting of productive boreholes at approximately predetermined localities within the basement areas. Mohammed (1992) carried out a geophysical investigation for groundwater development at the Federal University of Technology, Akure. His conclusion was that deep weathered zones and fractured or brecciated basement which are characterized by relatively low resistivity constitute the main aquifer unit in the area. Salem (1999) submitted that fluid transmissivity (layer thickness x permeability) and electric transverse resistance (layer thickness x resistivity) are important parameters in groundwater and hydrocarbon exploration. The determination of these parameters provides a good knowledge of the potential of porous media, because they relate fluid flow to electric current conduction in terms of layer thickness, permeability and resistivity. The author concluded that direct relationships between fluid transmissivity and the electric transverse resistance, with coefficients of correlation of 0.99 (for the aquifers) and 0.94 (for the reservoirs) suggest that an increase in both parameters indicate presence of zones of high fluid potential within the aquifers and the reservoirs. Ademilua (1997) attempted to classify both Ondo and Ekiti States into different groundwater potential zones but was constrained by few VES data points as well as sampled localities. Hence, the groundwater potential map produced by the researcher may not be adequately representative. There is therefore the need for detailed assessment of the groundwater potentials of the state not only to expand the scope of study carried out by the researcher by using detailed hydrogeomorphological, geological/hydrogeological (using the recent satellite imageries of the state) and more geophysical data points spread around towns and villages that cut across the state but also to prepare database for future borehole drilling and development programme in the state. It is the aim of this study to carry out a more detailed evaluation of the groundwater potential of the study area using a borehole-validated synthesis of the results of the geomorphological, hydrogeological and geophysical assessments contained in Bayowa et'al (2014a;2014b***)***] in order to produce a more reliable groundwater potential evaluation of Ekiti State to enhance future groundwater development in the study area.

The Study Area

the study area lies within Latitudes 7º 15' 00" and 8º 10' 00" North of the Equator and Longitudes 4º 45' 00" and 5º 50' 00" East of the Greenwich Meridian. The area covers the whole of Ekiti-State of Nigeria. Ekiti State has 16 Local Government Areas (Figure 1). Some of the major towns in Ekiti-State include Ado-Ekiti, Efon-Alaaye, Aramoko, Ikole,

Ikere, Ijero, Ise, Otun, Ido, Emure, Ifaki, Iyin, Igede, Ilawe, Ode, Oye, Omuo, Ilupeju, Ikoro, Igogo, Iye, Ijesa-Isu, Ayedun, Okemesi, Igbara-Odo, etc. Its capital is located at Ado-Ekiti. Physiographically, the state is divided into: (i) Hilly terrain and (ii) Plains with isolated hill locks. According to http://ekitinigeria.net, the area is mainly an upland zone rising over 250 metres above the sea level and has a rhythmically undulating surface. The area enjoys tropical climate with high rainfall of about 1600 mm and is characterized by two distinct seasons Ayoade (1988***)***. These are the rainy season (April-October) and the dry season (November-March). Temperature ranges between 21^0 and 28^0 C. The mean monthly relative humidity is less than 70%. The South-Westernly wind and the North-East Trade winds blow in the rainy and dry (Harmattan) seasons respectively (http://ekitinigeria.net). The vegetation of the area is of the rain forest type. Tropical forest exists in the south. It is characterized by dense evergreen forest of tall trees with thick vegetation. However, Guinea Savannah occupies the northern peripheries (http://ekitinigeria.net).

Geology

The study area is underlain by the Precambrian rocks of the Basement Complex of Southwestern Nigeria which covers about 50% of the land surface of Nigeria (Figure 2). The Basement Complex forms part of the mobile-belt east of the West African craton and it is polycyclic. The rocks are concealed in places by a variably thick overburden. The major lithologic units according to Rahaman,((1976; 1988)) are the migmatite-gneiss complex; the older granites; the charnockitic rocks; the slightly migmatised to unmigmatised paraschists and metaigneous rocks and the unmetamorphosed granitic rocks. The migmatite-gneiss complex is composed mainly of early Gneiss, mafic and ultramafic bands and the granitic or felsic components. The rock type is the most widespread rock type, covering about half of the study area (Figure 3). The older granites comprises the porphyritic-biotite granite and the medium-coarse grained granite gneiss. The charnockitic rocks are composed of quartz, alkali feldspars, plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite and accessory amount of opaque ore apatite, zircon and allanite. The slightly migmatised to unmigmatised paraschists and metaigneous rocks consist of pelitic schists, quartzites, amphibolites, talcose rocks, metaconglomerates, marbles and calc-silicate rocks. The umetamorphosed granitic rocks manifest as dolerite dykes, pegmatites and quartz veins.

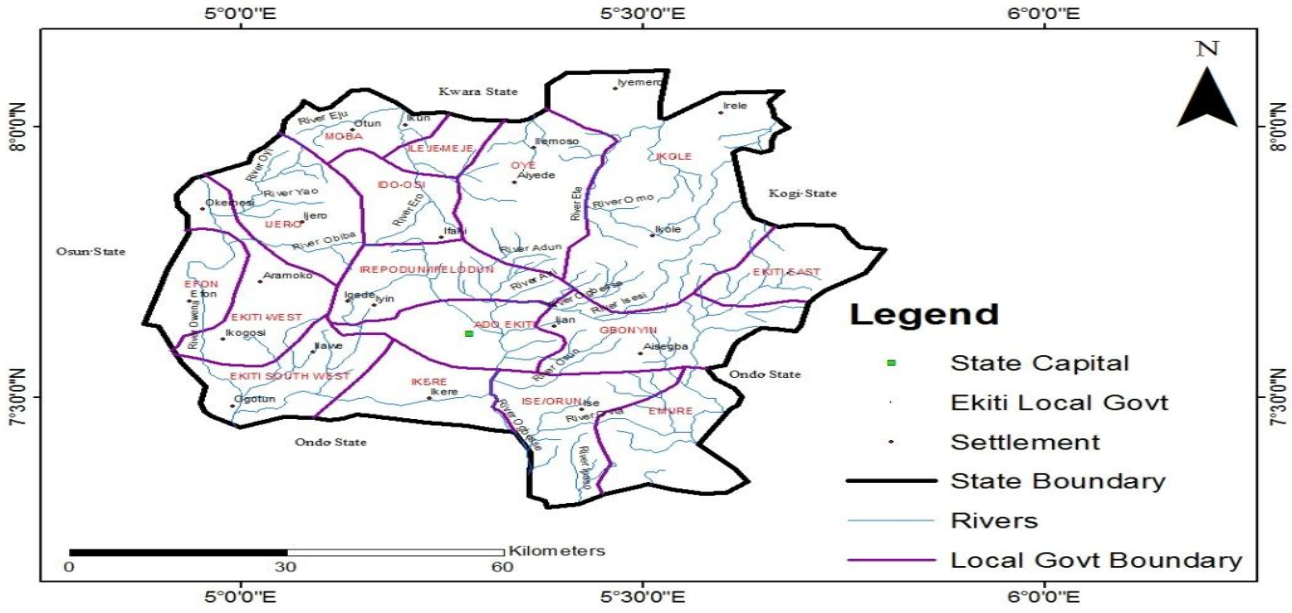

Figure 1: Map of Ekiti – State showing the Local Government Areas. (Digitized from Administrative Map of Ekiti-State, 2000).

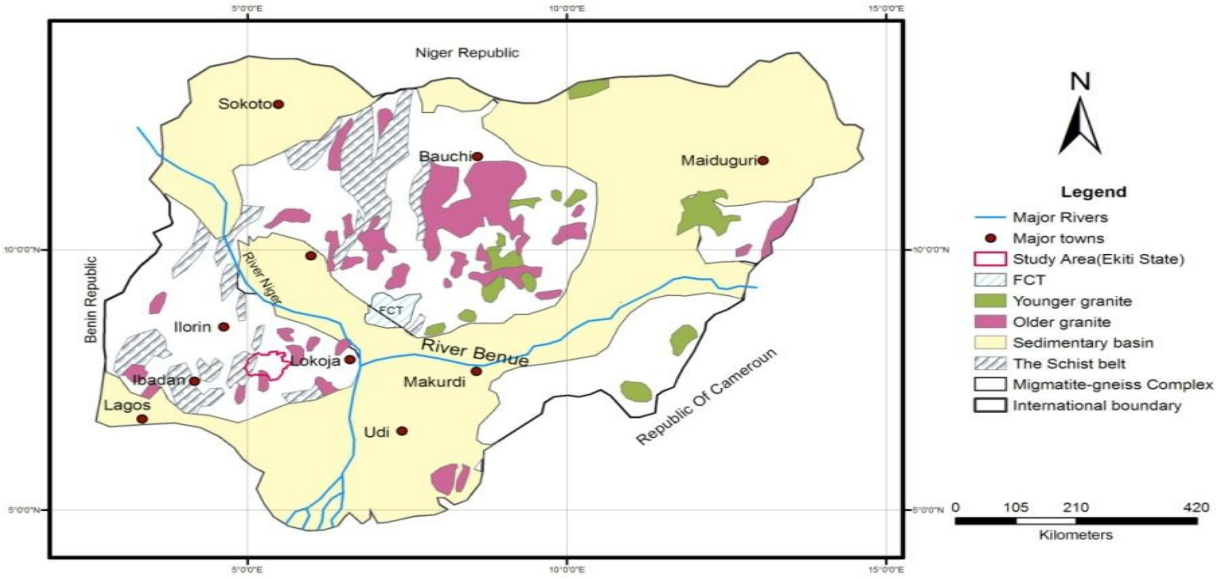

Figure 2: Geological Map of Nigeria (Digitized from Ajibade and Umeji, 1989)

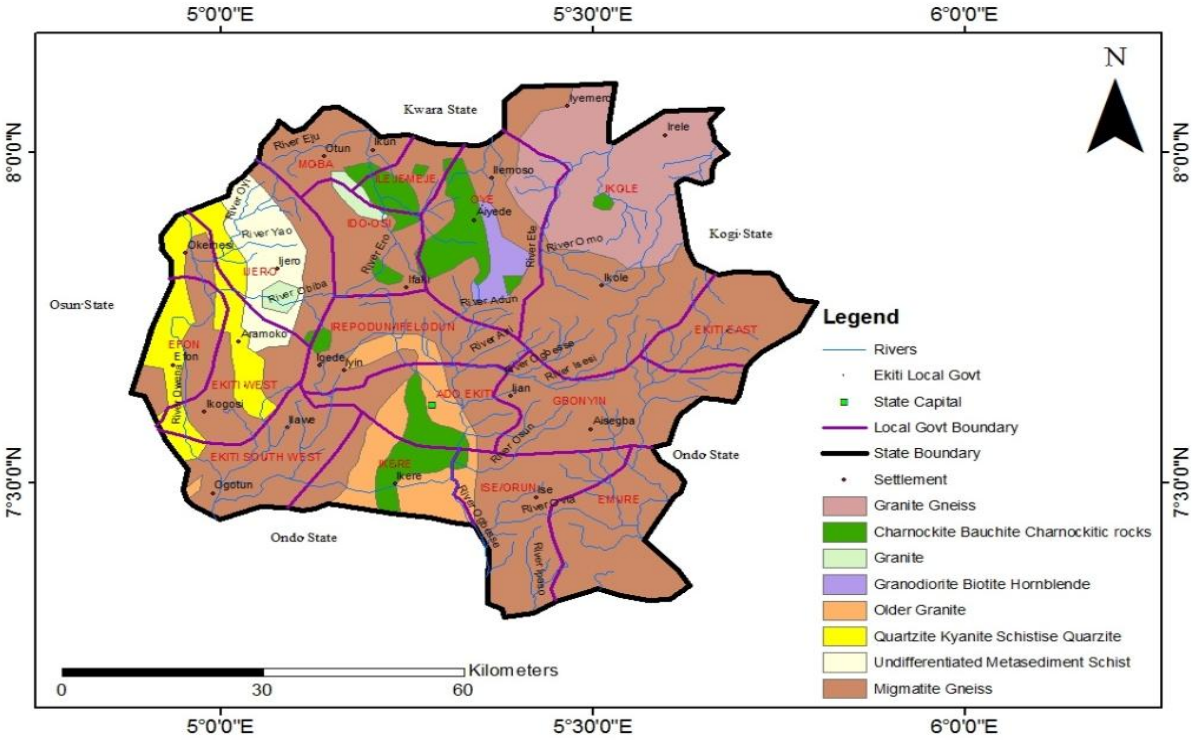

Figure 3: Geologic Map of Ekiti-State (Digitized from Ademilua, 1997)

Methodology

Borehole logs and other ancillary information in the study area were secured from various archives and reputable drillers. Parametric Vertical Electrical Sounding (VES) were carried out on the forty (40) existing boreholes, using the Schlumberger electrode array. The VES data were interpreted quantitatively by partial curve matching and 1-D computer iteration

Hydrogeology

The hydrogeology of an area is controlled by such factors as geology, structures and climate of an area Ademilua, (1997**).** This is because the geological formations underlying the area and the structures determine the types of aquifer to be encountered and the means of recharging them while the climate determines the amount and rate of recharge of the aquifer Mailu (1987); Lewis, (1987); Shemang (1990). Therefore, the hydrogeology of an area is considered under two aspects: (i) surface water and (ii) groundwater.The major surface waters in the study area are rivers Ogbese, Osun, Oni, Osse and Ero. Others are the small tributaries joining the major rivers. It has been observed that wells dug close to the river normally contained water at shallow depths Shemang (1990). However, the water table falls progressively throughout the dry season. Generally, the closer a well is to the river channel, the smaller the fall. This lowering of the water table is mainly controlled by subsurface movement of water into larger river valleys. Within the weathered zone, discontinuous water table occurs and water level shows marked seasonal fluctuations Dan-Hassan (1993). The highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones Olorunniwo and Olorunfemi (1987); Olorunfemi. and Fasuyi (1993). The water below the watertable is generally called the groundwater, and the zone below the watertable is called the zone of saturation (phreatic zone). The overburden coefficient of anisotropy (λ) was calculated for all the parametric VES points to the drilled boreholes and related to the borehole yield. A groundwater potential map was generated based on the relationship between coefficient of anisotropy and borehole yield. The hydrogeomorphological, lineament density, lineament intersection density thematic maps presented by Bayowa et'al (2014a***)*** the coefficient of anisotropy map were integrated for proper classification of the study area into groundwater potential zones. Borehole yield data were used to validate the final groundwater potential map.

RESULTS AND DISCUSSION

Borehole Hydrogeological Characteristics

Borehole yield values obtained in the study area range between 0.1 l/s and 4.1 l/s. Five (5) different aquifer combinations were identified from the analysis of the borehole completion records. The overburden thickness for areas underlain by charnockite is between 2.6 m and 41.6 m with a mean value of 22.1 m while for areas underlain by metamorphic rocks, the range is between 0.9 m and 71.1 m with a mean value of 36 m. The borehole depths for areas underlain by charnockite range from 19 m to 48 m with an average value of 33.5 m. while for areas underlain by metamorphic rocks, the range is between 21 m and 35 m with a mean of 28 m. Figure 4 shows the superposition of borehole site/yield on the solid geology in the study area. The borehole yield from charnockite underlain areas vary between 0.35 l/s and 1.50 l/s with a mean value of 0.93 l/s while that from metamorphic rocks ranges from 0.1 l/s to 4.1 l/s. with a mean value of 1.47 l/s. The groundwater yields of boreholes located on quartzitic rocks has a mean of 1.56 l/s. The mean groundwater yields for metasediment (schist) is 1.14 l/s. The relatively high mean groundwater yields may not be unconnected with the high fracture (lineament) density. Figures 5 and 6 respectively show superposition of borehole points/yields on the lineament and lineament intersection density maps of the study area. The average borehole yield on, close to and outside the lineament and lineament intersection are 1.20, 1.21 and 0.88 l/s and 1.20, 1.50 and 0.89 l/s respectively. This analysis showed that boreholes located on or close to lineament and or lineament intersection have relatively high groundwater yield. The deduction is corroborated by the findings of Edet (1996). Edet, et'al (1994); Edet and Okereke (1997).

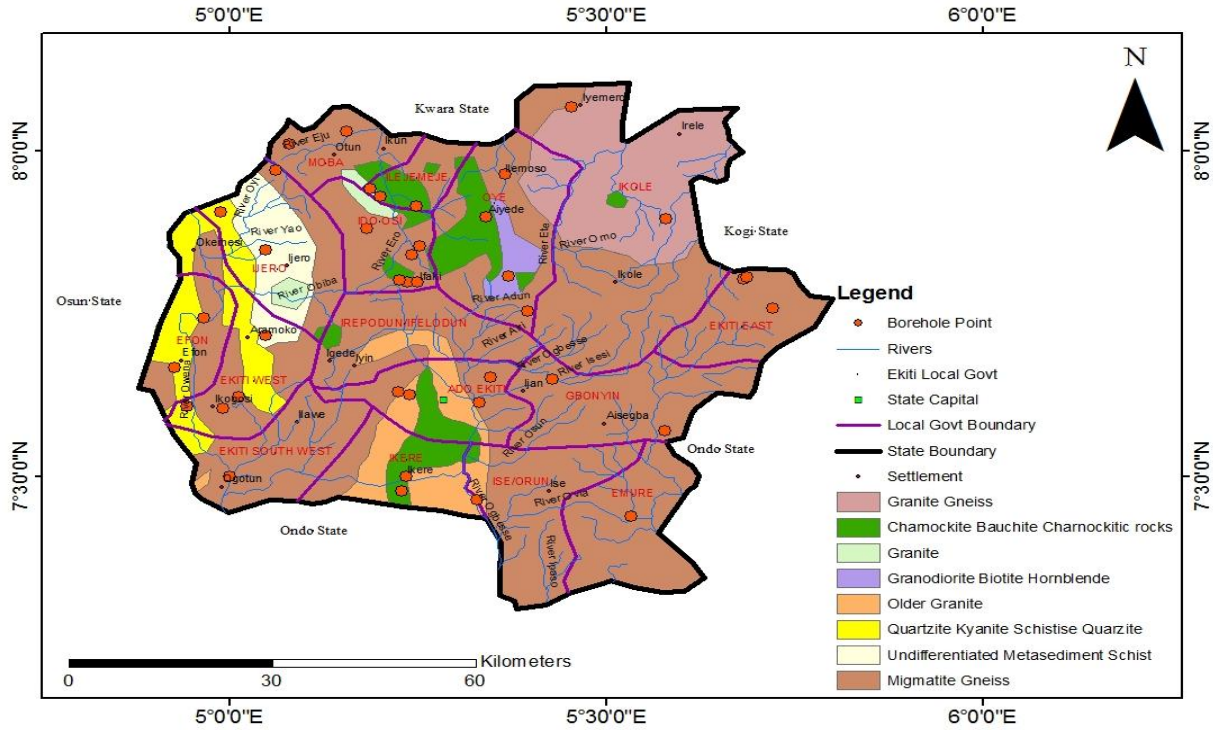

Figure 4: Superposition of Borehole Points on the Solid Geology.

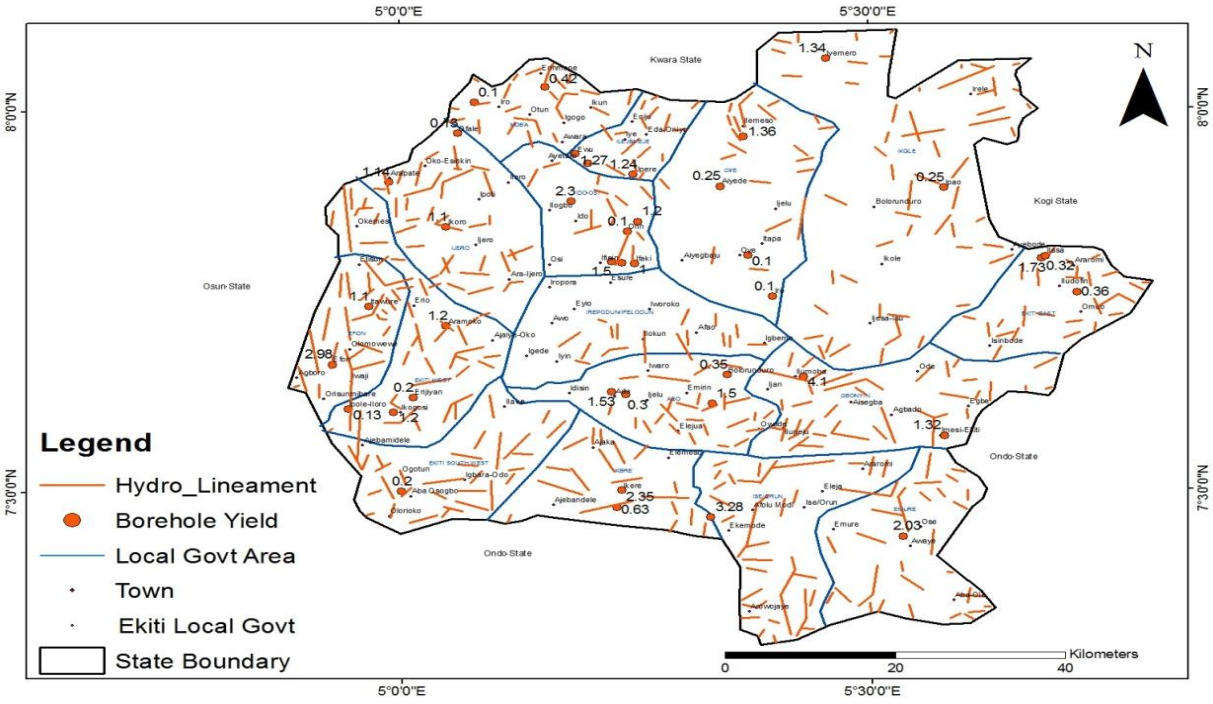

Figure 5: Superposition of Borehole Points/Yields on Hydro-Lineament Map.

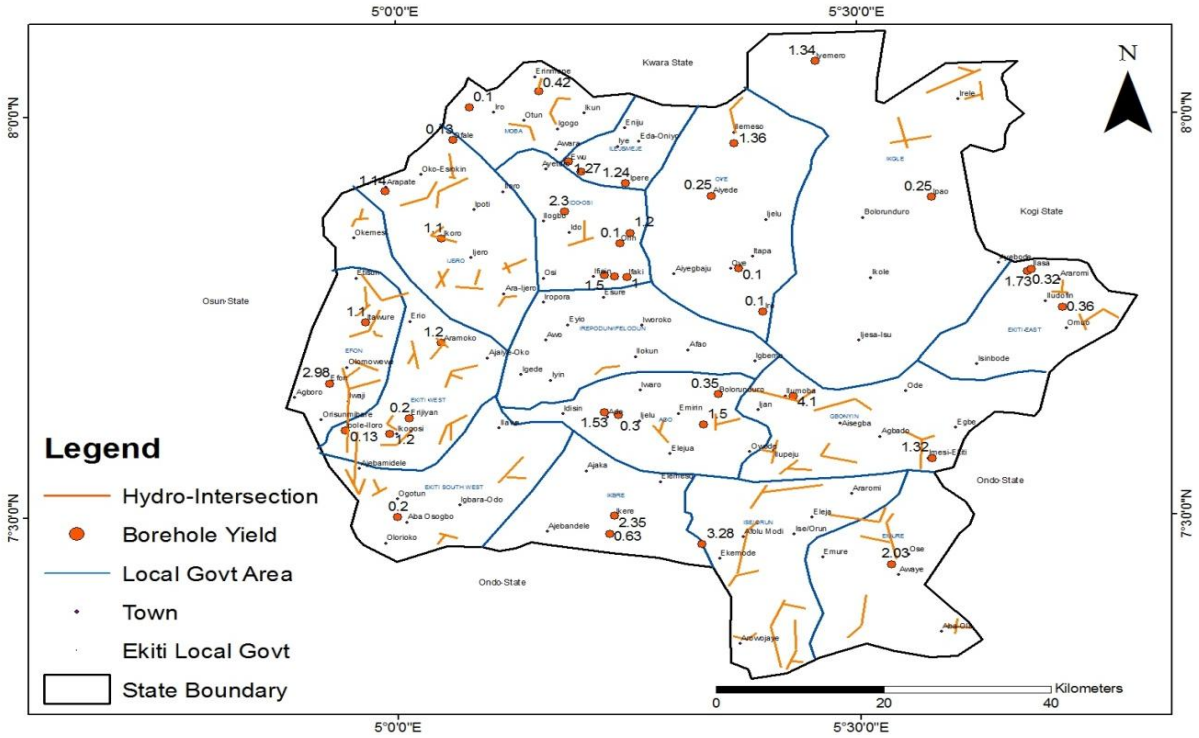

Figure 6: Superposition of Borehole Points/Yields on Lineament Intersection Map.

Deduction from Overburden Coefficient of Anisotropy and Groundwater Yield Parametric Cross Plot.

In an attempt to partition the study area into different groundwater potential zones, the coefficient of anisotropy (λ) was calculated for each of the parametric VES to the drilled boreholes in the study area. The value for the electrical coefficient of anisotropy (λ) for each of the drilled borehole localities ranges between 1.00 and 1.60 units. The values obtained in the present study fall within the range obtained for areas underlain by metamorphic rocks in the southwestern part of Nigeria Olorunfemi, et'al (1991). Based on the fact that there is a strong relationship between the electrical coefficient of anisotropy and the borehole yield value of a particular area Olorunfemi, et'al (1991), the coefficient of anisotropy and borehole yield values were cross plotted as shown in Figure 7. The figure shows a weak linear correlation between groundwater yield and coefficient of anisotropy of 0.6. The groundwater yield of a basement complex area can be classified in terms of groundwater potentials as shown in Table 1. Borehole yields in the range of 0.1 – 1.0 l/s are classified as low Carruthers and Smith (1992). The subsequent classifications are aided by Olorunfemi,(2008) and groundwater yield data spread on Figure 7. Table 2 classifies the coefficient of anisotropy in terms of groundwater yield values. The five ranges of values for the electrical coefficient of anisotropy were brought into ArcGIS environment using the kriging method to classify the study area into different groundwater potential zones (Figure 8).

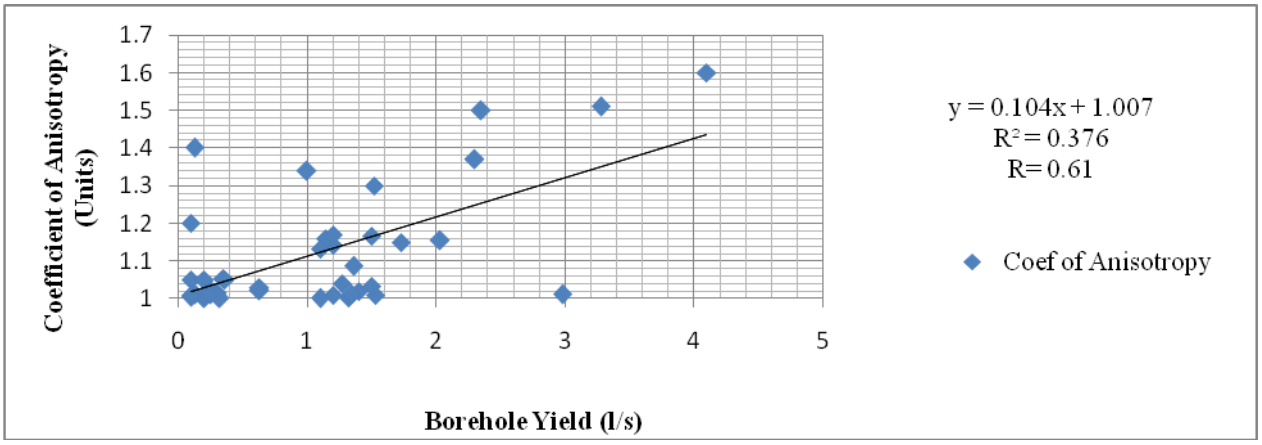

Figure 7: Coefficient of Anisotropy Versus Groundwater Yield Parametric Cross Plot for the Study area.

Table 1: Classification of Borehole Yield in terms of Groundwater Potential in the Basement Complex area of Ekiti State

Borehole Yield Range (l/s)	Groundwater Potential
0 – 0.49	Very Low
0.5 – 0.99	Low
1.0 – 1.49	Moderate
1.5 – 2.5	High
> 2.5	Very High

(Adapted from: Carruthers and Smith 1992, Olorunfemi, 2008 and Fieldwork Experience)

Table 2: Classification of Coefficient of Anisotropy in terms of Borehole Yield in the Basement Complex of Ekiti State.

Borehole Yield Range (l/s)	Coefficient of Anisotropy Range (Units)
0 – 0.49	1 - 1.05
0.5 – 0.99	1.06 – 1.11
1.0 – 1.49	1.12 – 1.17
1.5 – 2.5	1.18 – 1.32
> 2.5	> 1.32

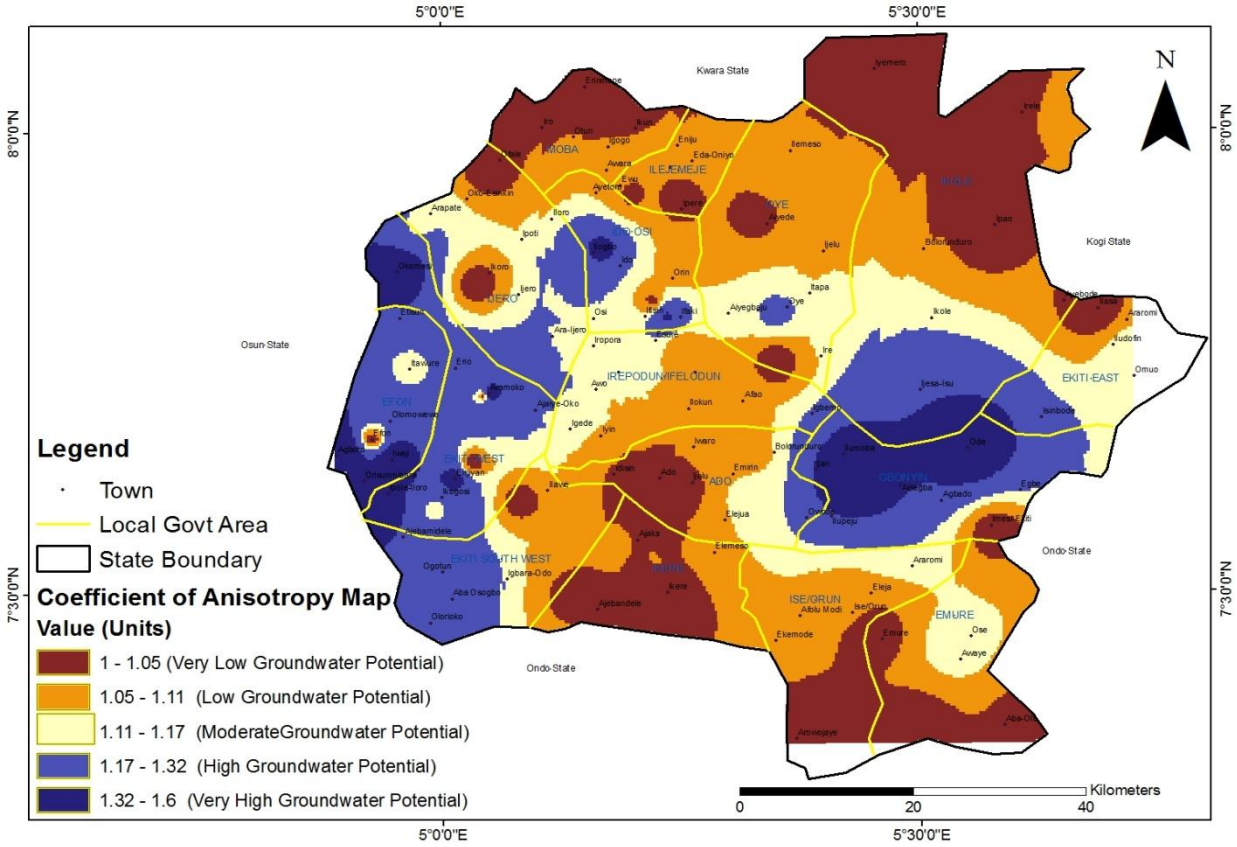

Figure 8: Groundwater Potential Map of the Study area obtained from Coefficient of Anisotropy.

The map shows that areas within Okemesi, Ilumoba, Ode, Ijan and Ipole-Iloro town fall within the very high groundwater potential zone. Aramoko, Ijesa-Isu, Ido and Ogotun are within the high groundwater potential range. Moderate groundwater potential is observed in areas around Ikole, oye, Iloro Eyio, Igede and Ipoti. Area around Iwaro, Iworoko, Ilemeso, Ewu, Ijelu and Iyin are characterized by low groundwater potential while very low groundwater potential is observed around Iyemero, Ipao, Aiyede, Otun, Erinmope, Irele, Emure, Ikere and Ado-Ekiti.

Generalized Groundwater Potential Evaluation of the Study Area

To classify the basement complex area of Ekiti-State into different groundwater potential zones, the following geologic and geoelectric parameters have been integrated in ArcGIS environment.(i) Hydrogeomorphic Conditions,(ii) Hydrogeologic Lineament Density Distribution, (iii) Lineament Intersections Density Distribution and (iv) Electrical Coefficient of Anisotropy and Groundwater Yield Cross Plot Consideration. By applying a trial and error method, the weighted indices in Table 3 (a-d) were used to integrate the hydogeomorphological, lineament density, Lineament intersection density and the electrical coefficient of anisotropy thematic maps. Four different generalized groundwater potential maps were generated and the reliability of each map checked with the existing groundwater yield data and the classification in Table 1. As shown in Table 3 the fourth weighting combination (Table 3 d) gave the highest correlation of 70% and was adopted in this study based on the resulting generalized groundwater potential map (Figure 9). The study area was classified into very low, low, moderate, high and very high groundwater potential zones. The groundwater map showed that areas within Ijelu-Ekiti, Ayede, Ipao, Ikole, Oye. Ayegbaju, Ofale-Ijero and Omuo-Ekiti are characterized by very low groundwater potential while low groundwater potential is observed in areas within Ijesa-Isu, Iludofin, Iyemero, Esure, Otun, Osi, Iropora, Ifaki, Ikun, Ijero, Ado, Emure and Ise/Orun. It is evident on the map that areas within Igbara-Odo, Ilawe, Ikogosi, Ido, Ipole-Iloro, Ipere, Ayetoro, Ikoro, Ifisin, Ilogbo, Isinbode, erinmope and Iwaro are underlain by moderate groundwater potential. High groundwater potential is suspected in areas within Ijan, Okemesi, Aramoko, Ilemeso, Ikere, Etisun and Itawure. However, there are few areas with very high groundwater potential while Efon-Alaaye and Ilumoba are suspected to be underlain by very high groundwater potential. Figure 10 shows the superposition of borehole yields on the final groundwater potential map. A generalized groundwater potential rating was carried out for each local government area in the study. Moba and Oye Local Government Areas have generally very low groundwater potential rating. Ekiti-East, Ido-Osi, Ikole and Irepodun-Ifelodun Local Government Areas are characterized by generally low groundwater potential. Ado-Ekiti, Emure, Ekiti South-West, Ekiti-West, Ijero, Ikere, Ilejemeje and Ise-Orun Local Government Areas have generally moderate groundwater rating. However, Gbonyin and Efon Local Government areas are characterized by generally high groundwater potential.

Table 3: Development of Weighted Index for the Parameters used for Groundwater Potential Map.

Parameters	Weighted Index (%)
Hydrogeomorphic	10
Lineaments Density	40
Lineament Intersections Density	30
Coefficient of Anisotropy and Borehole Yield	20

(a) First Trial (Percentage Correlation = 47%)

Parameters	Weighted Index (%)
Hydrogeomorphic	10
Lineaments Density	35
Lineament Intersections Density	25
Coefficient of Anisotropy and Borehole Yield	30

(b) Second Trial (Percentage Correlation = 38%)

Parameters	Weighted Index (%)
Hydrogeomorphic	05
Lineaments Density	30
Lineament Intersections Density	15
Coefficient of Anisotropy and Borehole Yield	50

(c) Third Trial (Percentage Correlation = 56%)

Parameters	Weighted Index (%)
Hydrogeomorphic	05
Lineaments Density	50
Lineament Intersections Density	30
Coefficient of Anisotropy and Borehole Yield	15

(d) Fourth Trial (Percentage Correlation = 70%)

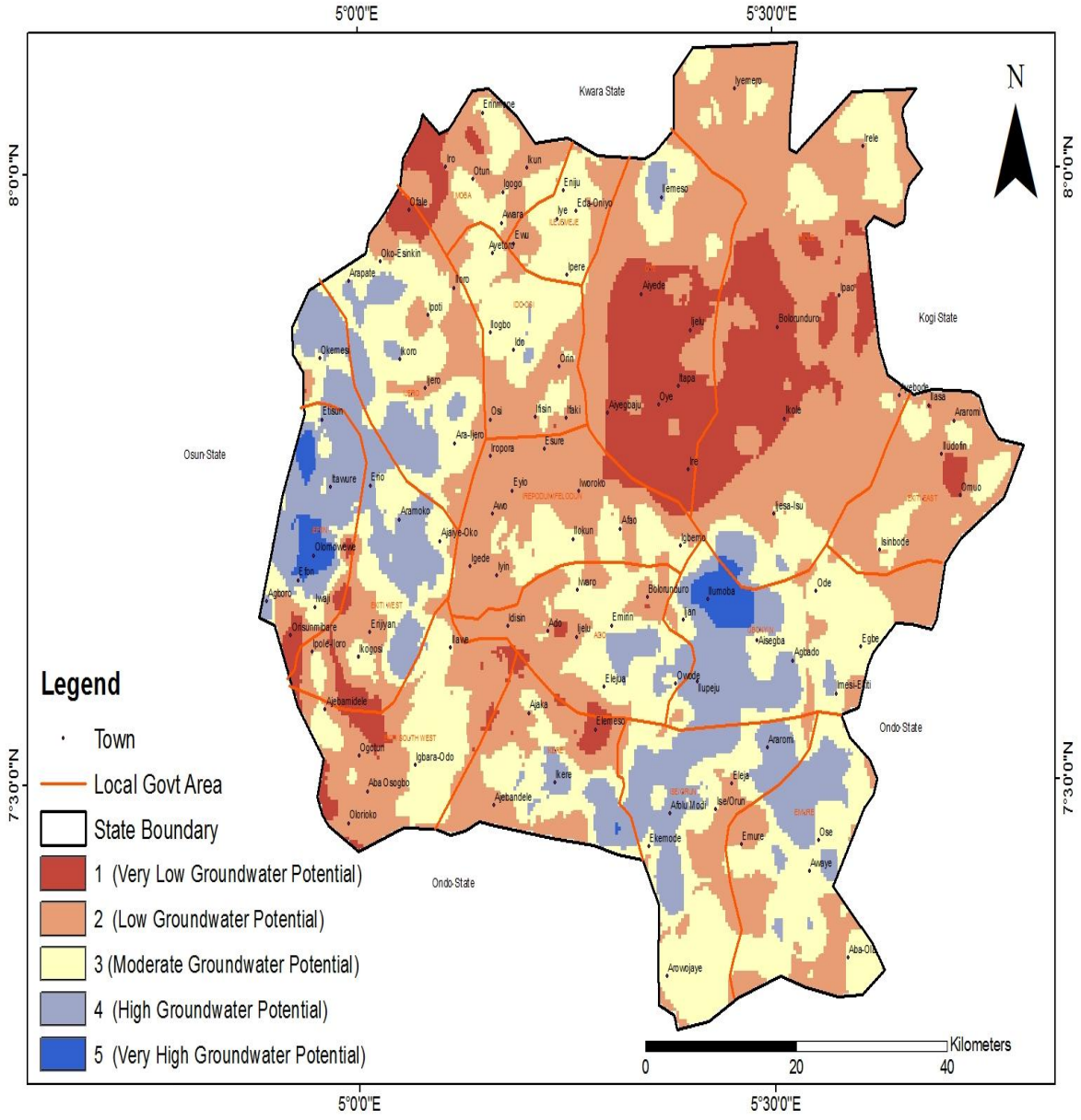

Figure 9: Generalized Groundwater Potential Map of the Study Area.

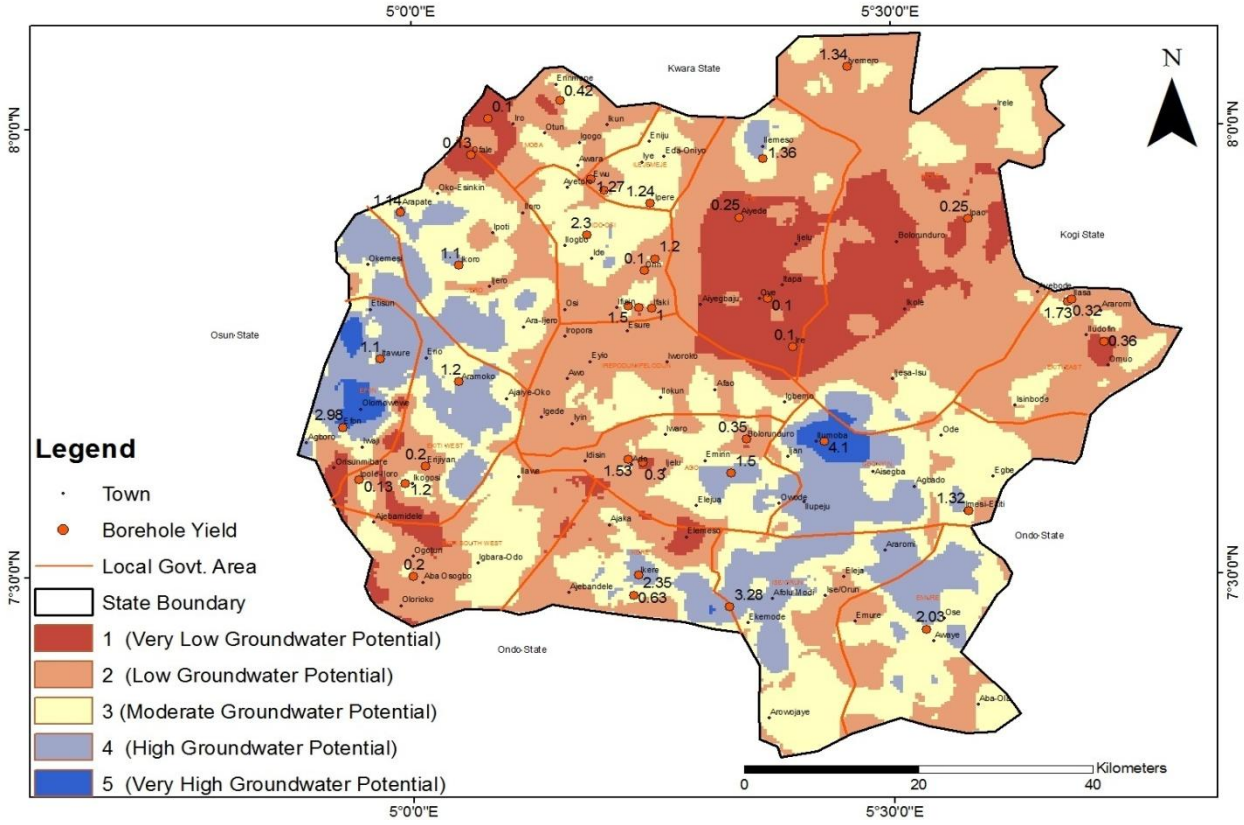

Figure 10: Superposition of the Borehole Yields/Points on Groundwater Potential Map of the Study Area.

Limitation of Groundwater Potential Map

The groundwater potential map shows a regional view of the groundwater potential of the basement complex area of Ekiti State. The heterogeneous and discontinuous nature of basement aquifers makes local variations possible. The groundwater potential zone map was generated from site specific borehole and geoelectric data, geologic/hydrogeologic, hydrogeomorphic and satellite imagery data of the study area. Majority of the GIS data sets are currently represented in vector format, which is convenient due to strong efficiency but can be difficult to manipulate analytically. The processes involved in vectorization as well as rasterization manifests error in a given GIS system.

CONCLUSIONS

The final groundwater potential map shows that the study area is divided into five different groundwater potential zones which are very low, low, moderate, high and very high. Ijelu-Ekiti, Ayede, Ipao, Ikole, Oye. Ayegbaju, Ofale-Ijero and Omuo-Ekiti are located within the very low groundwater potential zone. Low groundwater potential zone covers areas such as Ijesa-Isu, Iludofin, Iyemero, Esure, Otun, Osi, Iropora, Ifaki, Ikun, Ijero, Ado, Emure and Ise/Orun. Igbara-Odo, Ilawe, Ikogosi, Ido, Ipole-Iloro, Ipere, Ayetoro, Ikoro, Ifisin, Ilogbo, Isinbode, Erinmope and Iwaro are located within moderate groundwater potential zone. Ijan, Ilumoba, Okemesi, Efon-Alaaye, Aramoko, Ilemeso, Ikere, Etisun and Itawure fall within the high to very high potential zone. The generalized groundwater potential rating for each local government area in the study area showed that Moba and Oye Local Government Areas show generally very low groundwater potential. Ekiti-East, Ido-Osi, Ikole and Irepodun-Ifelodun Local Government Areas are characterized by generally low groundwater potential. Ado-Ekiti, Emure, Ekiti South-West, Ekiti-West, Ijero, Ikere, Ilejemeje and Ise-Orun Local Government Areas have generally moderate groundwater potential rating. However, Gbonyin and Efon Local Government areas are characterized by generally high to very high groundwater potential The study however concluded that the groundwater potential of Ekiti State is generally of very low – moderate level rating. There are however few areas with high to very high groundwater potential.

RECOMMENDATIONS

The present study has shown that consideration of the geomorphological units, lineament and lineament intersections in a typical basement complex terrain plays vital role in the preliminary assessment of the groundwater potential of such areas on a regional basis. Follow up work with the analysis and interpretation of the vertical electrical sounding electrical resistivity geophysical data helped further to ascertain prolific groundwater potential zones. In view of the appreciable success obtained in this study, the method adopted by integrating the hydrogeomorphological, lineament and lineament intersection and the coefficient of anisotropy constrained groundwater thematic maps to produce the final groundwater potential map of Ekiti State is

recommended for future similar regional groundwater potential study within the basement complex terrain.

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