# Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area southwestern Nigeria

# Povezava daljinskega ugotavljanja in GIS za oceno potenciala podtalnice v kristalinični podlagi območja Ekiti v jugozahodni Nigeriji

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**Abstract:** Occurrence of groundwater in the Basement Complex terrain of Ekiti area, southwestern Nigeria is controlled by secondary porosities developed through weathering and fracturing of the crystalline bedrocks. Here, the aquifers are characteristically discontinuous (localized) warranting assessment of the groundwater potential of the area to serve as a guide for groundwater exploration. Remote sensing (RS) and Geographical Information System (GIS) have been useful in assessing, monitoring and conserving groundwater occurrence. Hence, this paper presents the integrated approach of RS and GIS to groundwater potential zonation in the study area. Thematic maps of geology, geomorphology, lineament, slope, drainage and drainage density were prepared and integrated using ArcGIS 9.1 software to produce the groundwater potential map of the study area. The GIS evaluation produced a groundwater potential map in which the study area was categorized into zones; very good, good-moderately good and poor. Furthermore, superimposition of the groundwa-

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ter yield data from the study area on the groundwater potential map revealed that there are more number of high-yield wells in the favourable zones (very good to good-moderately good) indicated by the GIS approach. This study highlights that the groundwater potential map would apart from its role as exploration guide be useful for the development of sustainable groundwater scheme in the area.

**Izvleček:** Navzočnost podtalnice v stari podlagi območja Ekiti v jugozahodni Nigeriji je odvisna od sekundarne poroznosti, ki je posledica preperelosti in razpokanosti kristaliničnih kamnin. Značilno za vodonosnike v njih je, da so nepovezani (lokalizirani) in je zato mogoče podatke o potencialu podtalnice v njih uporabiti kot vodilo za njeno sledenje. Daljinsko ugotavljanje (RS) in geografski informacijski sistem (GIS) sta uporabni orodji za ocenjevanje, spremljanje in varstvo podtalnice. V članku je opisana povezana uporaba RS in GIS za zoniranje potenciala podtalnice na raziskovanem ozemlju. Izdelane tematske karte geologije, geomorfologije, lineamentov, nagiba reliefa, površinskih vodnih tokov in njihove gostote so združili s programsko opremo ArcGIS 9.1 v karto potenciala podtalnice raziskovanega ozemlja. Na tej karti, izdelani z uporabo GIS, je ozemlje razdeljeno na območja dobrega, dobrega do zmerno dobrega in slabega potenciala. Ob prekritju karte izdatnosti podtalnice na raziskovanem ozemlju s karto njenega potenciala se je dalje izkazalo, da so visoko izdatni vodnjaki številnejši v ugodnih območjih (z zelo dobrim in dobrim-zmerno dobrim potencialom), kakor so bili določeni z metodologijo GIS. Iz raziskave izhaja, da je karto potenciala podtalnice mogoče uporabiti ne le kot vodilo pri sledenju, vendar tudi za trajnostno gospodarjenje s podtalnico na danem ozemlju.

**Key words:** Remote sensing, GIS, groundwater potential zonation, Ekiti area, Basement Complex, thematic maps, high yield wells.
**Ključne besede:** daljinsko ugotavljanje, GIS, zonalnost vodnega potenciala, območje Ekiti, kristalinična podlaga, tematske karte, vodnjaki visoke izdatnosti

## Introduction

Water is an important constituent of all forms of life and is required in sufficient quantity and acceptable quality to meet the ever increasing demand for various domestic, agricultural and industrial processing operations. This requirement is hardly fulfilled because 97.5 % of the world global water is saline existing in the ocean, 69.5 % of the remaining 2.5 % world global water that is fresh is locked up in glaciers/permafrost while 30.1 % and 0.4 % of it represent groundwater and surface/atmospheric water respectively (http://ga.water.usgs.gov/edu/waterdistribution.html). Surface water on the one hand is prone to seasonal fluctuations and contamination through anthropogenic activities while groundwater on the other hand is more in quantity, readily available as it exists in virtually all geologic formations and is naturally protected from direct contamination by surface anthropogenic activities. In the basement terrain of Ekiti area, south western Nigeria, availability of surface water is seasonal; during the relatively dry period of November to February each year, shallow groundwater in form of hand-dug wells and boreholes remain the only source of water supply as most streams and rivers are dried up. However, the occurrence and movement of groundwater in this crystalline bedrock setting depend on the degree of weathering and extent of fracturing of the rocks (Oloruniwo & Olorunfemi, 1987).

The highlighted scenario warrants a detailed investigation of the groundwater potential characteristics of the area so that an exploration guide as well as sustainable groundwater management strategy can be developed.

Groundwater prospect in an area is controlled by many factors such as geology, geomorphology, drainage, slope, depth of weathering, presence of fractures, surface water bodies, canals and irrigated fields amongst others (Jain, 1998). Slope for example is one of the factors that control the rate of infiltration of rainwater into the subsurface and could therefore be used as an index of groundwater potential evaluation. In the gentle slope area the runoff is slow allowing more time for rainwater to percolate, whereas high slope area facilitate high runoff allowing less residence time for rainwater hence comparatively less infiltration. In one way or the other, each of the listed factors contributes to groundwater occurrence. These factors can be interpreted or analyzed with GIS using RS data. Burrough (1986) defined a GIS "as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose". GIS thus enables a wide range of map analysis operations to be undertaken in support of groundwater potential zonation of an area.

Several conventional methods exist for the exploration and preparation of groundwater potential map of an area. These methods include; geological, geophysical and hydrogeological. However, RS amongst these methods is considered to be more favourable as it is less expensive and applicable even in inaccessible areas. It is a rapid and cost effective tool in producing valuable data in geology and geomorphology. In classifying groundwater potential zones, visual integration of data generated from remote sensing is feasible but cumbersome. However, with the advent of GIS technologies, the mapping of groundwater potential zones within each geological unit has become easy.

Gustafsson (1993) used GIS for the analysis of lineament data derived from SPOT imagery for groundwater potential mapping in a semi-arid area in south eastern Botswana. Also, Jain (1998) demonstrated the use of hydro geomorphological map by using Indian Remote Sensing Satellite Linear Imaging Self-Scanning II geocoded data on 1 : 50 000 scale along with the topographic maps to indicate the groundwater potential zones in qualitative terms (i.e., good to very good, moderate to good and poor). Previous research efforts in the study area have been directed at locating and developing potable groundwater using geophysical and geological techniques. Such studies, including the work of Reboucas & Cavalcante (1989), classified the basement terrains aquifers into three; the weathered basement aquifer, the basement detrital overburden aquifer and the fractured rock aquifer. Also, Oyinloye & Ademilua (2005) examined the nature of aquifer in the crystalline Basement rocks of Ado-Ekiti, Igede-Ekiti and Igbara-odo areas, southwestern Nigeria and concluded that aquifers occurred both in the regolith and fractured basement rocks of the area.

The highlighted previous groundwater investigations concentrated on identifying fracture zones and areas with thick overburden employing geophysical and geological techniques as pathfinders to groundwater availabity. However, basic knowledge of groundwater location, its potential in terms of quantity and availability can provide basis for more rational planning. Therefore, the present study assessed the groundwater potentials of the study area using integrated RS and GIS approach.

## Study area

The study area (Figure 1) lies between latitudes $7^0 15'–8^0 5'$ N and longitudes $4^0 44'–5^0 45'$ E and fall within the Basement Complex setting of southwestern

Nigeria. It covers area extent of about 6 353 km$^2$. The study area enjoys tropical climate with two distinct seasons; rainy and dry seasons covering (April to October) and (November to March) respectively. The annual temperature range is between 25 °C and 30 °C while the annual rainfall is 1 500 mm. The study area is drained by many streams and rivers most of which dry off at the pick of the dry season usually between January and February causing supply of water for domestic and agricultural purposes to depend heavily on groundwater system. Groundwater supply in the area is mainly from shallow hand dug wells and limited boreholes. Two major aquiferous units (weathered and fractured layers) have been identified as source of supply to the wells and boreholes (Ademilua & Olorunfemi, 2000).

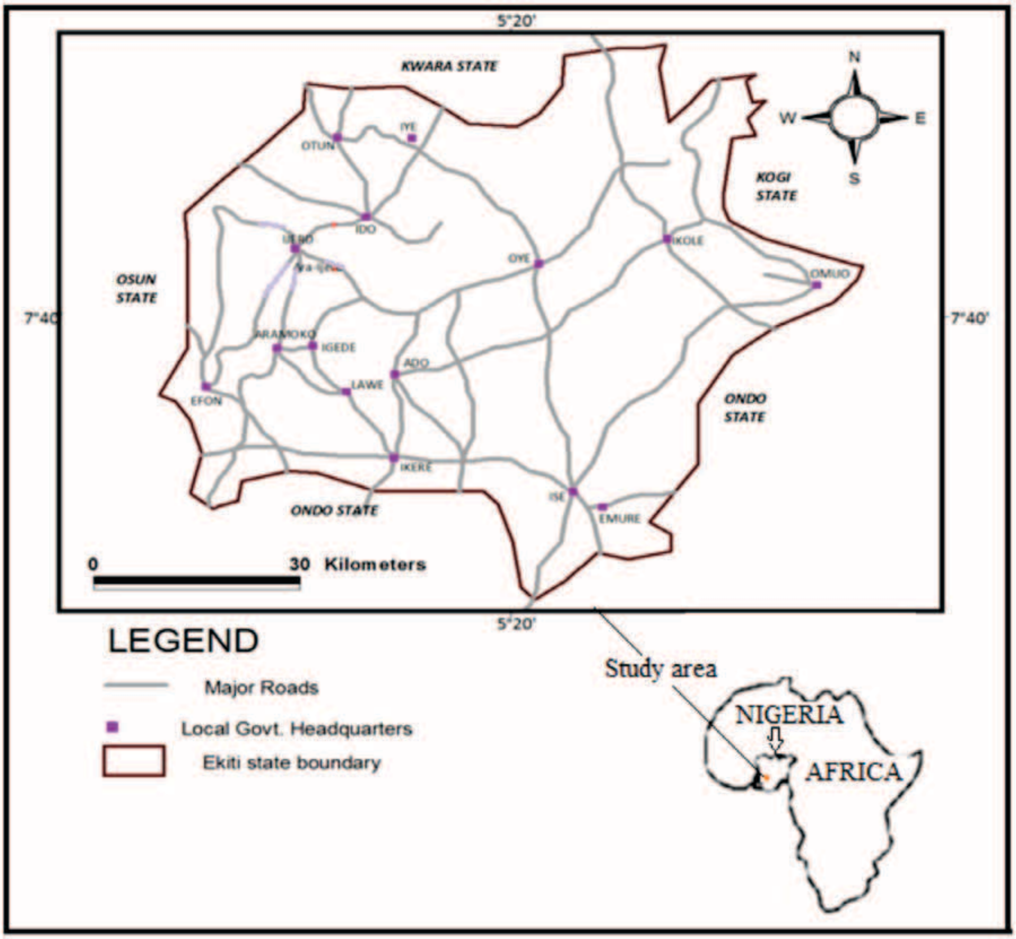



**Figure 1**. Location map of Nigeria showing the study area

The topography is generally undulating with most area lying above 250 m above sea level. The landscape is characterized by old plains, broken steep sided outcrops of dome shaped Inselbergs that may occur singularly or in ridges. Such outcrops exist mainly in form of rugged hills at Ado-Ekiti (central part of study area) and Ikere-Ekiti in the southern part of the study area.

**Geology of study area**

Geologically, the study area is underlain by Precambrian crystalline rocks mostly of igneous-metamorphic origin with isotopic ages greater than 300 Ma to 450 Ma (Matheis, 1987). Prominent rock units include porphyritic granite, fine-medium grained granite, granite gneiss, schist/quartz schist, migmatites and charnockite. The gneisses and migmatite are intimately associated such that they are hardly distinguishable on the field. The gneisses and the migmatite rock units are ubiquitous and form the bulk of the rocks in the study area. In some places, these rocks display characteristic feature of banding of varying width (Figure 2). Migmatite is a mixed rock composed of a gneissic host and intruded by the granitic and pegmatitic rocks. It covers over 50 % of the whole study area (Figure 3).

**Figure 2.** Migmatite rock outcrop along a road cut (Iworoko-Ifaki) in the study area.

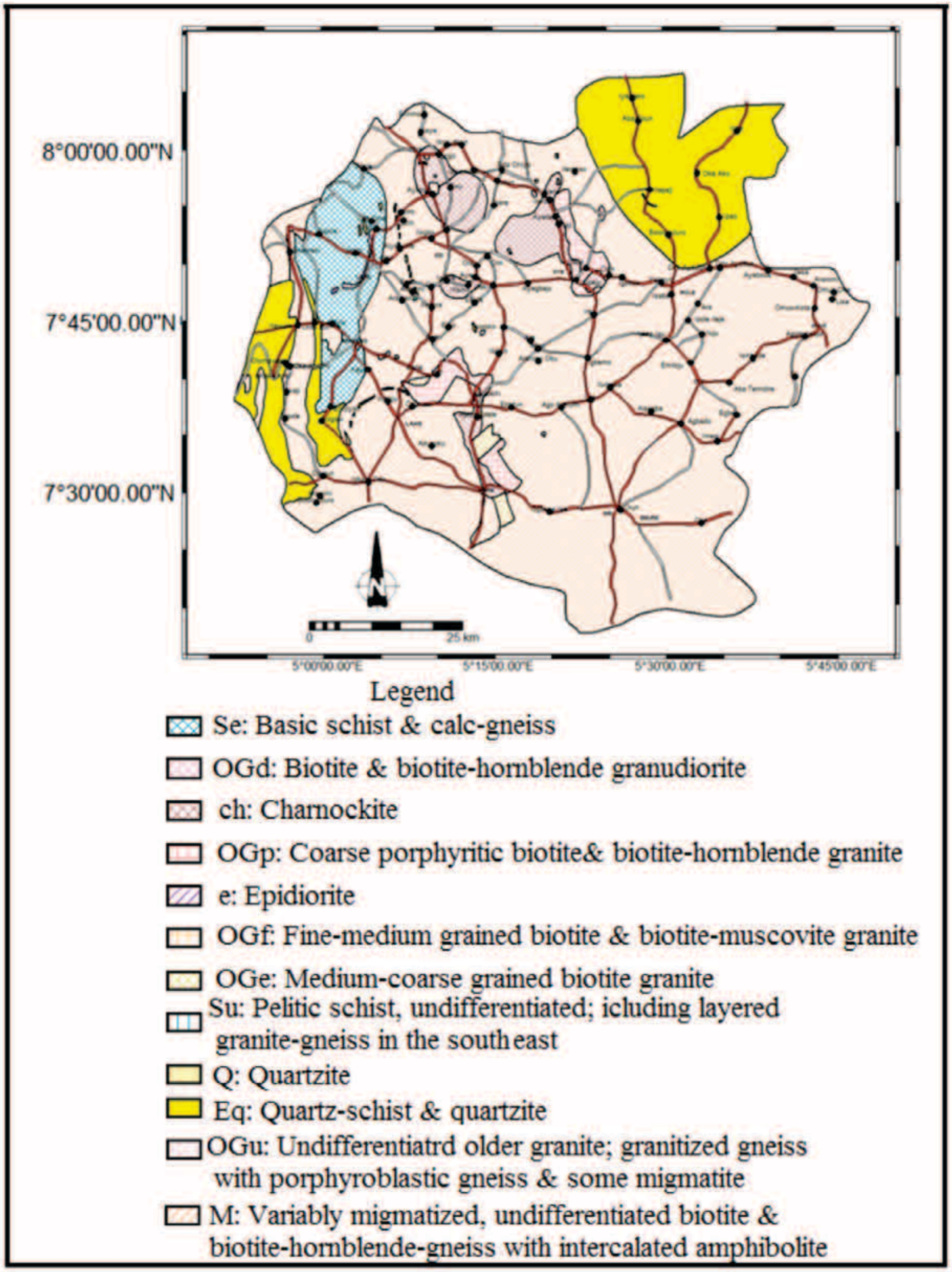



**Figure 3.** Geology Map of the Study Area.

The quartzite occurs as relatively minor concordant layers within the gneiss-migmatite units. On account of high content of late crystal1ised mineral and consequently resistance to weathering/erosion, the quartzite tends to stand out as prominent hills and ridges within the study area.

The granitic units occur as intrusive bodies of various dimensions in the pre-existing basement rocks i.e. the gneiss-migmatite units and the schist/quartz schist bedrock. The granitic units consisting of a suite of porphyritic and non-porphyritic granite rocks as well as medium to coarse grained textural varieties are widely distributed in the study area especially the central and south- eastern part. One striking feature of the granitic unit is the occurrence as picturesque inselbergs (prominent hills) rising sharply above their surrounding plains.

In some places, charnockite, a bluish-green rock, is found associated with the granitic units. The charnockite features prominently at Ikere and Ado towns in the study area.

## METHODOLOGY

System integration, which involves the integration of computer software (AutoCAD 2000, Cad overlay R.14 and ArcGIS 9.1) and hardware, imagery processing, information extraction and analysis formed the basic methodology of this work. System integration involves the use of computer hardware (equipment), software, data and personnel as well as other accessories such as digitizer and scanner at building capable expert system to extract geo-referenced information from the acquired satellite imagery. The processing flow chart of the methodology used in this study is presented in Figure 4. The first step in system integration is to identify data need, conceptualize how it would be captured and display in a GIS platform. The data required and used for this study were identified and their sources verified. The data sources include the Geological Survey Department of Nigeria, Abuja, National Institute of

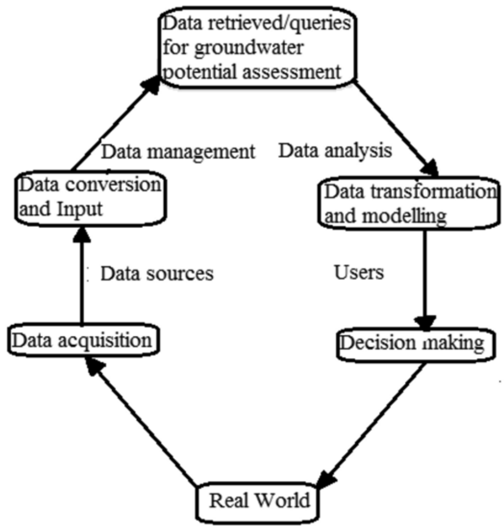



**Figure 4.** GIS in groundwater potential assessment

Remote sensing, Bukuru, Jos, Nigeria and Federal Ministry of Solid Mineral Resources, Abuja, Nigeria.

**Data acquisition, Conversion and Information extraction**

The relevant data acquired which include existing analogue maps, charts, plans and records are presented in Table 1. Consequently, assembling and detail data structuring were also carried out before the compilation and digital conversion for logical data structure. The data as highlighted in Table 1 conformed to the National Geospatial Data Infrastructure (NGDI) - an initiative for co-sharing information in a Geoinformation-based economy. Subsequently, the analogue spatial and attribute data acquired were captured, rasterized, georeferenced and manipulated in CAD software (CAD Overlay R14) and converted to GIS supported GeoTIFFs raster format. These were subsequently exported into ArcGIS 9.1 software for further processing which include editing of both spatial and tabular data on a continuous and interactive basis.

As part of the follow up activities, the information required were extracted using supervised, unsupervised and ground truthing approach plus existing data and information. To classify the image into unique characters comprising of pixels with similar spectral characteristics, unique clusters which represent one or more features according to some statistically determined criteria, were also employed. Subsequently, fieldwork was embarked upon to validate GIS processed information. Where outcrops were not visible, the slope and drainage were used to validate the results.

**Table 1.** Relevant spatial data, information extracted and data sources for the research

| Spatial Data | Attribute Data | Source |
|---|---|---|
| Land sat Imagery | Digital Elevation Modeling/ Terrain/Geology | National Institute of Remote Sensing, Bukuru, Jos, Nigeria |
| NigerSat-1 Imagery | Digital Elevation Modeling/ Terrain/Drainage | National Institute of Remote Sensing, Bukuru, Jos, Nigeria |
| Mineral Maps of Nigeria | Metadata | Geological Survey Department of Nigeria, Abuja, Nigeria |
| Aero Magnetic Map of Southwestern Nigeria | Lineation | Ministry of Solid Mineral Resources, Abuja, Nigeria |

**Integration of data**

Consequently, each of the thematic maps in raster format was assigned suitable weightage factor (Table 2) based on previous works of researchers such as SRINIVASA RAO & JUGRAN (2003), KRISHNAMURTHY et al. (1996), SARAF & CHOUDHARY (1998) and PARASAD et al. (2008). Each of the thematic maps such as geology, geomorphology, drainage density, lineament and slope provides certain clue in respect of the occurrence of groundwater. To unify these information, there is the need for integration of the data with appropriate factor. Though, it is possible to superimpose the information manually, however, it is time consuming and may be proned to errors. Therefore, the information were integrated through the application of GIS. Various thematic maps were reclassified on the basis

**Table 2.** Weightage assigned to various thematic maps based on prospective contribution of input factors to groundwater occurrence (SRINIVASA RAO & JUGRAN, 2003).

| Feature | Classification | Weightage |
|---|---|---|
| Geology | Migmatites<br>Charnockite<br>Granite gneiss<br>Granite<br>Quartzite/quartzite schist | 1<br>1<br>2<br>2<br>3 |
| Geomorphology | Hilly area<br>Lowland area | 1<br>3 |
| Slope | Extreme steep slope (76.3$^0$)<br>Very steep slope (35.2$^0$)<br>Steep slope (30.81$^0$)<br>Moderate-steep slope (22.13$^0$)<br>Moderate slope (9.21$^0$)<br>Gentle slope (8.4$^0$)<br>Very gentle slope (4.57$^0$)<br>Lowland/Nearly Level (0.25$^0$) | 1<br>1<br>1<br>1<br>1<br>2<br>3<br>4 |
| Lineaments | Present<br>Absent | 3<br>1 |
| Drainage density | Low density/coarse texture<br>Medium density/medium texture<br>High density/fine texture<br>Very high density/very fine texture | 4<br>2<br>1<br>1 |
| Drainage density | Low density/coarse texture<br>Medium density/medium texture<br>High density/fine texture<br>Very high density/very fine texture | 4<br>2<br>1<br>1 |

of weightage assigned and processed using the "Raster Calculator" function of Spatial Analysist Extension of ArcGIS 9.1 for integration.The procedure adopt simple arithmetical model to integrate the various thematic maps by averaging of the weightage to produce a final groundwater potential map of the study area. Finally, to validate or authenticate the evaluation method, existing borehole yield data were correlated with the various groundwater potential zones in the study area.

## Results and discussion

Results of the integrated approach of RS and GIS to delineate groundwater potential zones in hard rock terrain of Ekiti area are presented in form of thematic maps (Figures 3, 5 & 7–10).

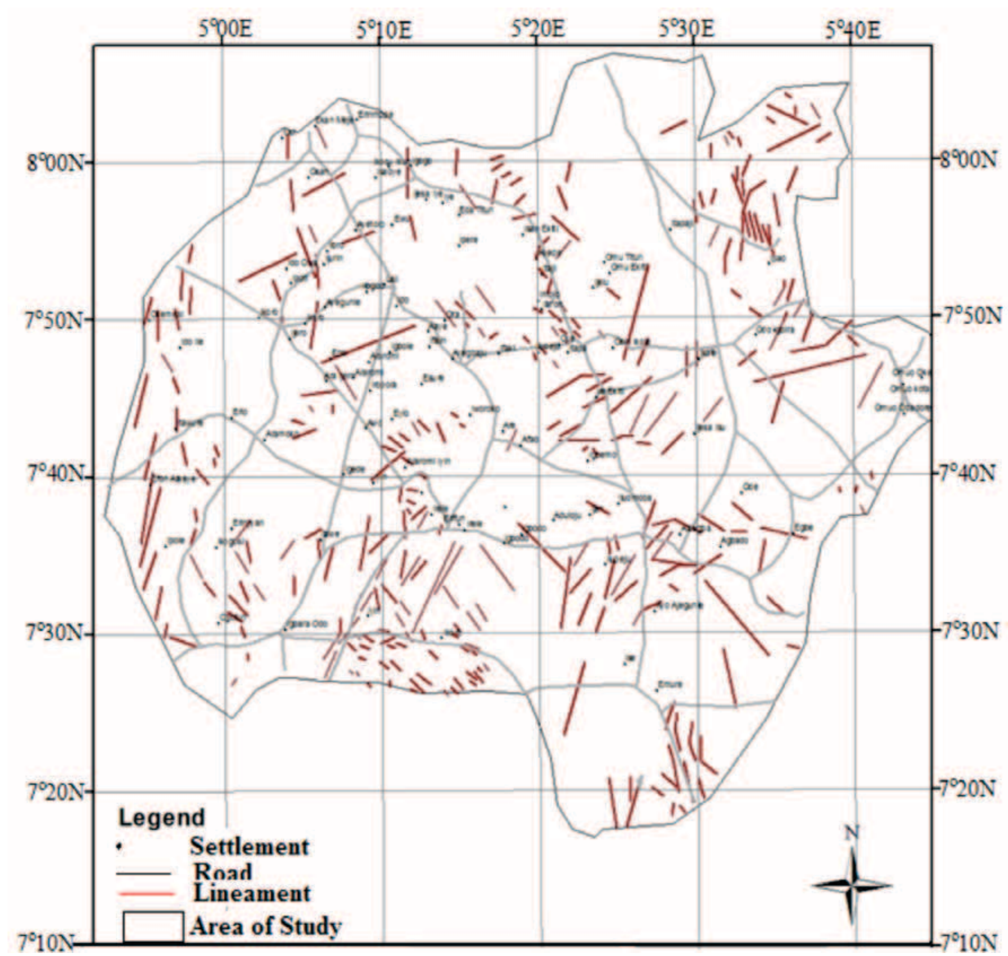



**Figure 5.** Lineament map of the study area.

The final groundwater potential map in which the study area were zoned into three categories (Very good, good-moderately good & poor) is represented in Figure 11. Furthermore, Figure 12 represents a typical weathered overburden soil in charnockite bed rock terrain at Ikere in the southern partof the study area while graphical evaluation of the highlighted zones with well depths and yield data are presented in Figures 13 and 14 respectively.

**Lineaments**

The study area is criss-crossed with lineaments characterized by dominant NW-SE and NE-SW directions while a few numbers of the lineaments also trend E-W (Figure 5) this strongly agree with result of the directional analysis presented in rose diagram (Figure 6). Lineaments cut across the entire bedrock units of the whole area. Futher evaluation revealed that migmatite has low lineament density with 0.02 km$^{-2}$ com-

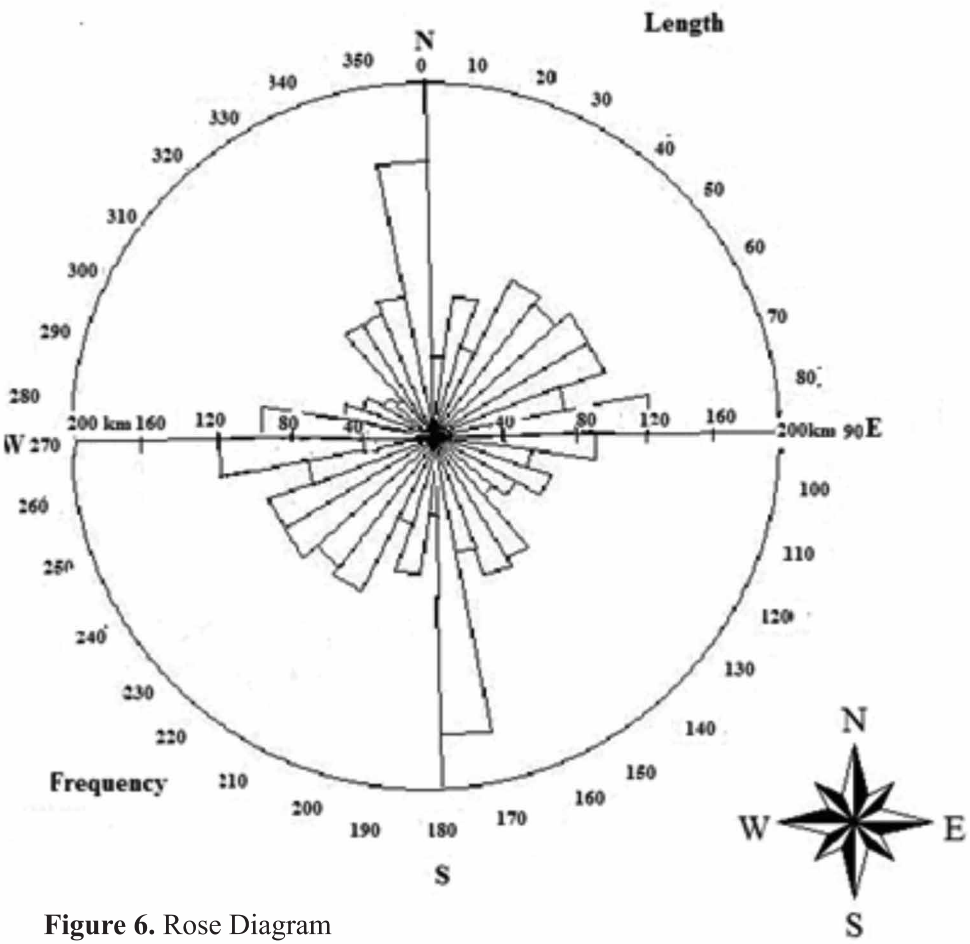



**Figure 6.** Rose Diagram

pare to quartzite, granite and charnockite with density range from 0.05 km$^{-2}$ to 0.13 km$^{-2}$. These lineament density revealed existence of more lineaments on the granitic /charnockitic rocks which might be as a result of transpressive forces exhibited during intrusion of the rocks into the parent migmatite/metasedimentary rocks. However, the lineaments in the low lying part of the study area are of significant interest with respect to groundwater occurrence because the lineaments on migmatite are mostly on the hilly and high slope areas with little or no overburden which are regarded as less significant due to possible high runoff rather than favouring vertical groudwater infiltration.

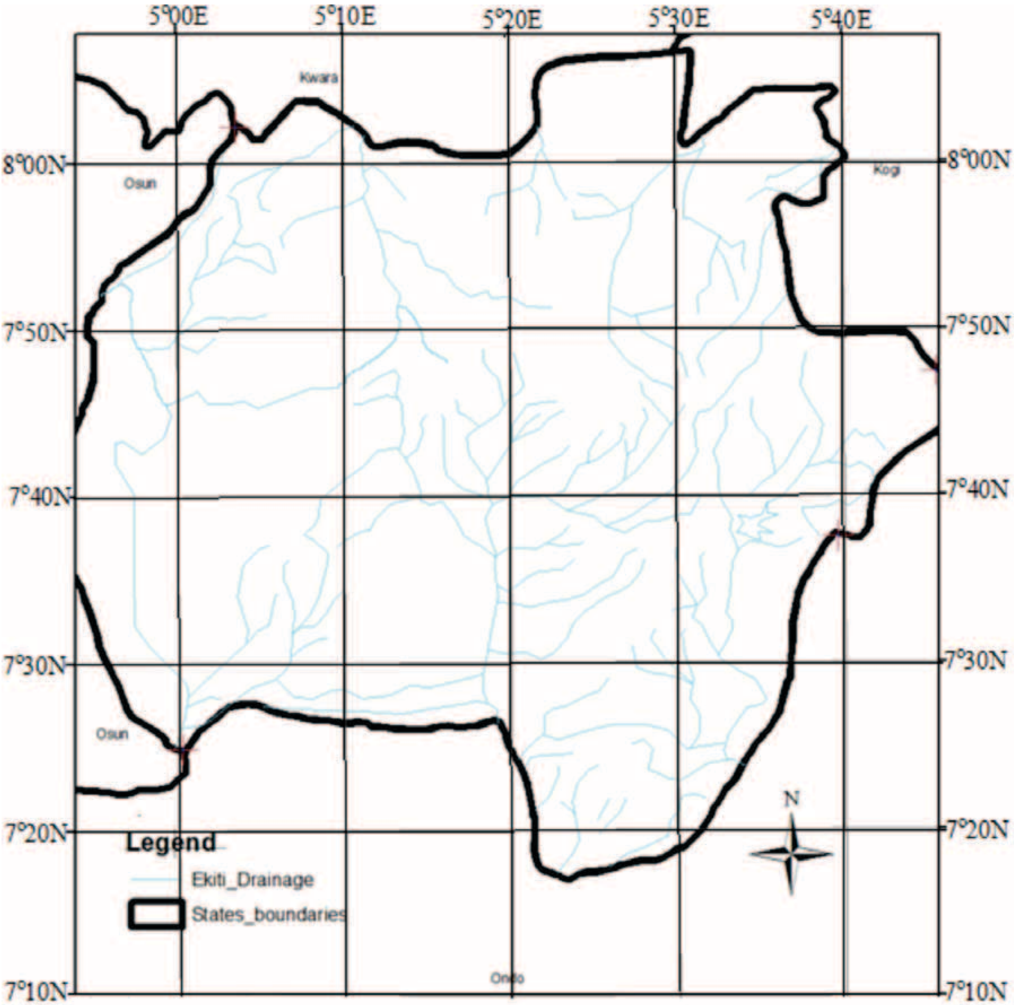



**Figure 7.** Drainage Map of the Study Area

**Drainage**

Usually, drainage patterns are said to be reflections of surface and subsurface formations while drainage density is proportional to surface run-off due to the fact that the more the drainage density, the higher the runoff. (Parasad et al, 2008). Hence, the drainage density characterizes the runoff in an area as the volume of relative water that was unable to penetrate into the subsurface. In addition, drainage density do give

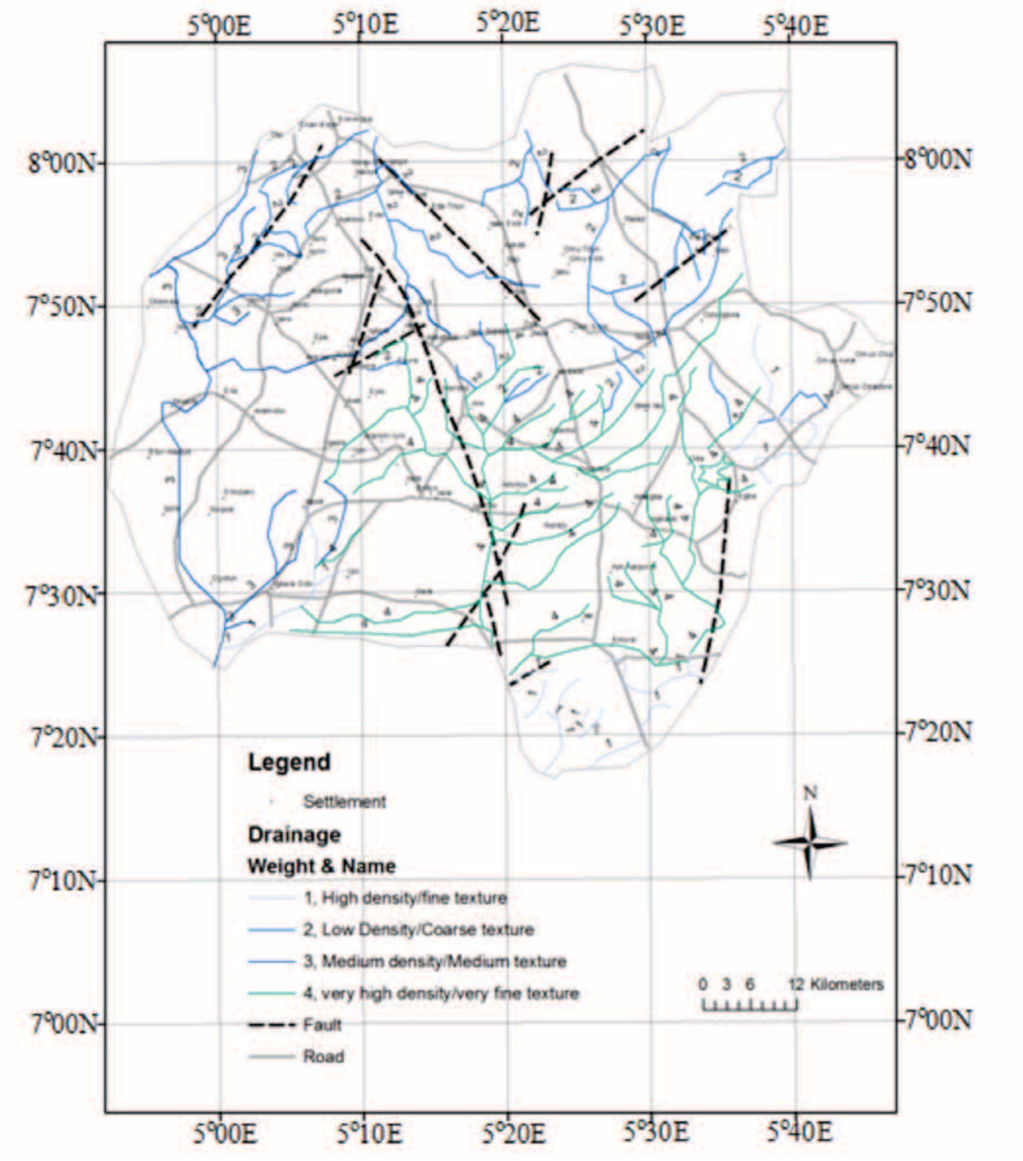


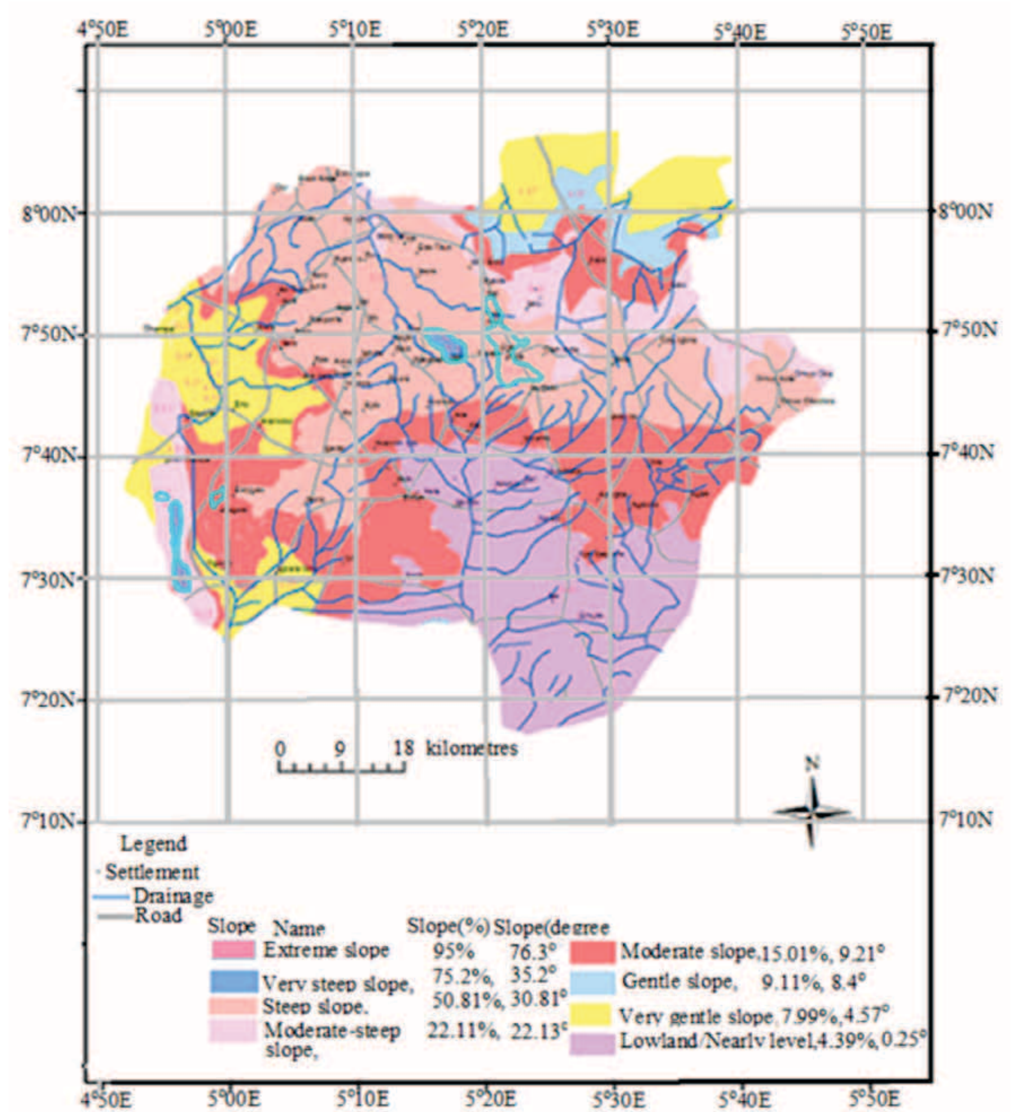

**Figure 8.** Drainage Density Map of the Study Area

indications of closing or otherwise of stream/river channels which inturn will depend on the nature and degree of weathering of the surface and subsurface lithologic units. Low drainage density therefore enhances the chance of recharge and contributes positively to groundwater availability if other groundwater occurrence conditions are favourable. In this study thematic map extracted from the topographic map shows dendritic pattern (Figure 7) while the drainage density map presented in Figure 8 reflects the infiltration characteristics with high drainage density indicating low-infiltration and the low drainage density high infiltration respectively. Most of the drainage originates from the quartzite ridge and granitic/charnockitic hills with dense drainage pattern. The lowland part of the study area that are characterized mainly by diverse rock units (porphyritic granite, fine-medium grained granite, granite gneiss and migmatite) presents low density an indication of favourable condition for vertical infiltration of runoff from surrounding hills and thus enhancing grounwater occurrence.This observation signify that groundwater occurrence in the lowland part of the study area is not only controlled by rock formations but other factors like topography and weathering as weathering products from the surrounding hills pile up to form overburden thickness aquifer while during igneous rocks intrusion fractures favourable for vertical infiltration were developed and thus additionally support groundwater occurrence.

**Slope/Geomorphology**

Results of slope and geomorphology thematic maps produced from integrated RS and GIS as presented in Figures 9 and 10 respectively revealed eight slope categories ranging from extreme slope to lowland and two main geomorphic units; hilly area and lowland area. Geomorphology is a reflection of the various landform and structural features of an area. Such landform and structural features are useful in categorizing groundwater occurrence. Generally, field observation revealed that the lowland areas are covered by thick weathered material representing alluvium matrials from the hilly areas (Figure 12). The weathered overburden revealed three principal horizons designated A, B and C. The “A” horizon is dark brown to redish lateritised soil, littered with some plant residues which implies organic soil form. The “B” horizon is subdivided into three distinct sub-units but all the three units are generally finer in texture compared to “A” horizon and of a lighter brown. The first two subunits of ‘‘B” horizon constitute the vadoze zone where active leaching and vertical of infiltration water occurs.The third sub-unit of the horizon constitute the phreatic zone representing the aquiferous layer.Soil horizon ‘‘C” is grey to white in colour due mainly to absence or substantial reduction of weathering activities and represents fresh parent rock which may or may not be fractured. However, when the parent rock is fractured, it compliments the overburden thickness in terms of groundwater occurrence.

The hilly areas comprise of gentle sloping surfaces with transported sediments lying between hills and plains. Additionally, the hilly areas are also characterized by presence of residual hills occuppying over 64 % of the study area (Figure 11). The ground-



water prospect in this zone is poor. Further evaluation with respect to the slope characteristics of the study area revealed that gentle slope are indicative of slow runoff allowing more time for rainwater infitration, whereas extremly steep slope area facilitate high runoff allowing less residence time for rainwater hence, comparatively less infiltration. Extreme slope to moderately

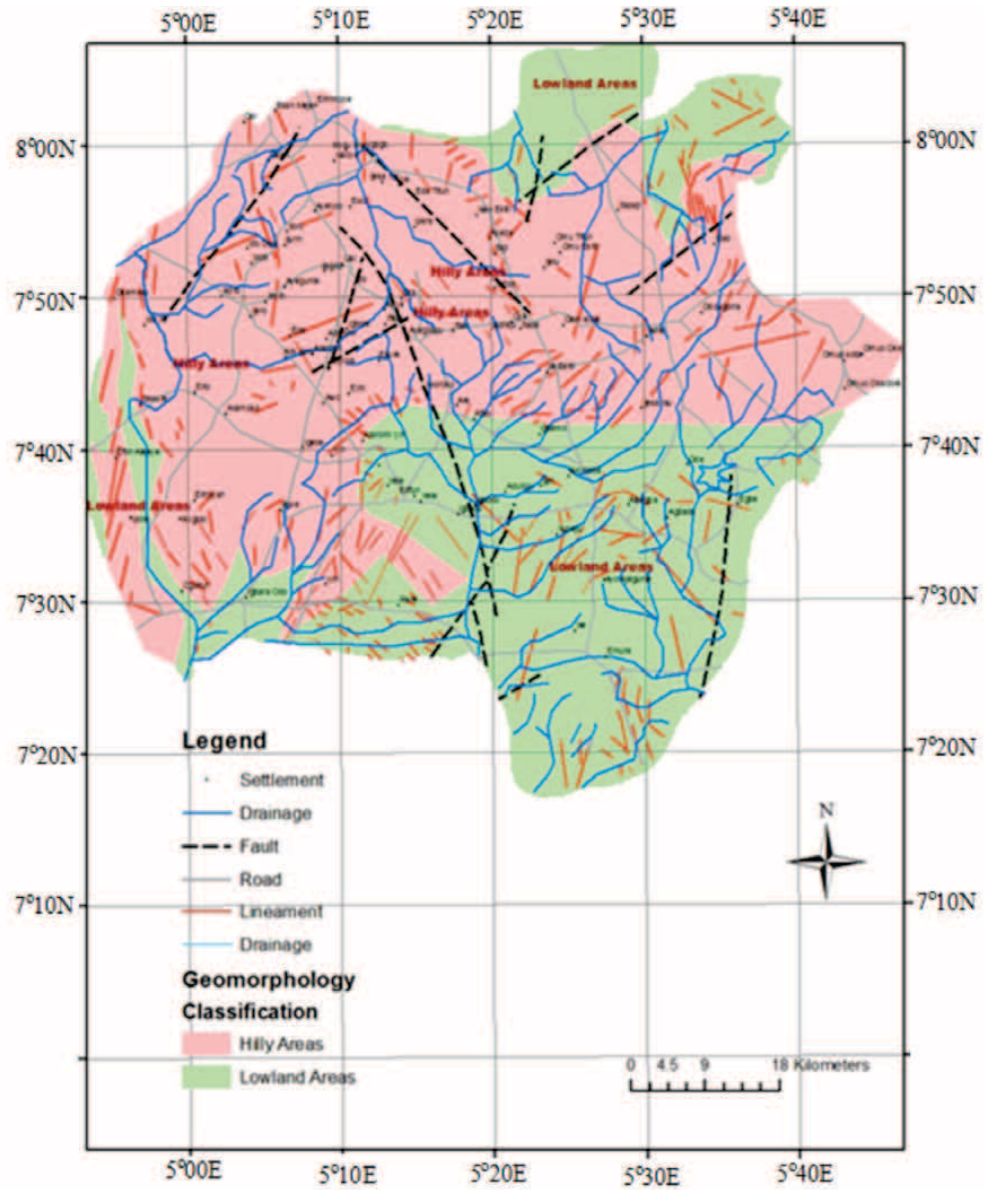



**Figure 10.** Geomorphology Map of the Study Area

steep slope occupy over 50 % of the study area and groundwater prospect in this area is poor in agreement with the earlier observation infereed from geomorphologic thematic map.

**Synthesis and Groundwater potential map of the study area**

The integration of the thematic maps resulted in the production of groundwater potential map of the study area

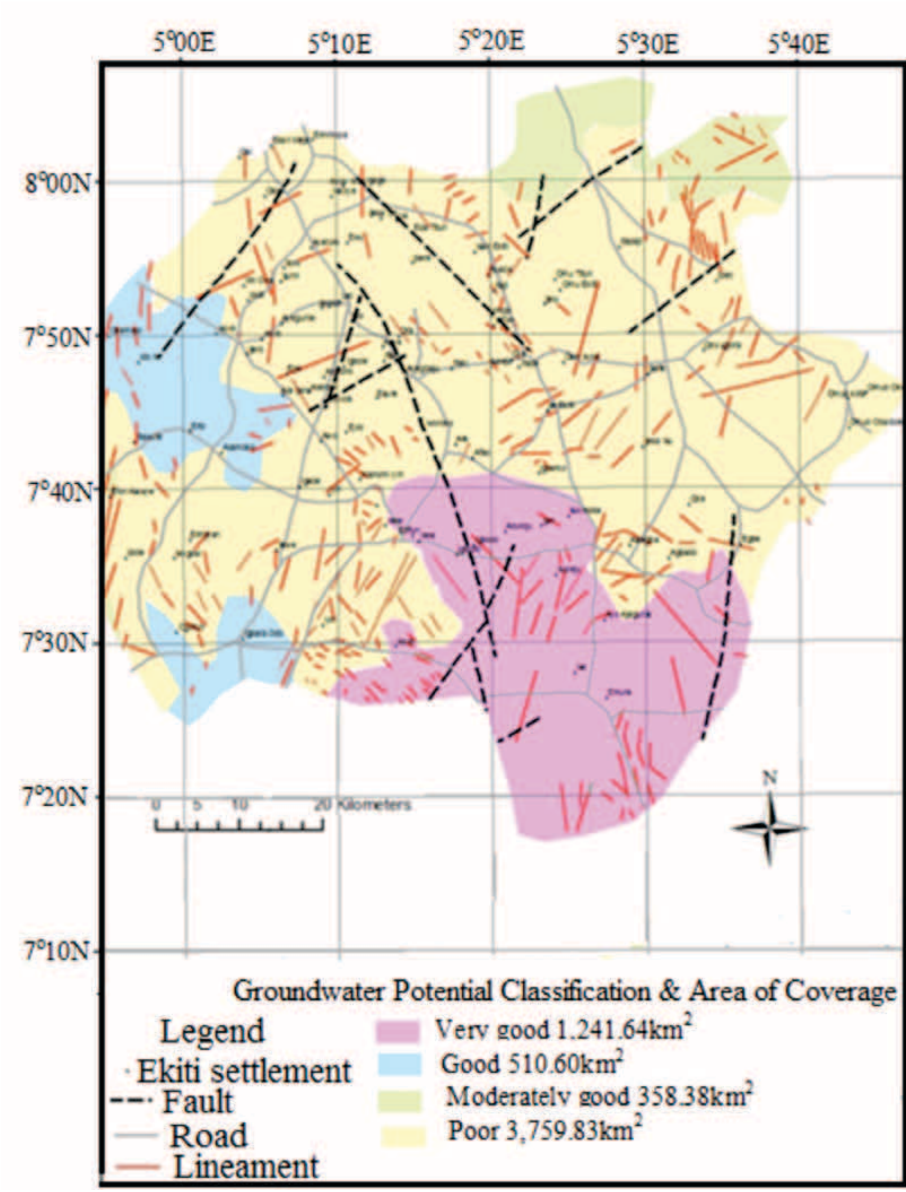



**Figure 11.** Groundwater Potential Map of the Study Area

(Figure 11). As shown in the map, the area that has very good potential for groundwater is situated in the south eastern part covering about 21.15 % of the study area. The good to moderately good potential area covers only 6.12 % while the greatest portion of the area about 64.04 % belongs to poor groundwater potential zone. The poor groundwater potential zone on the one hand is characterized majorly by migmatite and migmatite gneiss with quartzite/quartz-schist and charnockite constituting the minority rock units while on the other hand, the very good and good to moderately good groundwater potential zones are covered majorly by granitic and charnockitic rocks with migmatite and quartzite constituting minority rock units. The various rock units cut across the different groundwater potential zones. However, the migmatite rocks that cover greater parts of poor groundwater potential zone are less fractured and in most cases covered with shallow overburden

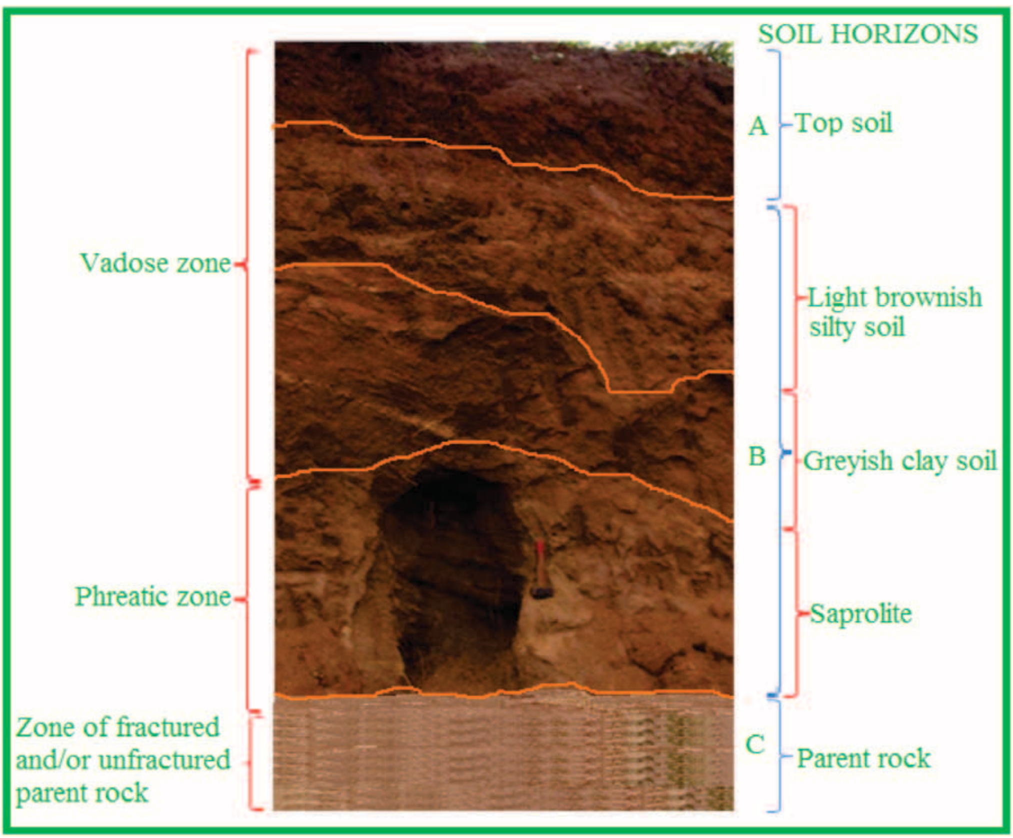



**Figure 12.** Showing weathered overburden soil in a typical charnockite bed rock terrain at Ikere

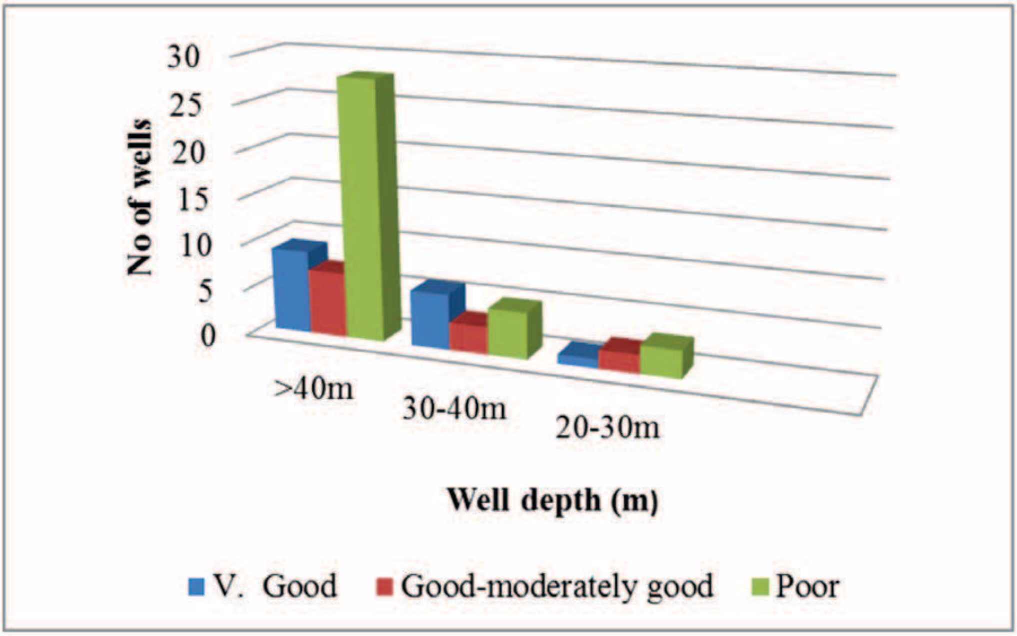



**Figure 13.** Frequency distribution of well depth with respect to groundwater potential zones.

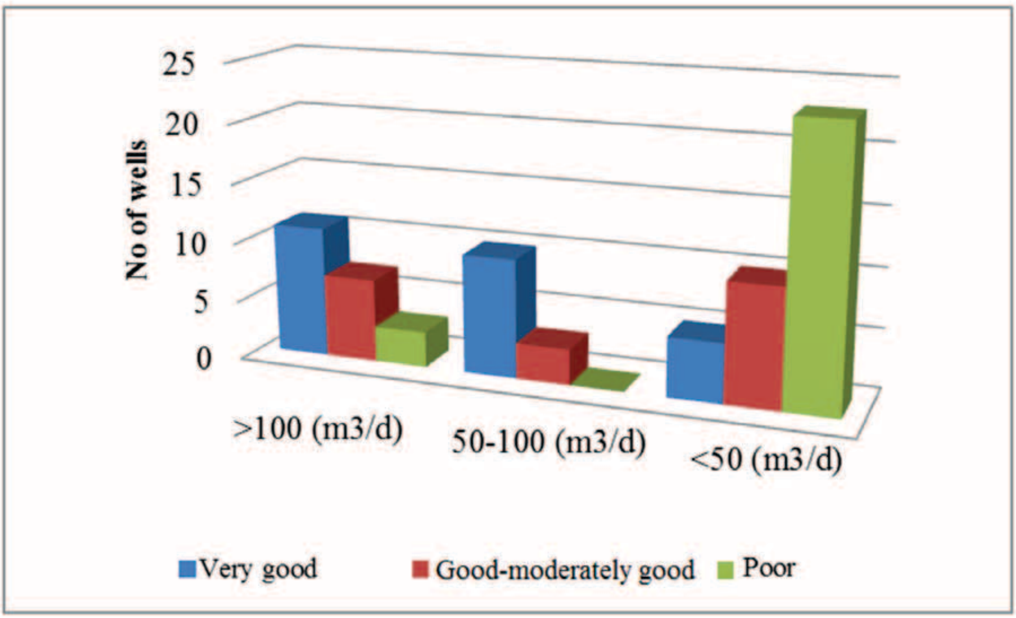



**Figure 14.** Frequency distribution of well yield with respect to groundwater potential zones

thickness when compared to the granitic and charnockitic rocks that form the major rock units of the very good and good to moderately good potential zones. Obviously, weathering, thickness of overburden mateerial as well as fracture system in the various groundwater potential zones are major factors controlling groundwater occurrence in the study area and these factors are more favoured in the very good and good to moderately good groundwater potential zones compared to the poor groundwater potential zones.

**Result validation**

In order to validate the classification of the study area into different groundwater potential zones (i.e. very good, good to moderately good and poor), bohole yield data of existing wells from Benin/Owena River Basin Development Authority (BRBDA), Ikere-Ekiti, and Federal Ministry of Water Resources, Lagos, Nigeria were collected and evaluated. The data revealed that boreholes in the study area can be categorized into high (>100 $m^3$/d), moderate (50–100 $m^3$/d) and low yield (<50 $m^3$/d). In additipon, the depth range varies from 21.3 m to 92 m while the yield range between 8.64 $m^3$/d to 354.24 $m^3$/d (Table 3). The data also revealed that 46 % of wells within granitic terrain are of high yield (>100 $m^3$/d) while 21 % of well in both migmatite and charnockitic also exhibited high yield compared to 12 % of the quartzite terrain. These are characteristics of very good to good groundwater potential zones which is consistent with the trend of the GIS-based potential zones. However, migmatite, charnockite, granite and quartzite bedrocks are characterized by 63 %, 16 %, 13 % and 3 % of the low yield (<50 $m^3$/d) wells respectively which are typical of poor groundwater potential zones in the study area.

**Table 3.** Summary of Borehole completion records in Ekiti Basement area

| S/NO | Location | *BHD*/m | *SWL*/m | Yield ($m^3$/d) | GWZ | Bedrock |
|---|---|---|---|---|---|---|
| 1 | Ogbesse | 45 | 4.1 | 86.4 | Very good | migmatite |
| 2 | Ikere (Ogoga palace) | 53 | 8.9 | 103.68 | Very good | granite |
| 3 | Ikere(Benin/Owena office) | 40 | 3.9 | 103.68 | Very good | charnockite |
| 4 | Emure(Owode) | 35 | 1 | 103.68 | Very good | granite gneiss |
| 5 | Emure(Awopegba house) | 30 | 5.7 | 69.12 | Very good | granite gneiss |
| 6 | Ise(oraye) | 45 | 4.8 | 103.68 | Very good | migmatite |
| 7 | Orun | 40 | 4.5 | 69.12 | Very good | migmatite |
| 8 | Ado(Bolorunduro) | 36 | 3.9 | 86.4 | Very good | charnockite |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | Ado(Italaoro) | 30 | 3.3 | 86.4 | Very good | granite |
| 10 | Igede | 35 | 8 | 69.12 | Very good | granite |
| 11 | Temidire | 43.8 | 6 | 131.33 | Very good | granite |
| 12 | Ilumoba | 45 | 7 | 354.24 | Very good | migmatite |
| 13 | Ago-Aduloju | 29.6 | 2.7 | 129.6 | very good | charnockite |
| 14 | Bolorunduro | 31.3 | 3.2 | 30.24 | very good | charnockite |
| 15 | Ado-Com. School | 40 | 6.8 | 132.19 | Very good | granite |
| 16 | Aro Camp-Ikere | 42 | 3.2 | 54.43 | Very good | charnockite |
| 17 | ESGSC-Ikere | 68 | 18 | 203.04 | Very good | charnockite |
| 18 | Ado grammar school | 51.4 | 7.2 | 25.92 | Very good | granite |
| 29 | Ogbese | 48.6 | 1.5 | 283.39 | Very good | migmatite |
| 20 | Itawure | 37 | 2 | 103.68 | Good | quartzite |
| 21 | Ikoro | 60 | 9 | 112.32 | Good | migmatite |
| 22 | Egbewa | 50 | 21 | 103.68 | Good | migmatite |
| 23 | Owode | 43 | 2.1 | 175.39 | Good | granite gneiss |
| 24 | Ilupo | 26 | 4 | 103.68 | Good | granite gneiss |
| 25 | Imesi | 46.6 | 8 | 114.05 | Good | quartz-schist |
| 26 | Ijero-Ekiti | 80 | 8.1 | 304.99 | Good. | quartz-schist |
| 27 | Aramoko-Ekiti | 48 | 14.61 | 160.70 | Good | granite gneiss |
| 28 | Ogotun-Ekiti | 92 | 2 | 129.6 | Good | granite |
| 29 | Iloro-Temidire | 38 | 9.1 | 95.04 | Good | granite |
| 30 | Soso | 31.4 | 8.7 | 98.49 | Good | granite |
| 31 | Itawure | 21.3 | 5.7 | 95.04 | Good | quartzite |
| 32 | Ado-Ekiti | 74 | 2.7 | 191.81 | Good | granite |
| 33 | Ifaki | 40 | 18 | 69.12 | Poor | migmatite |
| 34 | Ijero(palace) | 50 | 6 | 69.12 | Poor | quartz-schist |
| 35 | Ipoti | 50 | 1.7 | 53.57 | Poor | migmatite |
| 36 | Epe | 31 | 12 | 69.12 | Poor | migmatite |
| 37 | Are | 40 | 4.6 | 34.56 | Poor | migmatite |
| 38 | Iworoko | 42 | 5 | 43.2 | Poor | migmatite |
| 39 | Ipoti | 50 | 11.8 | 51.84 | Poor | migmatite |
| 40 | Erinjiyan | 40 | 10 | 43.2 | Poor | quartzite |
| 41 | Igede-Ekiti | 72 | 1.3 | 114.91 | Poor | granite |

| | | | | | | |
|---|---|---|---|---|---|---|
| 42 | Orin farm settlement | 60 | 12.4 | 8.64 | poor | charnockite |
| 43 | Aba Igbira | 37.8 | 13.9 | 17.28 | poor | migmatite |
| 44 | MGHS Ifaki | 59 | 1 | 86.4 | poor | migmatite |
| 45 | Ofale community | 50 | 11 | 11.23 | poor | migmatite |
| 46 | Ipao CHC | 25.5 | 2.9 | 21.6 | poor | migmatite |
| 47 | Eda-Ile | 54.7 | 12.3 | 31.10 | poor | migmatite |
| 48 | Ilasa | 46.6 | 6.2 | 27.65 | poor | migmatite |
| 49 | Kajola | 30 | 7.2 | 17.28 | poor | migmatite |
| 50 | Ipole Iloro | 43.5 | 9.2 | 11.23 | poor | migmatite |
| 51 | Ipoti-Ekiti | 72 | 13.97 | 95.90 | poor | granite |
| 52 | Igede-Ekiti | 72 | 1.33 | 114.91 | Poor | granite |
| 53 | Otun-Ekiti | 72 | 3.89 | 102.81 | poor | migmatite |
| 54 | Ilawe-Ekiti | 89 | NN | 86.4 | poor | granite |
| 55 | Usi-Ekiti | 80 | 10.63 | 64.8 | poor | charnockite |
| 56 | Iyin-Ekiti | 72 | 9.15 | 26.78 | poor | granite |
| 57 | Ilogbo-Ekiti | 70 | 4.85 | 44.06 | poor | migmatite |
| 58 | Iworoko-Ekiti | 78 | 3.5 | 120.09 | poor | migmatite |
| 59 | Ire-Ekiti | 74 | 12.8 | 28.512 | poor | migmatite |
| 60 | Ijan-Ekiti | 70 | 1.9 | 40.61 | poor | charnockite |
| 61 | Igogo-Ekiti | 46 | 1.33 | 40.61 | poor | migmatite |
| 62 | Usi-Ekiti | 80 | 10.63 | 64.8 | poor | migmatite |
| 63 | Ajebandele | 41.5 | 3 | 17.28 | poor | migmatite |
| 64 | Ikogosi | 42 | 14.4 | 103.68 | poor | quarzite |
| 65 | Irare Fulani | 46.1 | NN | 36.29 | poor | migmatite |
| 66 | Irare community | 48.4 | 6.1 | 8.64 | poor | migmatite |
| 67 | Ogunnire School | 29 | 8.5 | 8.64 | poor | charnockite |
| 68 | Obalatan | 50.6 | 4.5 | 8.64 | poor | charnockite |
| 69 | EKSC Ayede | 23.4 | 2.1 | 21.6 | poor | migmatite |

Source: Federal Ministry of Water Resources, Lagos, Nigeria and Benin/Owena River Basin Development Authority, Ikere- Ekiti, Nigeria
NN: Not known
BHD: Borehole depth
SWL: Static water level
GWZ: Groundwater zones

Further evaluations revealed low correlation ($r$ = 0.37) between well yield and well depth  suggesting that well yield depends on aquifer characteristics such as porosity, permeability and fracture system rather than depth. This is consistent with the frequency distribution of well depth with respect to groundwater potential zones (Figure 13) revealed that well yield is not controlled by depth due to the fact that wells with depth >40 m are more represented in the poor groundwater potential zone. This is a clear indication of the localized nature of weathered basement aquifer in the study area. Nonetheless, the frequency diagram of well yield distribution (Figures 14) support the early observation because wells with low yield (<50 $m^3$/d) are predominant in the poor groundwater potential zone and minimal in the good to moderately good groundwater potential zone. Thus the frequency of occurrence of high yielding wells decreases from very good groundwater potential zone to poor groundwater potential zone in agreement with the GIS evaluation of the groundwater potential of the study area.

Further evidence to support this observation is the fact that the shallowest well with depth of 21.3 m located on quartzite has a yield of 95.04 $m^3$/d well with depth of 89.0 m on a granite bedrock has a yield of 86.4 $m^3$/d. This scenario is an indication of the tendency of the unqualified local driller to drill deeper in the hard granitic and migmatite bedrocks with the hope of intersecting fractures at deeper depth. The is an indication of lack of adequate knowledge of the hydrogeological settings by these local  unqualified drillers as the assumption is not always applicable in such Basement bedrock setting hence the need to use professionally trained drillers in the drilling exercise not only reduce cost but also to ensure sustainable groundwater exploitation.

## Summary and conclusions

This study provides an integrated RS/GIS approach to groundwater potential zonation in Ekiti Basement terrain to serve as a guide for groundwater exploration and development in the study area. As part of the study approach, thematic maps were prepared and susequently integrated using Arc GIS 9.1 software to produce groundwater potential map of the study area.

The groundwater potential assessment revealed;

1) That the very good groundwater potential zones are located mainly in the south-eastern part of the study area with an area extent of 1 241.64 $km^2$ representing 21.15 % coverage. Also, the good to moderately good groundwater potential zones are concentrated in the north-

eastern and south-western parts of the study area. These zones have an area extent of 868.97 $km^2$ representing 6.12 % coverage. However, the poor groundwater potential zone with an area extent of 3 759.83 $km^2$ represents 64.04 % coverage and is variably located in the remaining portions of the study area.

2) That the very good potential groundwater zone is undelain mostltly by granitic/ charnockitic rocks while the good to moderately good groundwater potential zone is covered by quartzite/quartz-schist, granite and charnockitic rocks. The poor groundwater potential zone, however, are underlain by predominantly by migmatite/ migmatite gneiss bedrock with few charnockite and granitic rock units.
3) That fractures on the migmatite bedrocks are poorly developed with thin overburden thickness accounting for the poor groundwater occurrence in this terrain. However, the relatively moderate to thick weathered overburden units characterized the quartzite and granitic bedrocks where greater proportion of high yield (>100 $m^3/d$) are located.
4) That yield is not controlled by well depth as wells with depth >40 m are more represented in the poor groundwater potential zone compared to very good and good to moderately good groundwater potential zones. This is a clear indication of the localized nature of weathered basement aquifer in the study area.
5) That superimposition of existing groundwater yield data on the deciphered groundwater potential zones revealed more frequent occurrence of high to medium yield wells in the favourable groundwater potential zones which support the result of integrated GIS thematic maps.

In summary the overall asssessment as presented in this study highlight that mapping of groundwater potential using integrated RS/GIS approach could be an effective means of charcaterization of groundwater potential zones as well as serving as a usuful tool and guide in groundwaer exploration and development in the study area. However, further geophysical investigation to determine the aquifer characteristics and the overburden thickness of various groundwater potential zones highlighted is recommended to compliment the present study.

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