**ORIGINAL ARTICLE**

# Characterizing groundwater potentials in parts of the basement complex of Nigeria using GIS and remote sensing

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## Abstract

Groundwater prospect in parts of southwestern Nigeria was delineated by inferring the subsurface models from the responses of remote sensing and GIS data. In characterizing the area, both primary and secondary data were used. The primary data include *landsat8 OLI* and *ASTER* Digital Elevation Model, while the secondary data includes geology, soil, and topography maps of the area. Hence, thematic maps of potentials and lineament density, and land cover/use maps for the area were derived from the *landsat8 OLI/TRS* image. Thus, the area was characterized as follows: very low, low, moderate, high, and very high potentiality that covered 1.4 km$^2$ (0.59%), 72.18 km$^2$ (9.59%), 372.3 km$^2$ (49.44%), 272.12 km$^2$ (36.14%), and 35 km$^2$ (4.64%), respectively. The western part of the area is dominated by very low to low potential, while the southern part of the area is dominated by high to very high potential. Hence, low and moderate potentials occupy the highest landmass (59.03%) in the area. In conclusion, the basement complex terrain in question has a moderately low aquifer capability.

## Introduction

Groundwater remains the most important source of water for drinking and domestic usage in Nigeria. However, while water appears in some areas in abundance, it remains a scarce commodity in several others. This leads to water shortage and can hurt the lives of the dwellers of such communities.

Over 63% inhabitant of the study area experience acute shortage of safe water (Olayinka 2012). This menace has led to an over dependence on the few available crude sources of water in the area. Therefore, the provision of quality water in sufficient quantity has always been a critical Government agenda at all levels in this country. However, most of the borehole projects embarked upon by the Government and the private sectors failed partly due to poor predrilling surveys. Further, when the little available sources of water fails the populace, it often results in sources of water from unsafe

hand-dug well and open flowing stream which are prone to contaminants.

The unavailability of sophisticated water supply systems has made development through hand-dug wells and boreholes a necessity in Nigeria. However, the success of the development program is predicated on a good understanding of the geomorphological, geological, hydrogeological, and geophysical characteristics of the basement complex terrain. These characteristics are required for the assessment of the potential (Bayowa et al. 2014). In other words, the prospect of an area can be delineated by mapping the subsurface water potential sites using a combination of hydrogeophysical, geological, remote sensing, and GIS techniques. These techniques are inexpensive, rapid, accurate with wide area coverage, and can also be carried out with limited time and resources.

The Basement complex terrain of Nigeria is said to be abundant in areas where thick overburden overlies a fractured basement (Olorunniwo and Olorunfemi 1987; Olorunfemi and Fasuyi 1993; Olasehinde 1999). The water resources inventory of southwestern Nigeria shows that water supplies are mostly from surface sources, such as dams and weirs in streams and rivers. A borehole and hand-dug wells tapping are used to supplement the short supply of surface water. Available data from

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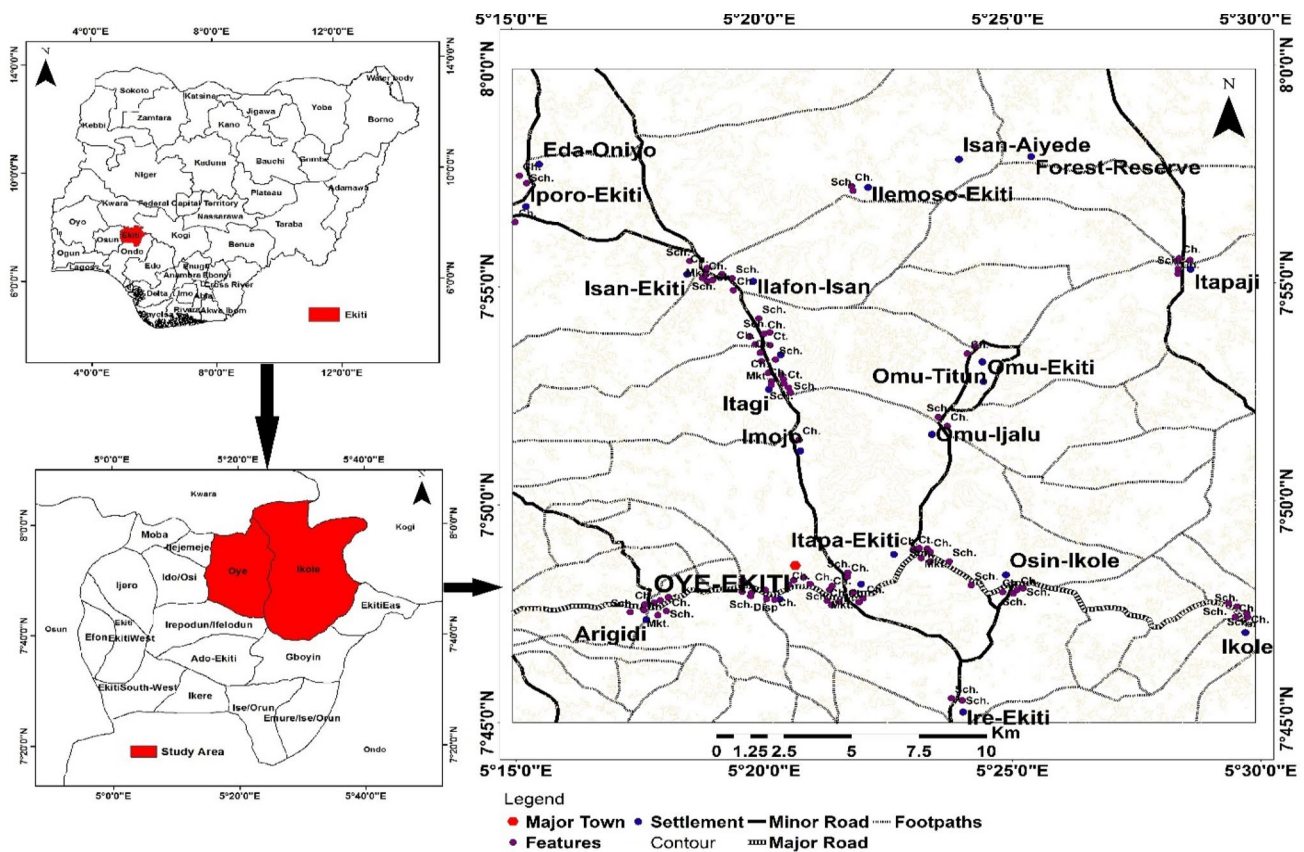
**Fig. 1** Study location

UNICEF-water-assisted projects have shown that boreholes in southwestern Nigeria are designed to tap water from the weathered zone aquifer or the jointed/fractured basement rock aquifer (Adelana et al 2008). From the foregoing, it is obvious that there is an urgent need for a sophisticated scientific approach to groundwater mapping, hence the essence of this study. The present study is aimed at characterizing groundwater potential in a typical basement complex of southwestern Nigeria using GIS and Remote sensing techniques, and this will serve as a guide to policymakers, government, and private drillers to make wise decisions as regards siting of boreholes for groundwater intended for public and private consumptions. This will help to reduce the wastage of time and resources that may arise from borehole failure.

Several works have been done to evaluate the groundwater potential of Ekiti; Bayowa et al. (2014) assessed the potential of the basement complex terrain of Ekiti state using integrated hydrogeophysical parameters as well as GIS and remote sensing. They were able to classify the state's groundwater potential into five different zones, which were very low, low, moderate, high, and very high. Ijelu-Ekiti, Ayede, Ipao, Ikole, Oye. Ayegbaju, Ofale-Ijero, and Omuo-Ekiti were classified as very low potential areas, while the low 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 potential zones. The high groundwater potential was recorded in Ijan, Okemesi, Aramoko, Ilemeso, Ikere, Etisun, and Itawure. Efon-Alaaye and Ilumoba fall within a very high potential zone. They remarked that the potential of Ekiti State is generally of very low–moderate level rating and that there are few areas with high to very high potentials. In addition, Fashae et al. (2014) investigated groundwater potential within the southwestern basement complex of Nigeria using multi-criteria decision analysis of nine thematic layers which includes; geology, rainfall geomorphology, soil, drainage density, lineament density, land use, slope, and drainage proximity. Their result categorized the studied part of the southwestern basement complex into three different potential zones: high, medium, and low. The

**Fig. 2** Geology map of Nigeria showing the study area (Modified after Obaje et al. 2009)
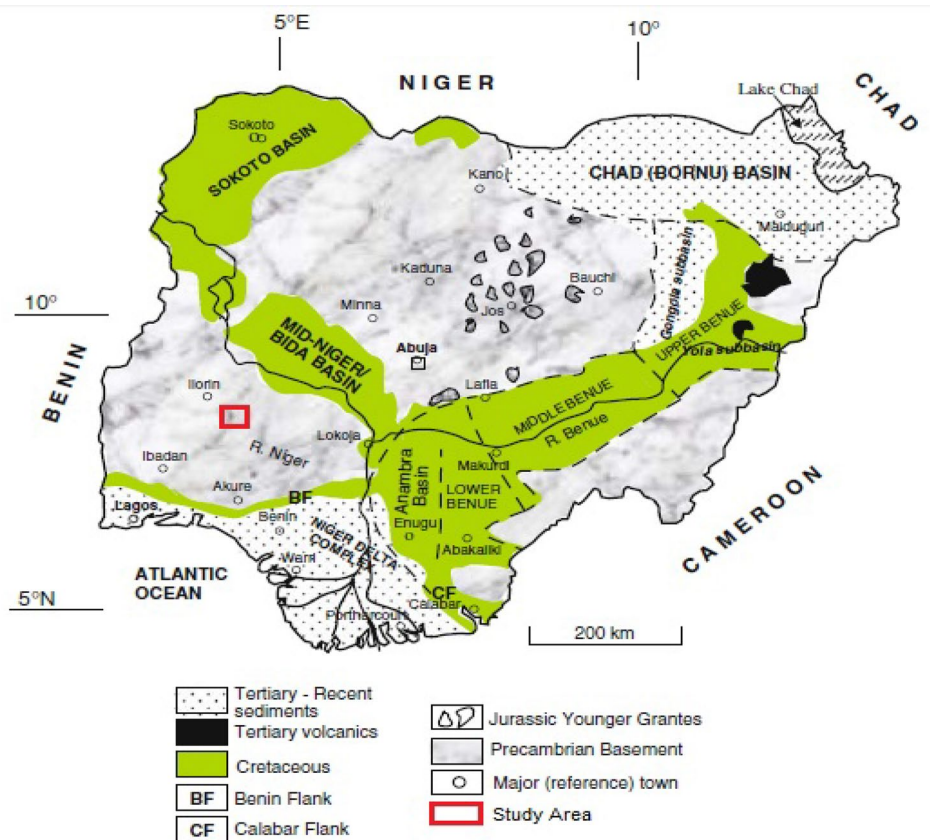


**Table 1** Data types and sources

| S/N | Data | Source | Scale |
|---|---|---|---|
| 1 | Landsat 8 OLI/TIRS | Glovis (http://glovis.usgs.gov) | 30 m |
| 2 | ASTER DEM | Glovis (http://glovis.usgs.gov) | 90 m |
| 3 | Geological map | Nigeria geological survey Agency | 1:100,000 |
| 4 | Soil map | Center for world food studies (SOW-UV) (1997) | 1:1,300,000 |
| 5 | Topographical map | Nigeria geological survey agency (NGSA) | 1:50,000 |

larger portion of the study area (84,121.8 km$^2$) representing about 78% of the total area falls within the medium potential zone which is generally underlain by medium-porphyritic granite, biotite-hornblende granite, and granite gneiss bedrock settings. About 18,239.7 km$^2$ (17%) fall under the high potential zone which is characterized by weathered/fractured quartzite, quartz-schist, amphibolite schist, and phyllite bedrock settings. However, areas of low potentials constitute only 3% (3,416.54 km$^2$) of the total study area and are mostly underlain by migmatite, banded and augen gneiss bedrock settings.

Okoli (2019) mapped potential in Ado Ekiti using GIS and Remote sensing techniques. Six thematic layers which include geology, lineament density, flow accumulation, elevation, land use, and slope were combined for groundwater potential zone delineations. The result showed that the potential is mostly high in the South-West to the North-West and North central part of Ado Ekiti, and low potential was indicated in the southeastern part. The present study area lies within longitudes 5′15' to 5′30' E and latitudes 7′45' to 8′00' N covering approximately 753 km$^2$. It lies in between the Iye/Ilejemeje, Oye, and Ikole Local Government Areas of Ekiti state (Fig. 1). Major towns within the study area include Eda Oniyo, Iporo-Ekiti, Ilemoso Ekiti, Isan-Ekiti, Ilafon Ekiti, Aiyede/Itaagi Ekiti, Omun titun, Omu-Ekiti, Itapaji, Imojo, Omu Ijelu, Itapa Ekiti, Aiyegbaju, Oye, Ilupeju, Osin Ekiti, and Ire-Ekiti.

Physiologically, the study area is composed of hilly terrain and plains with isolated hill locks. The area is mainly
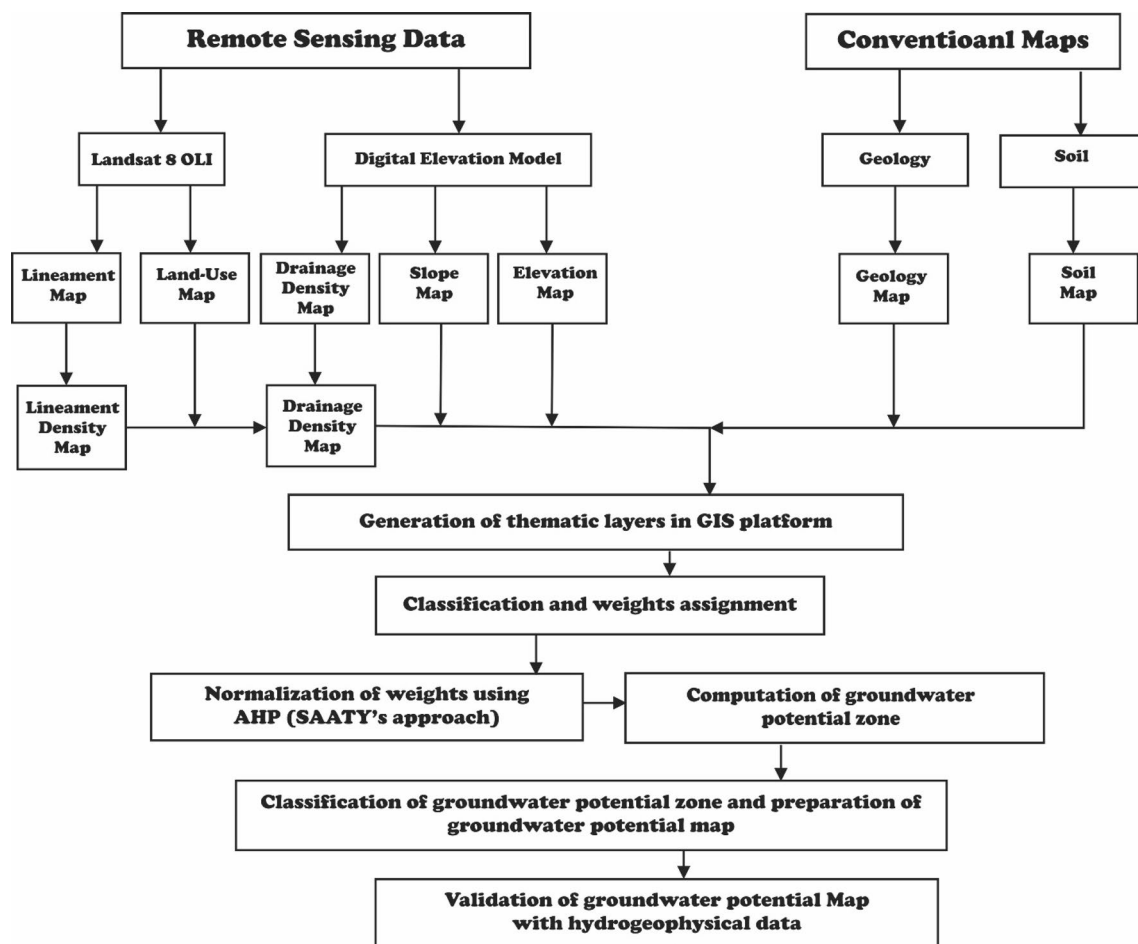
**Fig. 3** Flowchart for characterizing potential in the study area

an upland zone and has a rhythmically undulating surface with an elevation that ranged between 352 and 753 m above sea level. The area enjoys a tropical climate with rainfall that ranged between 1200 and 1400 mm and is characterized by two distinct seasons which are the rainy season which usually starts in April and lasts till October and the dry season which starts in November and lasts till March. Temperature ranges between 21 and 28 °C while the mean monthly relative humidity is less than 70% (NIMET 2019; Bayowa et al. 2014).

Geologically, the area of study lies within the southwestern basement complex of Nigeria (Fig. 2). The area is underlain by rocks of the Precambrian basement complex of southwestern Nigeria (Rahman 1976). The area falls within three major lithostratigraphic units in which gneiss and granites are more pronounced. The granitic rocks dominate the area (Fig. 2). It is coarse-grained corresponding to the Precambrian age and is called Porphyritic granite. The granites occur as intrusive in low-lying outcrops within the biotite gneiss. In basement terrain, groundwater occurs in the weathered basement and the joints, fractures, or faults within the bedrock (Ademilua and Olorunfemi 2000). The rock consists of Precambrian metasediments, migmatites, gneisses, granites, and other intrusive igneous rock.

Groundwater potential mapping using GIS and remote sensing has not been previously carried out in the current area of study. Ilejemeje/Iye, Oye, and Ikole local Government areas are going to be the major focus of this study.

## Materials and methods

This study made use of both primary and secondary data. The primary data included *Landsat8 OLI* and *ASTER* Digital Elevation Model. The secondary data included geology, soil, and topographical maps of the study area (Table 1). ArcGIS, Rockworks, ENVI, and PCI Geomatic Software were used for data processing.
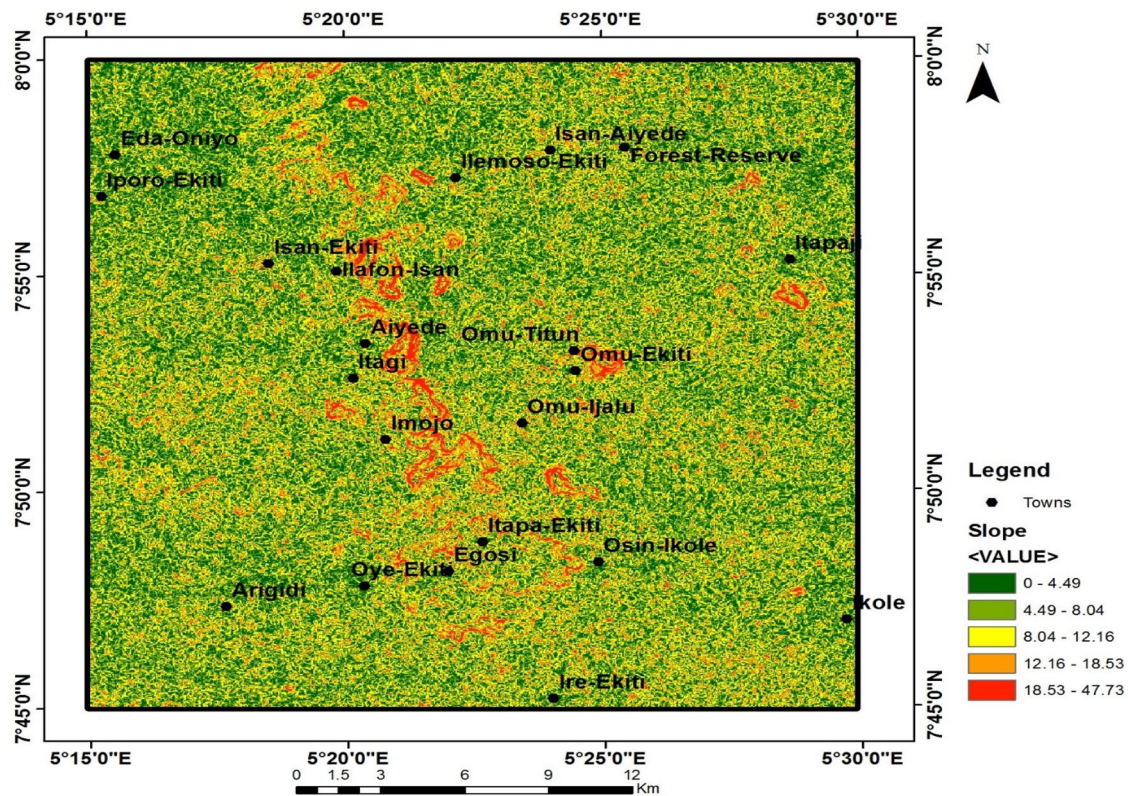
**Fig. 4** Slope map of the study area

The procedure adapted comprises desk studies, field-work, and validation of findings. The steps involved are also presented in Fig. 3. Desk studies involved the studying of literature and previous works on groundwater across Ekiti, Nigeria, and the world in general. Fieldwork involved geological mapping as well as geophysical surveys, while validation involves comparing the results of the outcomes of the GIS analysis with the geophysical survey.

To develop thematic maps of the groundwater potential of the study area, lineament and land use/cover maps were derived from the *Landsat8* OLI/TRS image using *ENVI*, PCI *Geomatica*, *Rockworks*, and *ArcGIS* software (Fig. 3). Maximum Likelihood Classification (MLC) was used to produce the land use/cover map of the study area. Elevation, slope, and drainage maps were produced with the spatial analyst tool and the *Archydro* tool of *ArcGIS*, respectively. To derive the thematic maps from the secondary data, hard-copy maps (geology and soil) were scanned and imported into the *ArcGIS* software then georeferenced to World Geodetic System (WGS 84) coordinate system.

The weighting of the thematic maps was carried out using the Analytical Hierarchical Process (AHP). The AHP calculates weights based on the consideration of each theme's influence on accumulation by the technique of pairwise comparison to compare the influence of one criterion with another on a scale of 1 to 9. Thus, 1 denotes equal importance between a pair of criteria, 3 means moderately more important, 5 is strongly more important, 7 is very strongly more important, and 9 implies extremely more importance of one criterion to the other. Meanwhile, 2, 4, 6, and 8 were used as intermediate values (Saminu et al. 1999). The scale for comparison was determined based on previous studies (Sarup et al. 2011).

Mapping of the potentials of the study area was done by the weighted index overlay method in *ArcGIS*. Before the overlay operations, the next step after weighing the maps was to carry out reclassification. This was done by assigning the new weight values to the maps' sub-units (sub-criteria) computed from the AHP. The reclassify tool in the spatial analyst tool of *ArcGIS* was used for this task. The potential zones map of the study area was produced by overlaying all thematic layers using the weighted index overlay:

**Table 2** Calibration and weight evaluation for groundwater potential

| Factors | Domain of effect | Descriptive level (groundwater) | Ranks | Weights | Area (km$^2$) | Area (%) |
|---|---|---|---|---|---|---|
| Drainage density | 197.58–320.88 | Very low | 1 | 22 | 5.55 | 0.74 |
| | 149.74–197.56 | Low | 3 | | 80.85 | 10.74 |
| | 104.44–149.74 | Moderate | 5 | | 210.05 | 27.9 |
| | 69.14–104.44 | High | 7 | | 272.33 | 36.16 |
| | 0–69.14 | Very high | 9 | | 184.22 | 24.46 |
| Elevation (m) | 592–753 | Very low | 1 | 15 | 52.73 | 7 |
| | 546–598 | Low | 3 | | 201.64 | 26.78 |
| | 507–546 | Moderate | 5 | | 237.63 | 31.56 |
| | 458–507 | High | 7 | | 188.5 | 25.03 |
| | 352–458 | Very high | 9 | | 72.5 | 9.63 |
| Slope | 18.53–47.73 | Very low | 1 | 5 | 34.94 | 4.64 |
| | 12.16–18.53 | Low | 3 | | 89.45 | 11.88 |
| | 8.04–12.16 | Moderate | 5 | | 182.94 | 24.29 |
| | 4.49–8.04 | High | 7 | | 253.92 | 33.72 |
| | 0–0.49 | Very high | 9 | | 191.75 | 25.47 |
| Land use/land cover | River | Very low | 1 | 15 | 0.52 | 0.07 |
| | Built-up | Low | 3 | | 53.06 | 7.05 |
| | Rocks | Moderate | 5 | | 185.25 | 24.6 |
| | Farmland | High | 7 | | 275.67 | 36.61 |
| | Forest | Very high | 9 | | 238.5 | 31.67 |
| Geology | Charnockite | Low | 3 | 12 | 123.56 | 16.41 |
| | Granite | Moderate | 5 | | 83.12 | 11.04 |
| | Granite Gneiss | High | 7 | | 150.39 | 19.97 |
| | Migmatite | Very high | 9 | | 395.93 | 52.58 |
| Soil | Leptosol-14 | Very low | 1 | 8 | 9.38 | 1.25 |
| | Lixisol-14 | Low | 3 | | 264.51 | 35.13 |
| | Lixisol-12 | Moderate | 5 | | 48.12 | 6.39 |
| | Lixisol-17 | High | 7 | | 282.97 | 37.58 |
| | Lixisol/Regosol-12 | Very high | 9 | | 148.02 | 19.65 |
| Lineament | 0–0.5 | Very low | 1 | 23 | 474.32 | 62.99 |
| | 0.5–1.01 | Low | 3 | | 161.27 | 21.42 |
| | 1.01–1.51 | Moderate | 5 | | 87.59 | 11.63 |
| | 1.51–2.02 | High | 7 | | 25.19 | 3.35 |
| | 2.02–2.52 | Very high | 9 | | 4.63 | 0.61 |

Groundwater Potential Zone Map (GWPZ); $\sum_{(i,j=1)}^{8} WiXj$

where $Wi$ = % weight for each thematic map, $Xj$ = reclassified map.

# Results

## Slope

The slope is one of the important terrain parameters that affect groundwater recharge and infiltration, and it determines the rate of infiltration and runoff of surface water. Less sloppy surface permits low runoff and allows more time for infiltration of rainwater, while high-slope area enhances high runoff with short residence time for infiltration and recharge. In order words, the gentle and flat surface areas
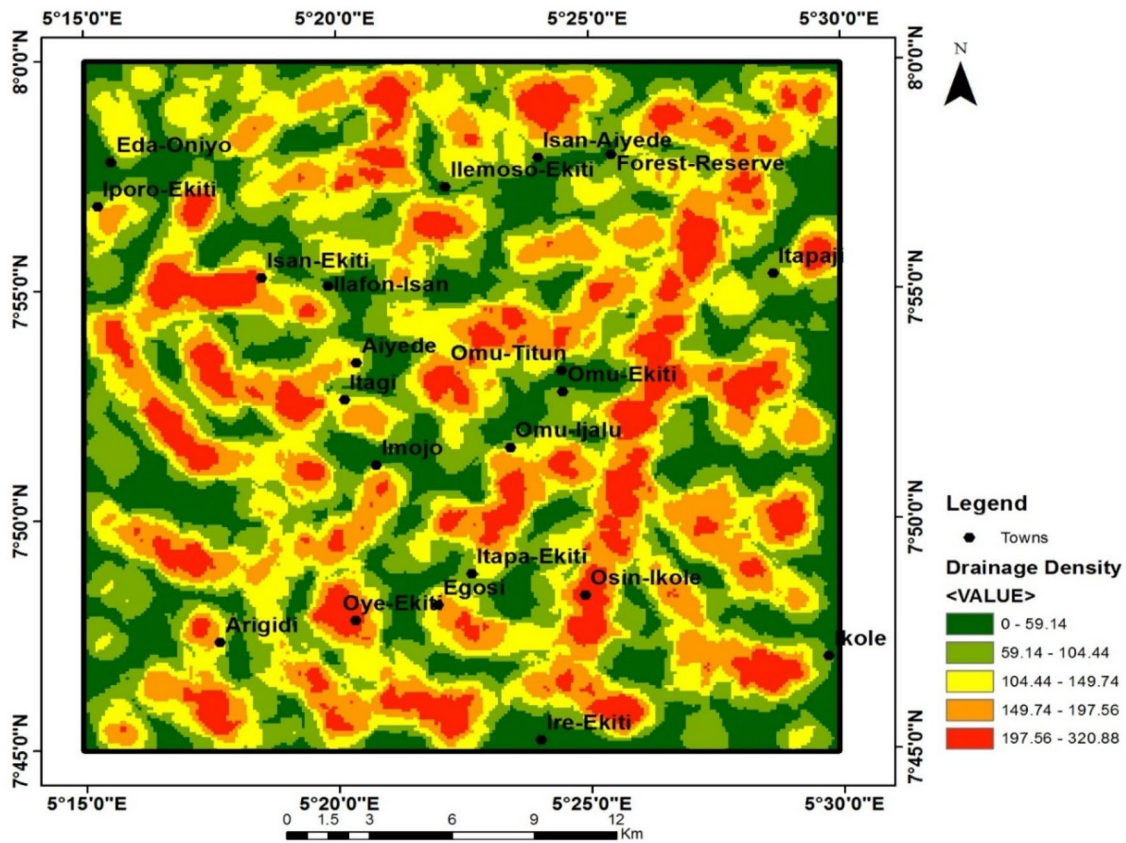
**Fig. 5** Drainage density map of the area of study

can hold and drain water into the ground, thereby boosting recharge, while steep slopes increase runoff and decrease the rate of infiltration of surface water into the ground. In this study, the slope thematic map as presented in Fig. 4 revealed slope values in degrees and ranged from 0 to 47.73 degrees. The heterogeneity of slope values within the area of study is an indication of variation in the rate of runoff and recharge which implies variation in the potential characteristics of the study area. The 0–4.49 degree range was classified as having very high, 4.49–8.04 high, 8.04–12.16 moderate, 12.16–18.53 low, and 18.53 and above as having a very negative influence on groundwater accumulation. Approximately, about 191.75 km$^2$ of the total area is occupied by less than 5% slope, which indicates nearly flat surfaces to very gentle slopes and constitutes about 25.47% of the study area, while about 34.94 km$^2$ is occupied by steep slope which also forms 4.64% of the total area. This area also coincides with the location of granites and charnockite plutons and boulders in the area, respectively. Based on the above, higher weights are assigned to lower slope values, while lower weights were assigned to higher slope values as shown in Table 2.

## Drainage density

Drainage density also constitutes a major factor in groundwater flow and accumulation. A high drainage density represents the closeness of drainage channels and vice versa, the higher the drainage density, the greater is the runoff, while the lower the drainage density, the lower the runoff and the higher the probability of recharge or potential zone. In other words, water runoff will be high if drainage density is high, so the infiltration of water into the ground would be lesser, whereas in the low drainage density areas, a surface water runoff will be less, so infiltration of surface water into the ground will be high (Fashae et al. 2014; Ghodratabadi et al. 2015). Drainage density in the study area as presented in Fig. 5 showed that the area of study has drained density values that ranged from 0 to 320 km$^2$. The obtained drainage density values were reclassified into five categories: very high, high, moderate, low, and very low. 0–59.14 km$^2$ was classified as very high and covered a total of 24.46% was assigned a high weight, 59.14–104.44 km$^2$ (high) covering a total of 36.16%, 104.44–149.74 km$^2$ (moderate) and covers
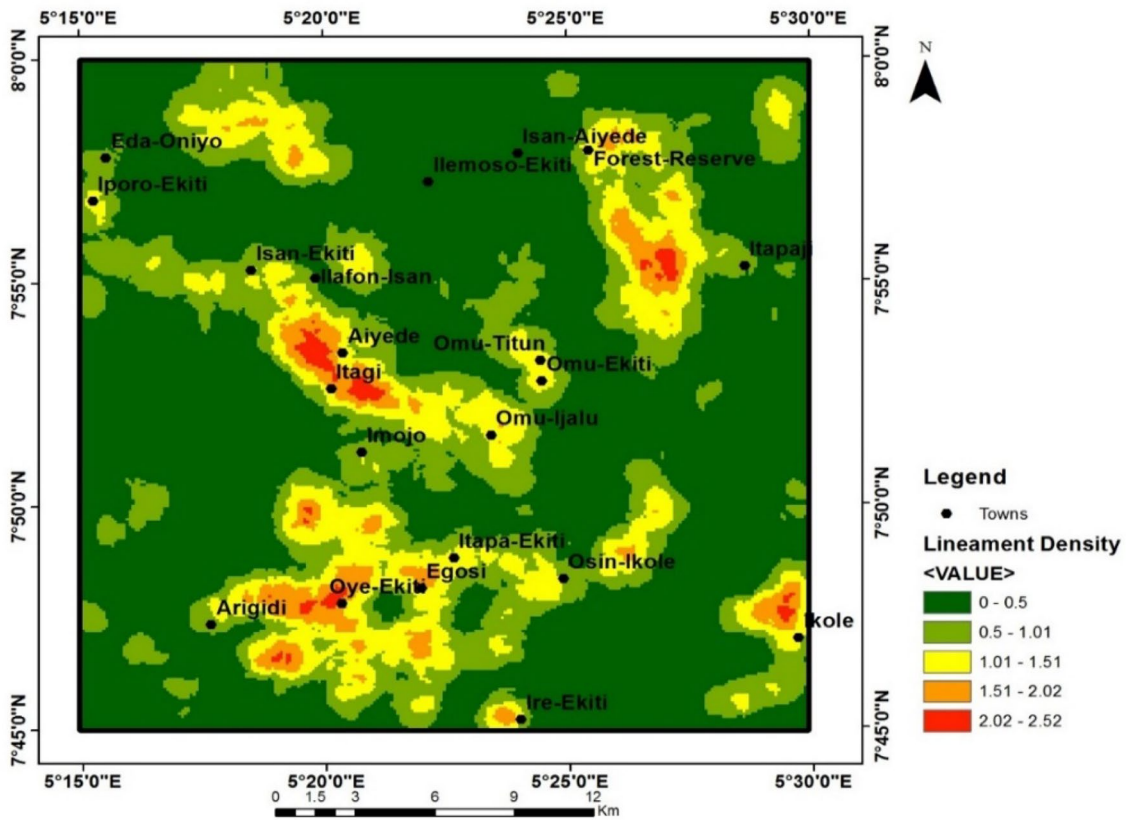
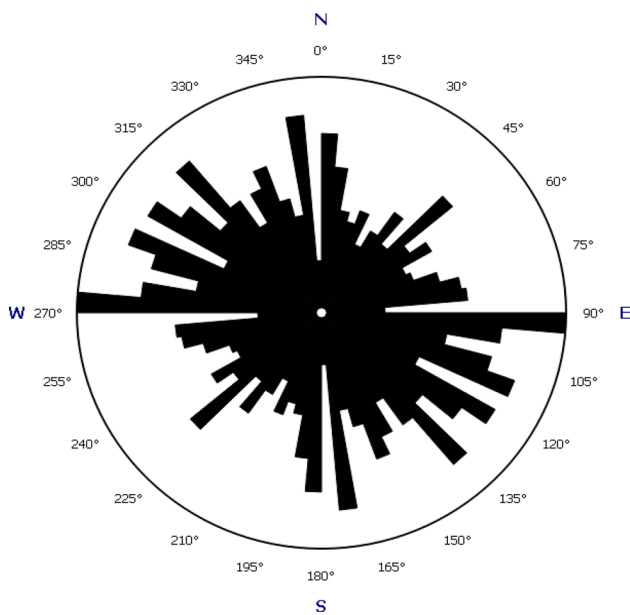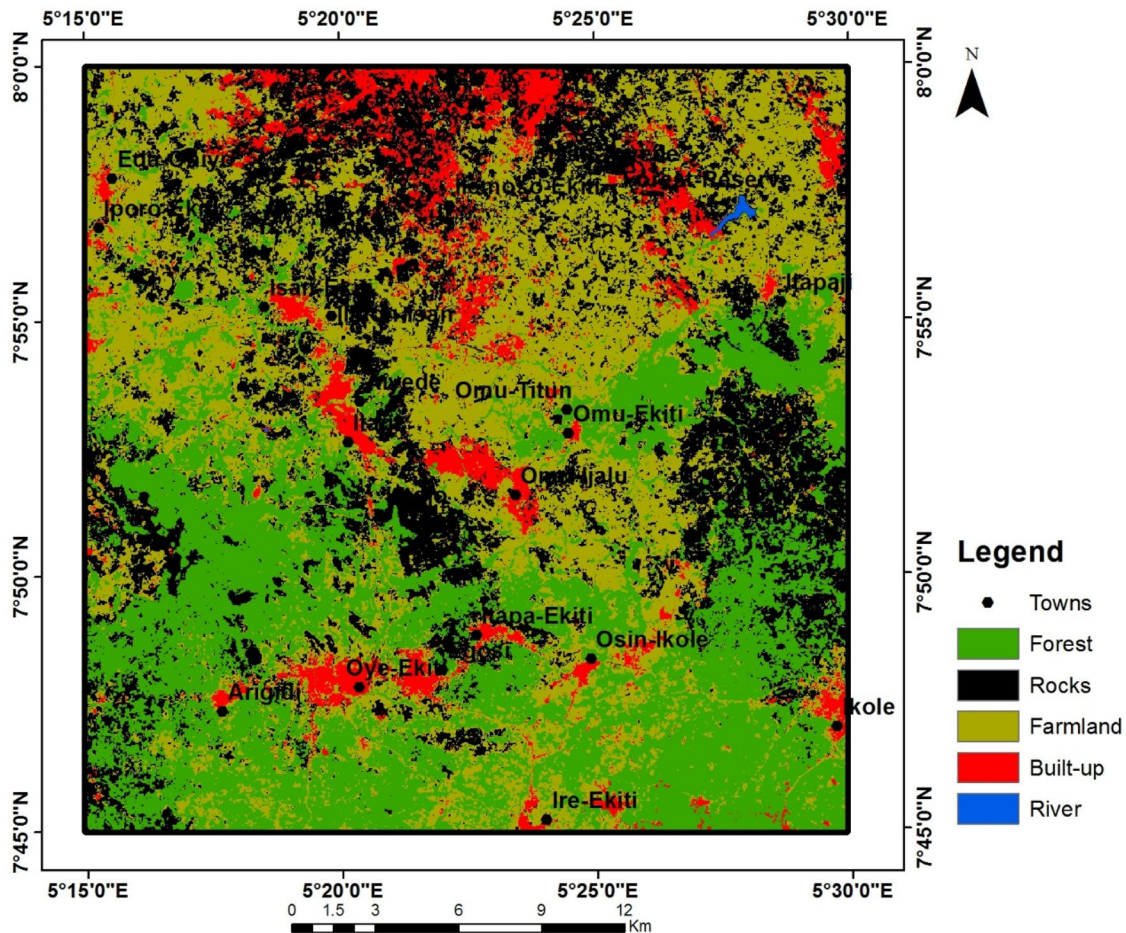**Fig. 6** Lineament density map of the study area



**Fig. 7** General orientation of lineaments within the study area

27.9%, 149.74–197.56 km$^2$ (low) covering a total of 10.74%, 149.74–320.88 km$^2$ (very low) covering a total of 0.74% and assigned low weight.

## Lineament density

Lineaments are straight or approximately linear landforms that are widely distributed across the surface of the Earth and are closely related to underground concealed faults. Lineaments are related to fractures and faults in slightly inclined stratigraphic regions. The direction and number of lineaments reflect rock mass fracture patterns and can provide valuable information related to geological structures, tectonics, hazard assessment, and natural resource availability (Okoli et al. 2019). Further, lineaments can be identified from satellite imagery by their relatively linear alignments (Nag et al. 2016). Lineaments represent zones of faulting and fracturing which could result in increased secondary porosity and permeability. From the lineament density map

**Fig. 8** Land use/cover map of the study area

of the study area (Fig. 6), four dominant lineament orientations are present, and these are N–S, E–W, NW–SE, and NE–SW (Fig. 7). These orientations are typical of the structures and deformation pattern within the basement complex of Nigeria. A lineament density map is a measure of the quantitative length of linear feature per unit area which can indirectly reveal the potentials as the presence of lineaments usually denotes a permeable zone.

In the area of study, lineament density values ranged from 0.0 to 2.52 km$^2$; areas with high lineament density are best for groundwater accumulation, while areas with low lineaments are less favorable for groundwater accumulation, as such higher weights were assigned to high lineament values and low weights to low lineament values.

## Land use/cover

Land use/cover map depicts the effect of man's activities on land and also plays a huge role in groundwater development. The presence or absence of man-made features on land influences runoff, infiltration, and recharge of groundwater. The identified land use/land cover features in the study area as shown in Fig. 8 are forest, farmland, rocks, built-up, and river. Farmland dominates the studies part of Ekiti, covering a total of 36.61% of the study area, followed by forest which covers a total of 31.67%, rocks also cover a good part of the study area (24.6%), while built-up areas occupied 7.05%. The river covers the lowest part of the study area at 0.07%. Higher weights are assigned to forest and farmland as they are more open and permit easy surface water penetration into the ground, thereby recharging the groundwater and also accumulating within the subsurface, while lower weight were assigned to built-up areas and river as these areas do
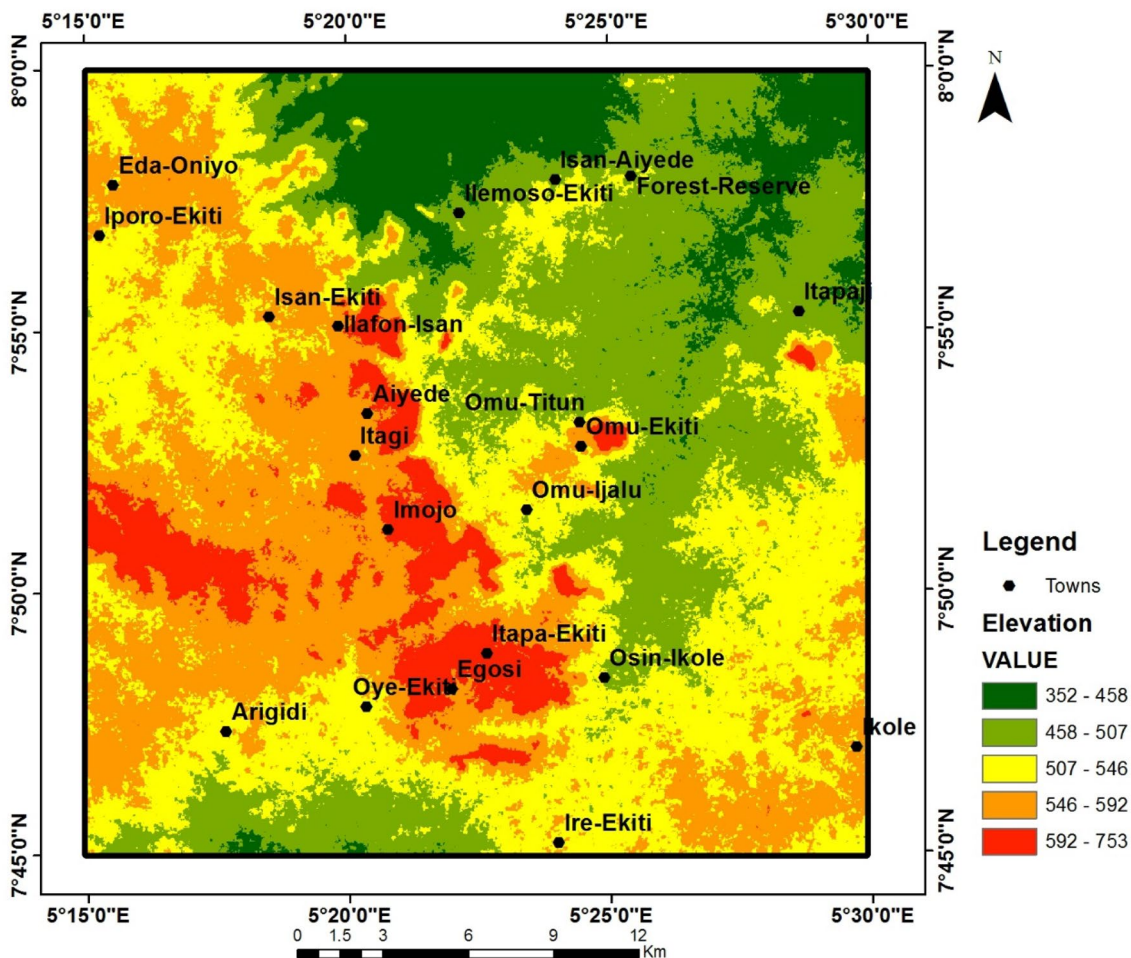
**Fig. 9** Digital elevation model map of the study area

not permit surface water to percolate into the subsurface and do not allow for recharge and accumulation.

## Elevation

Topography plays an important role in groundwater flow and accumulation as well as groundwater recharge; topographic factors have a direct effect on flow size and runoff velocity (Kia et al. 2012). Elevation refers to the height of an object above sea level. The DEM image of the study area shows that elevation values ranged from 352 to 753 m. The low elevation is much more significant in groundwater development as surface water flows from areas of higher elevation to areas of lower elevation. From the elevation map of the study area (Fig. 9), low elevation values cover a total of 9.63% while high elevation covers 7% of the area. Intermediate

values make up the remaining 83.46%. Higher values were assigned to low elevation while lower values were assigned to high elevation.

## Soil

Soil types play a vital role in the amount of water that infiltrates subsurface formations and hence have a high influence on recharge (De Reu 2013). Soil texture and hydraulic characteristics are the main factors considered for the estimation of the rate of infiltration. The movement of and infiltration of surface water into the ground is based on the porosity and permeability of the soil. Further, fine-grained soils limit infiltration due to low permeability, unlike coarse-grained soil materials where water can infiltrate easily because of high permeability (Fashae
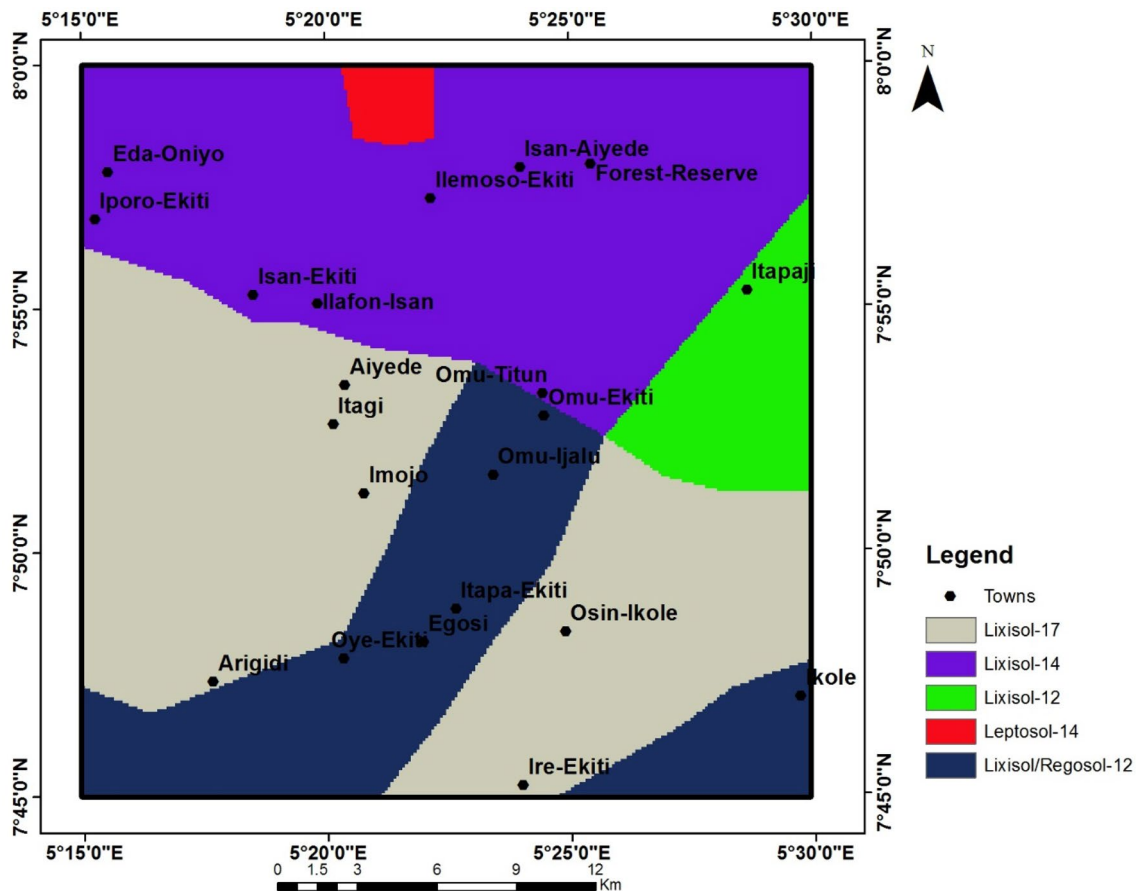
**Fig. 10** Soil map of the study area

et al. 2014). From the soil map of the study area (Fig. 10), three different soil types are present in the area, namely Lixisol, leptosol, and Regosols. These soils were ranked according to their properties and how it affects groundwater development as given by FAO 2005. Lixisol forms the dominant soil type in the study area, covering a total of 79% of the study area followed by Lixisol/Regosol at 19.65% and Leptosol covering 1.25%.

## Geology

The geology of an area can help determine the aquifers where is likely to be stored. The porosity and permeability of a formation determine its quality as an aquifer. Sedimentary rocks are known to have a far higher primary porosity and permeability in comparison to crystalline rocks which have less than 3% (Bouwer 1978). However, fracturing can greatly increase the ability of crystalline rocks to serve as aquifers (Davis and De Weist 1966) and

indicators of secondary porosity and permeability are commonly sought when prospecting for in such terrains (Gupta 2003). The study area is underlain by a suit of rocks that forms part of the southwestern basement complex of Nigeria, and these rock suits comprise igneous and metamorphic rocks (Charnockite, granite, granite gneiss, and migmatite). Migmatite dominates the study area covering a total of 52.58%, followed by granite gneiss (19.97%), charnockite (16.41%), while granite covers the smallest area (11.04%) (Fig. 11). Since sedimentary rocks are not present in the area of study, the basement complex rocks were weighted based on their age and level of deformation. The older the rock, the higher the level of deformation and development of faults, fractures, and joints which can serve as an opening for surface water infiltration into the subsurface. In this regard, metamorphic rocks were assigned higher weights while igneous rocks were assigned lower weights as shown in Table 2.
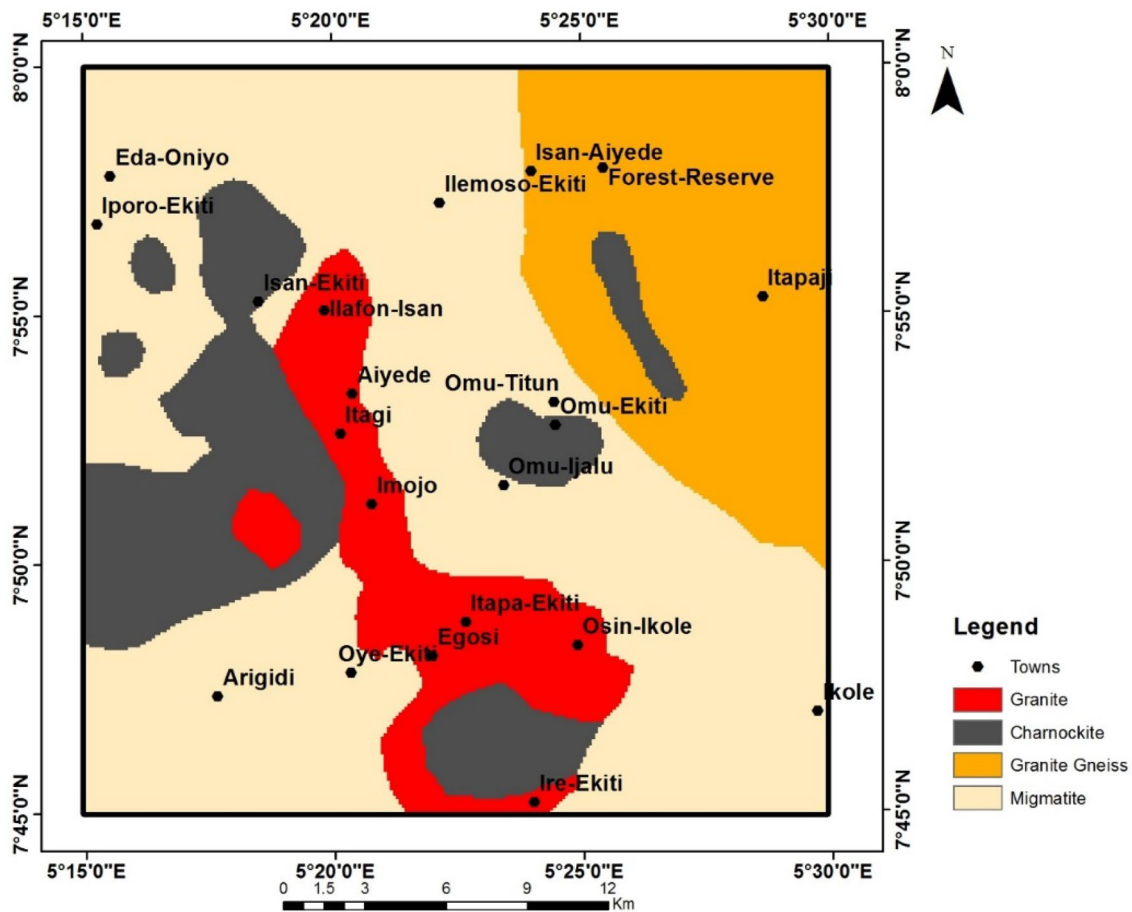
**Fig. 11** Geology map of the study area

**Table 3** Groundwater potential and their areal coverage

| Groundwater potential | Area covered (Km²) | % Covered |
|---|---|---|
| Very low | 1.4 | 0.19 |
| Low | 72.18 | 9.59 |
| Moderate | 372.3 | 49.44 |
| High | 272.12 | 36.14 |
| Very high | 35 | 4.64 |

## Groundwater potential

The various weights assigned to the thematic maps, produced earlier, were finally used to produce the groundwater potential zones in the area of study. The groundwater potential of the study area is shown in Fig. 12 and has been classified into five, namely very low, low, moderate, high, and very high. Very low groundwater potential covers 1.4 km² (0.59%) of the total area, low covers 72.18 km² (9.59%), moderate covers 372.3 km² (49.44%), high groundwater potential covers 272.12 km² (36.14%), and very high groundwater potential covers 35 km² (4.64%), as presented in Table 3. From Fig. 12, the western part of the area of study is dominated by very low to low groundwater potential while the southern part of the area of study is dominated by high and very high groundwater potential. Generally, low and moderate groundwater potential occupies the highest landmass in the area of study, and this is to show that the basement complex terrain of Nigeria has a very low aquifer capability.

Places such as Isan-Ekiti, Osin-Ikole, Imojo, and Ilafon-Isan lie within the very low and low groundwater potential areas, while Oye-Ekiti, Egosi, Itapa Ekiti, Eda Oniyo, Omu-Ekiti, Itagi, Iporo-Ekiti, etc. lie within moderate and high groundwater potential zone. Places such as Ikole, Ire-Ekiti, Arigidi Omu-Ijalu and Omu-Titun lie within the very high potential zone.
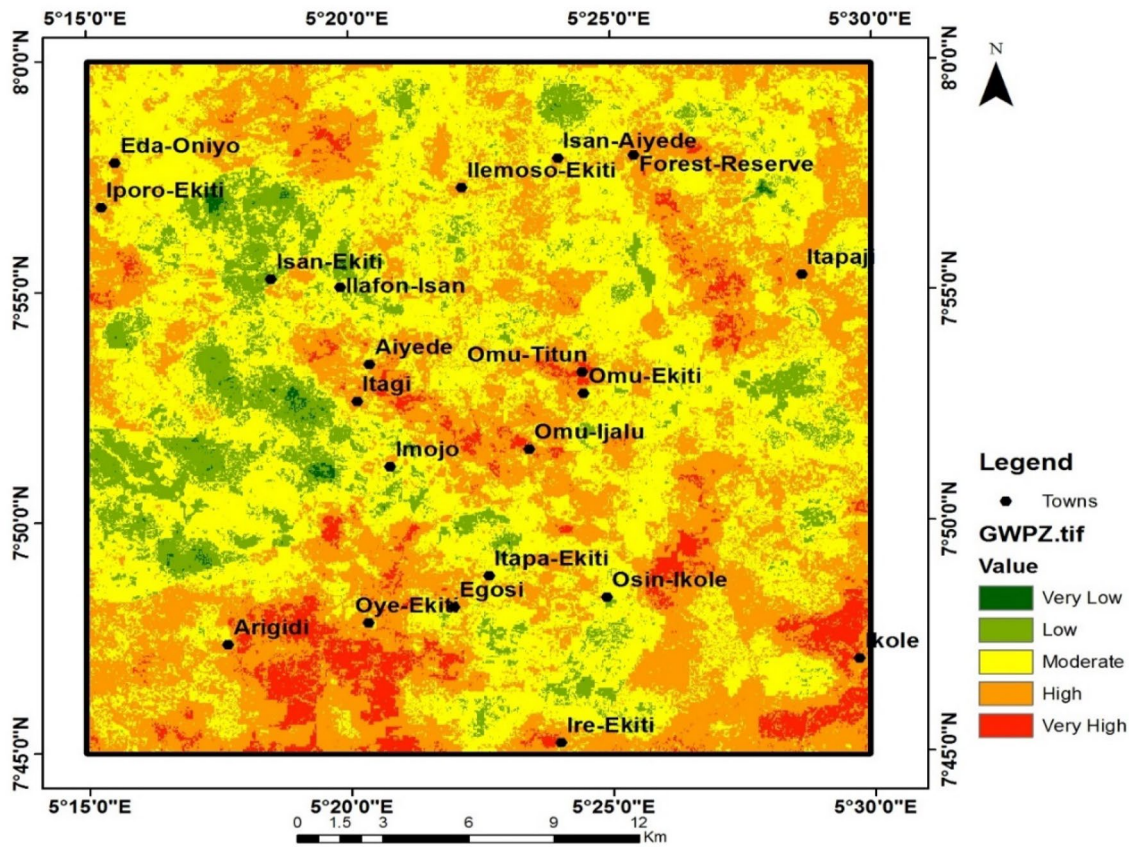
**Fig. 12** Groundwater potentials map of the study area

A close look at Fig. 12 shows that areas of higher slope and high elevation values have low groundwater potential, while places of high lineament density and low drainage density have high to very high groundwater potential. In addition, geology played an important part in the groundwater potential of the study area as well as high and very high groundwater potential could be seen within the metamorphic rocks and very low to moderate within the igneous rocks. For land use, high and very high groundwater potential cuts across the farmland and forest more than the built, rivers, and rocky areas because forest and farmland enhance surface water infiltration into the subsurface.

Validation of groundwater potential map.

# Conclusion

From the analysis, it shows that slope contributed to the groundwater recharge and infiltration, and it determined the rate of infiltration and runoff surface water; a high-slope area enhances high runoff with short residence time for infiltration and recharge. Gentle and flat surface areas can hold and drain water into the ground by increasing groundwater recharge, while steep slope increases runoff and decreases the rate of infiltration of surface water into the ground.

The thematic slope map has revealed a slope map in degree and ranged from 0 to 47.73 degrees, and heterogeneity in slope values in the study areas is an indication of variation in the rate of runoff and recharge which implies variation in groundwater characteristics in the study area. 0–4.49 degrees were classified as having very low, 4.49–8.04 high, 8.04–12.16 moderate, 12.16–18.53 low, 18.53 and above as having a very negative influence on groundwater accumulation about 191.75 km$^2$ of the total area is occupied by less than 5% slope, which indicates nearly flat surfaces to very gentle slopes and constitutes about 25.47% of the study area, while about 34.94 km$^2$ is occupied by steep slope which also forms 4.64% of the total area. This area also coincides with the location of granites and charnockite plutons and boulders in the area, respectively. Based on the above, higher weights are assigned to lower slope values, while lower weights were assigned to higher slope values.

Drainage density showed that the area of study has drained density values that ranged from 0 to 320 km². The obtained drainage density values were reclassified into five categories: very high, high, moderate, low, and very low. 0–59.14 km² was classified as very high and covered a total of 24.46% and was assigned a high weight, 59.14–104.44 km² (high) covering a total of 36.16%, 104.44–149.74 km² (moderate) and covers 27.9%, 149.74–197.56 km² (low) covering a total of 10.74%, 149.74–320.88 km² (very low) covering a total of 0.74% and assigned low weight.

Lineament density presents four dominant lineament orientations, these are N–S, E–W, NW–SE, and NE–SW, and these orientations are typical of the structures and deformation pattern within the basement complex of Nigeria. A lineament density map is a measure of the quantitative length of linear feature per unit area which can indirectly reveal the potentials as the presence of lineaments which usually denotes a permeable zone. Lineament density values ranged from 0 to 2.52 km², and areas with high lineament density are best for groundwater accumulation, while areas with low lineaments are less favorable for groundwater accumulation, as such higher weights were assigned to high lineament values and low weights to low lineament values.

From the elevation map of the study, low elevation values cover a total of 9.63%, while high elevation covers 7% of the area. Intermediate values make up the remaining 83.46%. Higher values were assigned to low elevation while lower values were assigned to high elevation.

The soil map showed three different soil types in the area, namely Lixisol, leptosol, and Regosols. These soils were ranked according to their properties and how it affects groundwater development as given by FAO 2005. Lixisol forms the dominant soil type in the study area, covering a total of 79% of the study area followed by Lixisol/Regosol at 19.65% and Leptosol covering 1.25%.

The groundwater potential of the study area has been classified into five, namely: very low, low, moderate, high, and very high. Very low groundwater potential area covers 1.4 km² (0.59%) of the total area, low covers 72.18 km² (9.59%), moderate covers 372.3 km² (49.44%), high groundwater potential covers 272.12 km² (36.14%), and very high groundwater potential covers 35 km² (4.64%), the western part of the area of study is dominated with very low to low groundwater potential while the southern part of the area of study is dominated by high and very high groundwater potential. Generally, low and moderate groundwater potential occupies the highest landmass in the area of study; this is to show that the basement complex terrain of Nigeria has a very low aquifer capability.

## Declarations

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