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ORIGINAL ARTICLE

Hydrogeologic characterization of Owo and its environs using remote sensing and GIS

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Abstract The application of remote sensing and GIS in groundwater potential characterization has been internationally acclaimed. Owo and its environment lack sufficient groundwater data that will aid proper planning and management of the resource. For this reason, the groundwater potential study of Owo and its environment within the Basement Complex was carried out using remote sensing and GIS. LANDSAT ETM + (Bands 1–8) was acquired and the acquired imageries were processed using image processing software. For drainage mapping, bands 4-3-2 were combined in a RGB (123) format. For lineament extraction, the Digital terrain model (DTM) was generated from the SRTM data. The DTM was used in extracting lineaments in the study area. Groundwater potential of the area was calculated using score values assigned to each parameter studied. Results show that the lineament distribution in the study area is polymodal with peaks between 80°–100°. The East–West fractures are most prominent, with the broad, positive correlation in frequency and length of the lineament, suggesting that they are of geological origin. Lineament density of the area shows that Owo has higher lineament density of about 0.85 km/km^2 when compared other part of the study area. The density of lineament in the study area is attributable to the high fracturing that affected the Basement Complex area during the Pan-African Orogeny. In addition, the study further revealed that there are more lineament intersection around the southeastern part of Owo Township and Iyere. These areas are more favourable sites for groundwater accumulation. The drainage density map generated for the study area reveals that there are more rivers around Emure-Owo than other parts of the study area. In conclusion, the groundwater potential of the study area is from low to high.

Keywords Hydrogeology · Remote Sensing · GIS · Groundwater · Lineaments

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Introduction

Groundwater resources are gaining increasing importance and they represent an increasing proportion of the water supplies used for different applications (Hernández-Mora et al. 2003). Groundwater plays an important role in supplying water to much of the global population for use for agriculture, drinking water, and industrial purposes (Luczaj 2016). Groundwater is a vital natural resource for reliable and economic provision of safe water supplies of both the urban and rural environments (Nwankwoala 2015). Nigeria is faced with increasing demands for water resources due to high population growth rate and growing prosperity (Nwankwoala 2011). The advantages of groundwater as a source of supply cannot be overemphasized especially where populations are still largely rural and demand are dispersed over large areas (Nwankwoala 2015). Groundwater is a dependable and assured resource and can be exploited with greater ease and flexibility. Groundwater offers the most abundant source of water to man and it is the cheapest and most constant in quality and quantity (Nwankwoala 2015).

In Nigeria, the occurrence of groundwater varies with the geology of the area. In the Basement Complex terrain, groundwater occurs in the weathered regolith and in fractures in the fresh crystalline rocks. Where thick weathered zones or fractures in fresh rocks occur, wells and boreholes tap the groundwater for water supply (Nwankwoala 2015). The geological structure of Nigeria gave rise to two types of groundwater pore-type water in sedimentary cover and fissure-type water found in crystalline rocks (Eduvie 2006). The following aquifer types occur in Nigeria: (i) fissure-type water in precambrian crystalline rocks, (ii) pore-type water in sedimentary deposits, and (iii) pore-type water in superficial deposits. In general, aquifer distribution in Nigeria is categorized into two systems: basement fluvio-volcanic aquifers and sedimentary aquifers (Eduvie 2006). The availability of groundwater in areas underlain by crystalline basement rocks depends on the development of thick soil overburden (overburden aquifers) or the presence of fractures that are capable of holding water (fractured crystalline aquifers). The storage of groundwater is confined to fractures and fissures in the weathered zone of igneous, metamorphic, and volcanic rocks, and the thickness of which range from <10–60 m in arid and humid rain forest. The groundwater resources here are usually limited (Eduvie 2006). Groundwater potential in Nigeria is far greater than the surface water resources, estimated to be 224 trillion l/year (Hanidu 1990). Rijswlk (1981) estimated groundwater resources at 0–50 m depth in Nigeria to be $6 \times 10\ km^3$ ($6 \times 1018\ m^3$).

Groundwater exploration techniques can be subdivided into four: aerial, surface, subsurface, and esoteric techniques (Badrinarayanan 2016). Aerial techniques for groundwater exploration include remote sensing and photogeologic techniques which involve the use of remotely sensed imageries and aerial photographs such as LANDSAT ETM. The surface method of exploration includes geological, geomorphological, hydrogeological, geophysical, geobotanical, and geochemical methods (Badrinarayanan 2016). Geophysical methods used in the surface method of groundwater exploration include electrical and electromagnetic, seismic, magnetic, and gravity methods. For subsurface groundwater exploration, geological, hydrogeological, tracer, and geophysical logging techniques are employed. Esoteric method involves the use of divining, astrological, and biophysical techniques (Badrinarayanan 2016).

Remote sensing is the science and art of identifying, observing, and measuring an object without coming into direct contact with it. This process involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, by which they may be identified and categorized by class/type, substance, and spatial distribution (Graham 1999). Remote sensing and GIS methods permit rapid and cost-effective natural resource survey and management (Nag 2008). The remote sensing data help in fairly accurate hydrogeomorphological analysis and identification and delineation of land features (Kumar and Srivastava 1991). With sufficient ground data, hydrological characteristics of geomorphological features can be deciphered (Nag 2008). Remotely sensed data serve as vital tool in groundwater prospecting (Horton 1945; Sharma and Jugran 1992; Chatterjee and Bhattacharya 1995; Tiwari and Rai 1996; Ravindran 1997). It also provides an opportunity for better observation and more systematic analysis of various geomorphic units, lineament features, following the integration with the help of Geographical Information System to demarcate the groundwater potential zones (Nag 2008). Therefore, an integrated approach, including studies of lithology, hydrogeomorphology, and lineament, has been taken up, using remote sensing and GIS techniques, for a proper assessment of groundwater potential zones in the study area (Nag 2008). Knowledge of groundwater location is important for both water supply and pollution control analysis. The identification of topographic and vegetation indicators of groundwater and the determination of the groundwater location discharge area (seeps and springs) can assist in the location of potential well sites. Groundwater recharge zones could be identified to protect these areas (through zoning restrictions) from activities that would pollute the groundwater supply (Elbeih 2015). Available image interpretation cannot be directly used to map the depth to water in a groundwater system. However, natural vegetation types are used as indicators of approximate depth to groundwater (Lillesand and Kiefer 2000).

Many groundwater exploration investigations have been carried out using remote sensing techniques in different parts of the world. In Nigeria, Edet et al. (1998); Obiefuna et al. (2010); Anudu et al. (2011); Mogaji et al. (2011); Talab and Tijani (2011); Adesida et al. (2012); Okereke et al. (2015); Yenne et al. (2015) and Adewumi (2016) all used remote sensing techniques in exploring for groundwater in different geological areas of the country. The use of remote sensing for groundwater exploration in other parts of the world includes El-Naqa et al. (2009) in Egypt, Bera and Bandyopadhyay (2012) and Bhunia et al. (2012), in India, Li (2012) in China, Phukon et al. (2012) in Assam, Arkoprovo et al. (2013) in India, and Chuma et al. (2013) in Zimbabwe.

Although many studies have been carried in both the basement complex and sedimentary terrains of Nigeria, no previous studies had been carried out on the groundwater potential in Owo area, Southwestern Nigeria. Therefore, in this study, we present a work centered on the use of remote sensing and GIS techniques for the exploration of groundwater. For this study, we used LANDSAT ETM^+ imageries, which were processed using ENVI 4.3 Image Processing software. Lineaments were picked after carrying out directional filtering on the image. Drainage pattern was generated from the topographical map of the area. To confirm the results generated from the satellite imageries, static and dynamic water levels in 213 wells were measured and a groundwater flow regime water of the area was generated using the SURFER software. All thematic maps used in this study were generated using the ARCMAP software. A groundwater potential map was generated after weighing and overlaying all thematic maps that were used. This study shall serve as a basis for further research on groundwater in the study area. It shall also assist policy makers in making right decisions on groundwater resources and management of the area of interest.

Site description

Location, accessibility, and land-use

The study area is located in the Northern part of Ondo State. It lies between latitude 7°00′ and 7°25′N and longitude 5°20′ and 5°45′E (Fig. 1). Towns covered by the study are Owo, Ogbese, Alayere, Uso-Owo, Amurin-Owo, Emure-Owo, Ipele-Owo, Ita-Ipele, and Oba-Akoko areas of Ondo State. It is located on path 190 and row 50 on the Landsat imagery. Ogbese which is on the Northwestern margin of the study area is about 15 km from Akure, the state capital of Ondo State. Ipele, which is in the Southeastern part of the study area, is about 30 km from Ifon, the headquarters of Osse Local Government Area. On the Northeastern margin is Oba-Akoko which is about 15 km to Idoani to the west and about 15 km from Oka-Akoko to the North. The major towns in the study area are Owo which is the largest, Uso-Owo, Ogbesse, Oba-Akoko, Ipele-Owo, Amurin-Owo, and Emure-Owo. Over 30% of the land is mainly used for cultivation. Other land use in the area includes government forest reserves which make up about 40% of the total land of the area. Ten percent of the area (10%) constitutes built-up areas. The remaining 20% constitute rivers which serve as a source of water for domestic and irrigation purposes.

Geomorphology, drainage pattern, and climate

The study area has a high topography (as high as 1200 ft above the sea level) which is the cause of ridges observed during the course of field study. In Owo township, the quartzite ridge runs from Emure-Owo (western part of the study area) to Ipele-Owo (eastern part of the study area). At Oba-Akoko, the granitic rock outcrops of high elevation forms inselberg and they generally form ridges, domes, and hills in other parts of the study area. Valleys are found especially around Ogbesse and Alayere all in the western part of the study area. This allows the easy flow of some major rivers in the area. The study area consists typically of dendritic drainage pattern which is geomorphologically controlled. The major rivers in the area are Rivers Iporo, Ubeze, and Aisenwen which run from east to west, and are major tributaries of the Osse River. The other major rivers in the study area are River Ogbesse which runs from North to South; the River Aisenwen runs from Northeast to Southwest. These major rivers are generally perennial in nature and their tributaries are majorly seasonal reaching their maximum dryness at the peak of the dry season.

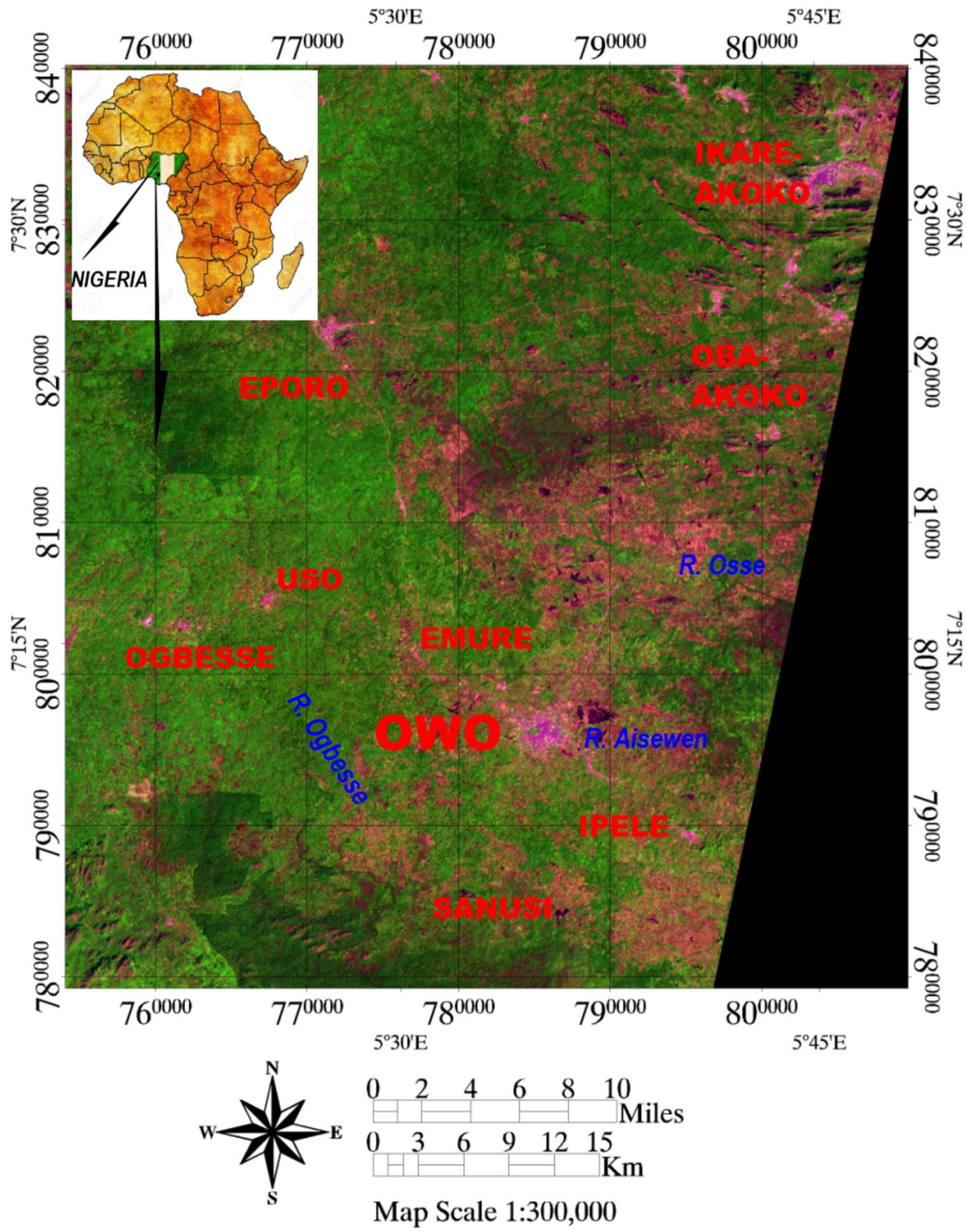
The study area is located within the tropical savannah belt of Nigeria. It has two basic climates: the rainy season which ranges between March and September and dry season between October and February. The temperature of the study area ranges from 12.8 and 42.7 °C. The precipitation in the study area ranges from 900 mm to 1800 mm.

Geology

The area under study is located within Pan-African mobile belt in between the West African and Congo cratons (Rahaman 1989; Oyinloye 2011).The Geology of Nigeria is dominated by crystalline and sedimentary rocks both occurring approximately in equal proportions (Woakes et al. 1987). The Precambrian basement rocks in Nigeria consist of the migmatite gneissic–quartzite complex dated Archean to Early Proterozoic (2700–2000 Ma) (Oyinloye 2011). Other units include the NE–SW trending schist belts mostly developed in the western half of the country and the granitoid plutons of the older granite suite dated Late Proterozoic-to-Early Phanerozoic (750–450 Ma) (Oyinloye 2011).The main lithologies in the southwestern part of Nigeria include the amphibolites, migmatite gneisses, granites, and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist talk-tremolite schist, and the muscovite schists. The crystalline rocks intruded into these schistose rocks (Oyinloye 2011). The southwestern Nigeria basement complex had undergone four major orogeneses which are the Liberian (Archaean) 2500–2750 ± 25 Ma, the Eburnean orogeny (Early Proterozoic), 2000–2500 Ma, the Kibaran orogeny (Mid-Proterozoic), 1100–2000 Ma, and the Pan-African Orogeny, 450–750 Ma.

Within the basement complex, tectonic deformation has completely obliterated primary structures (Oluyide 1988). The major faulting in the area is not evident and most of those recognized have been traced from aerial photographs and satellite imagery. Anifowose and Borode (2007) mapped out lineament in Okemesi area using photogeological methods. The study showed that the Itawure fault is

Fig. 1 Map of the study area



the major lineament in the region which passes through Itawure and Efon-Alaye. It trends from E–W and it is a transcurrent fault which displaces the fold nose resulting in the double plunging of the fold axis. Field observation according to Anifowose and Borode (2007) shows that fractures in the area are predominantly trending in the E–W direction, while a few of them are in ENE–WSW directions.

The basic rocks in the study area are migmatite, granite, schists, and quartzite (Fig. 2). The quartzite trends mainly from ENE–WSW. The schist and quartzite are predominantly found in Owo and Ipele, while Ogbesse, Uso-Owo, Oba-Akoko, Eporo, Amurin-Owo, and Emure-Owo are located on migmatite.

Research methods

This study was carried out following the flow chart shown in Fig. 3. The study is divided into two parts namely: Satellite data collection and processing and field data collection and processing. The satellite data collection involves the acquiring of satellite imagery (LANDSAT ETM+) followed by data correction, image enhancement and filtering, lineament mapping and extraction, drainage mapping, and digital elevation model (DEM) generation. Other data used are geological map from the Nigeria Geological Survey Agency (NGSA); topographic map of Owo Sheet 222 and that of Akure sheet of the scale of 1:100,000 were obtained from the Ministry of Lands and

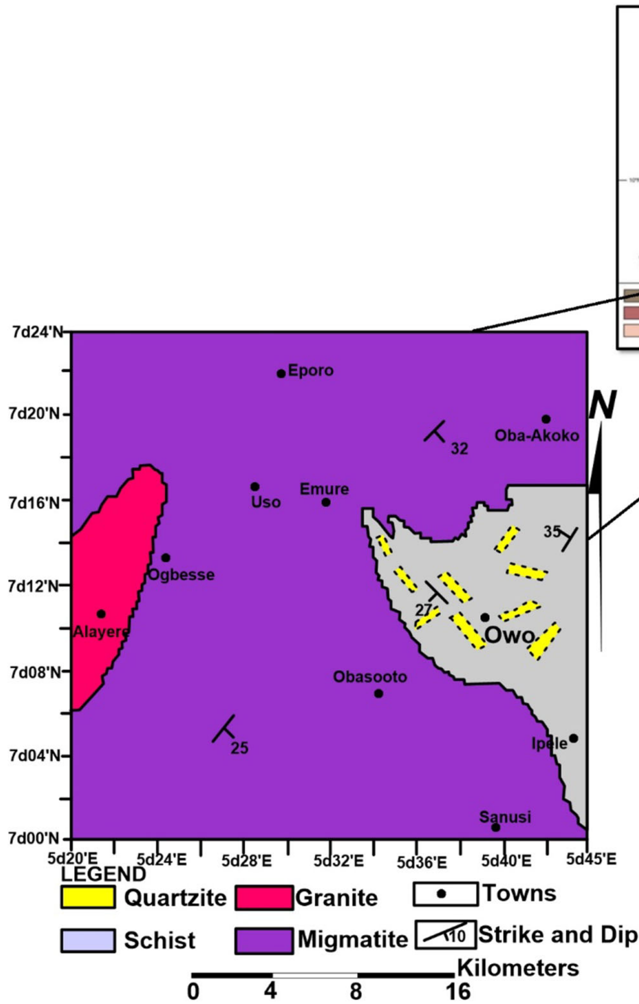


Fig. 2 Geological map of the study area

Housing, Akure, Nigeria. The rainfall data used were obtained from the Nigerian Meteorological Agency. The thematic maps derived from these are topographic map, slope map, rainfall pattern, drainage map, and lithological and lineament map. These were then incorporated into the Geographic Information System (GIS) environment for processing and spatial analysis which was achieved by modeling the generated data. Afterward, LANDSAT ETM (bands one to eight) imageries of the area were acquired. Each parameter for evaluating the groundwater potential was assigned score values after they have been weighed.

Image enhancement

The objective of image enhancement is to show features of interest in an enhanced manner, by applying certain operations available in the IP software (Meijerink et al. 2007). The image was enhanced to extract important groundwater information. Information extracted using image enhancement is drainage pattern of the study area and lineament densities. For drainage mapping, the LANDSAT ETM (bands 1–8) imagery was imported into the ENVI 4.3 software. The bands 5-4-3 were combined together in RBG (123) format. This was then enhanced using equalization method. This made the imagery to be clearer. The areas of sampling were easily identified and the drainages were seen. However, to clearly see the drainages in the study area, the enhanced image was stretched using linear stretching method. The stretch range was between 25 and 50% with an output data of 25–100%. The area of interest was submapped using the quick map technique. Digital Terrain Model (DTM) was generated using the SRTM data that were acquired. These data were corrected for bad values using the ENVI software. The corrected imagery was then imported into ERDAS where it was run as modeler. The DTM was used in manually extracting lineaments in the study area.

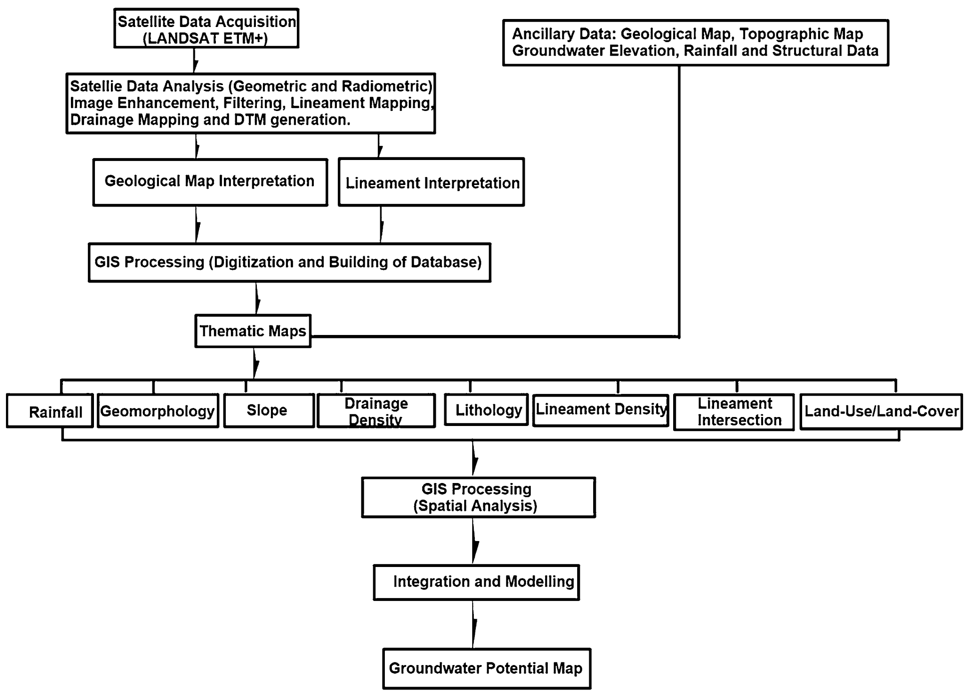


Fig. 3 Flow chart of methods used in calculating groundwater potential of the study area

Lineament mapping

Lineaments were mapped from the DTM which was earlier enhanced using the low pass Gaussian method using ENVI 4.1. Directional filtering method was also applied at 45°, 90°, 135°, 180°, 225°, 270°, 315°, and 360°. The lineament was extracted from the enhanced DTM of the area using an on-screen digitizing method in the ILWIS 3.1 software environment. The lineament density and intersection maps were generated using the ARCMAP software.

Drainage mapping and drainage density calculation

The drainages in the study area were mapped by combining bands 4-3-2 (RGB). The image was enhanced using linear enhancement method. This was then stretched to reveal drainage pattern in the study area.

Groundwater potential calculation

The groundwater potential of Owo and its environs was calculated using Eq. 1. The equation was derived by adding the score values of lithology, lineament density, drainage density, topographic elevation, slope gradient, land-use, annual rainfall, and groundwater flow pattern. Areas within Basement Complex lithology are scored low, because they lack primary porosity or openings that will assist in the accumulation of groundwater. In addition, areas with high lineament density are scored high when compared to areas of lower lineament density, because groundwater accumulates in areas with higher amount of fractures. Areas with lower drainage densities were scored higher when compared to areas with high densities, because they depicts that surface water have been lost to adjoining aquifers, whereas areas with high drainage density depict that the groundwater in the area loses its content to the surface water body:

$$\mathrm{Gp} = w\mathrm{Rf} + w\mathrm{Lt} + w\mathrm{Ld} + w\mathrm{Lu} + w\mathrm{Te} + w\mathrm{Sp} + w\mathrm{Dd} + w\mathrm{Gf}, \quad (1)$$

where Gp = Groundwater potential; w = weightage value, Rf = Rainfall; Lt = Lithology; Ld = Lineament density; Lu = Land-use; Te = Topographic elevation; Sp = Slope; Dd = Drainage density; Gf = Groundwater flow.

Results and discussion

Factors affecting groundwater distribution

Lineament density and intersections

Lineaments give a clue to movement and storage of groundwater (Subba et al. 2001) and, therefore, are important guides for groundwater exploration. Many groundwater exploration projects made in many different countries have obtained higher success rates when sites for drilling were guided by lineament mapping (Teeuw 1995).

In this study, the NE–SW lineaments are the most prominent followed by NW–SE, NNE–SSW, NNW–SSE, and E–W. The broad, positive correlation in frequency and length of the lineaments suggests that they are of geological origin (Odeyemi et al. 1999).

Based on their length, lineaments are generally classified into two: minor and major lineaments. For quantification purpose, major lineaments have length <3 km, while major lineaments have length >3 km. In this study, the length of lineaments ranges between 0.58 and 18.30 km. 59% of the lineaments belong to the minor group, while 41% belong to the major group.

The overlaying of lineament map over lithology map shows that 260 of the lineaments are found on migmatite and accounts for 78.78% and 60 are found on quartzite 18.18%, while 10 are found on granite gneiss and accounts for 3.03% of the total lineaments in the study area.

Isolinear contours (lineament density and lineament intersection density) are particularly advantageous in modern exploration geoscience in that they offer a quick glance at the spatial distribution of the density of lineaments and thus provide a useful database in hydrogeology and water borehole drilling (Odeyemi et al. 1999). The lineament density map of the study area (Fig. 4) shows that areas around Owo (Ijegunmo, Isijogun, and Sanusi) have higher lineament density. In these areas, the lineament density ranges between 0.55 and 0.85 km/km^2. Ita-Ipele and Ipele-Owo of the study area have lineament density of between 0.5 and 0.65 km/km^2, while Oba-Akoko has lineament density of between 0.35 and 0.65 km/km^2. Emure-Owo has lineament density between 0.35 and 0.5 km/km^2. Uso-Owo, Ogbesse, and Alayere areas have lineament densities of between 0.35 and 0.7 km/km^2, 0.15 and 0.3 km/km^2, and 0.25 and 0.35 km/km^2, respectively. The density of lineaments in the study area is attributable to the high fracturing that affected the Basement Complex area during the Pan-African orogenic cycle. This implies that groundwater will be concentrated more in areas around Owo and least concentrated in Ogbesse area. Furthermore, more groundwater is expected to accumulate in Owo, Isijogun, Ikare-junction, Ipele-Owo, Oba-Akoko, Uso-Owo, Emure-Owo, Alayere and Ogbesse, respectively.

Areas located in the northeastern and southern part of study area have more lineament intersection than other parts of the area. There are more lineaments intersecting at the southeastern part of Owo Township around Iyere. In addition, the southern parts of Owo also have higher lineaments intersection around Isijogun, Ijegunmo, Sanusi, pele-Owo Ita-Ipele, Oba-Akoko, Uso-Owo, Emure-Owo, Ogbesse, and Alayere that have the least intersection.

According to Odeyemi et al. (1999) points representing the intersections of two or more deep-seated, open lineaments are more favourable sites for groundwater accumulation. The implication of the aforementioned is that Iyere, Isijogun, Ijegunmo, Ipele-Owo, and Oba-Akoko that have high lineament intersection density will have more groundwater potential than Emure-Owo, Ogbesse, and Alayere Uso-Owo which have a low intersection (Fig. 5).

Drainage density

Drainage pattern is one of the most important indicators of hydrogeological features, because drainage pattern and density are controlled in a fundamental way by the underlying lithology. In addition, the drainage pattern is a reflection of the rate that precipitation infiltrates compared with surface runoff. The infiltration–runoff relationship is controlled largely by permeability, which is, in turn, a function of the rock type and fracturing of the underlying rock or bedrock surface (Edet et al. 1998).

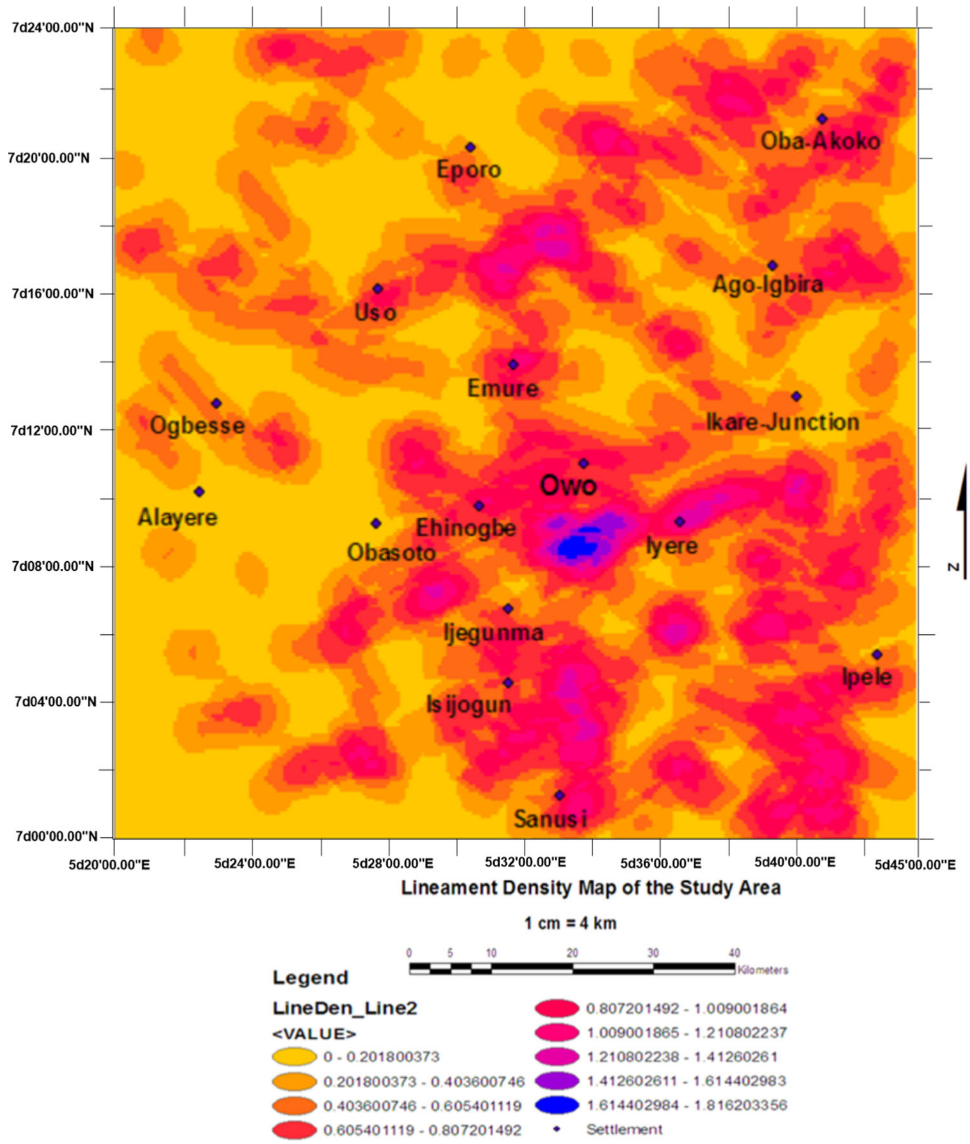
The drainage pattern in the study area is dendritic in nature and is geomorphologically controlled. The drainage density map generated for the study area (Fig. 6) reveals that there are more drainages around Emure-Owo (1.15 km/km^2), while the southern part of Owo (Sanusi, Ipele and Ita-Ipele) has the least drainage density which is less than 0.25 km/km^2. Uso-Owo has drainage density of between 0.5 and 0.85 km/km^2. The meaning of these is that areas with high drainage densities will have less groundwater potential, while areas with low drainage density will have high groundwater potential. Therefore, lesser groundwater potential is expected around Emure and Uso-Owo, while high groundwater potential is expected around Owo and Ipele area of the study area.

Geologically, areas with higher drainage densities tend to have lower groundwater potential. This condition is observable in unfractured rocks type. The soil types in such areas are usually less porous and less permeable making the loss of groundwater to the surface more prominent. However, in areas with fewer drainage densities, the rock would either have a primary or secondary porosity with the ability to allow the easy flow of groundwater. The soil types in this type of area are usually well drained, which makes more groundwater to be retained within the subsurface rather flowing to the surface.

Slope

The slope or gradient of a line describes its steepness, incline, or grade (Nag and Gosh 2013). A higher slope value indicates a steeper incline. The slope is defined as the ratio of the “rise” divided by the “run” between two points or line (Nag and Gosh 2013). It can also be defined as the ratio of the altitude change to the horizontal distance between any two points on the line. Slope plays a

Fig. 4 Lineament density map of the study area



significant role in infiltration against runoff (Nag and Amindita 2011). Infiltration is inversely related to slope, i.e., more gentle the slope, the more the infiltration and the lesser the runoff (Nag and Amindita 2011). Isijogun, Ijegunmo, Eporo, and Owo have a very gentle slope (6.7618°–15.2976°), while Amurin-Owo, Ikare-Junction, Iyere, and Ehinogbe are gently sloping (15.2976°–22.9014°). Emure-Owo, Ipele-Owo, Isuada, Obasoto, Sanusi, and Uso-Owo are moderately sloping (43.5109°–50.2729°), while Alayere and Ogbesse are steeply sloping (50.2727°–58.2106°). Oba-Akoko has a very steep slope of 58.2106°–74.9681° (Fig. 7). This means that areas with very gentle slope will have highest groundwater potential, while Oba-Akoko with the highest degree of slope will have the least groundwater potential.

Geomorphology

Geomorphological features recognized in the area are hills, pediments, and valley flats. The topography of the study area is undulating. A hill is a landform that extends above the surrounding terrain. In this study, hills are typically observed in areas underlain by gneissic rocks that are well exposed in the northwestern parts of the study area. Areas with hills usually have less groundwater potentials. Floodplain is an area of land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge (Goudie 2004). Rainwater travels deep into the ground of a floodplain to replenish groundwater supply (Maness 2015). Therefore, it is expected that

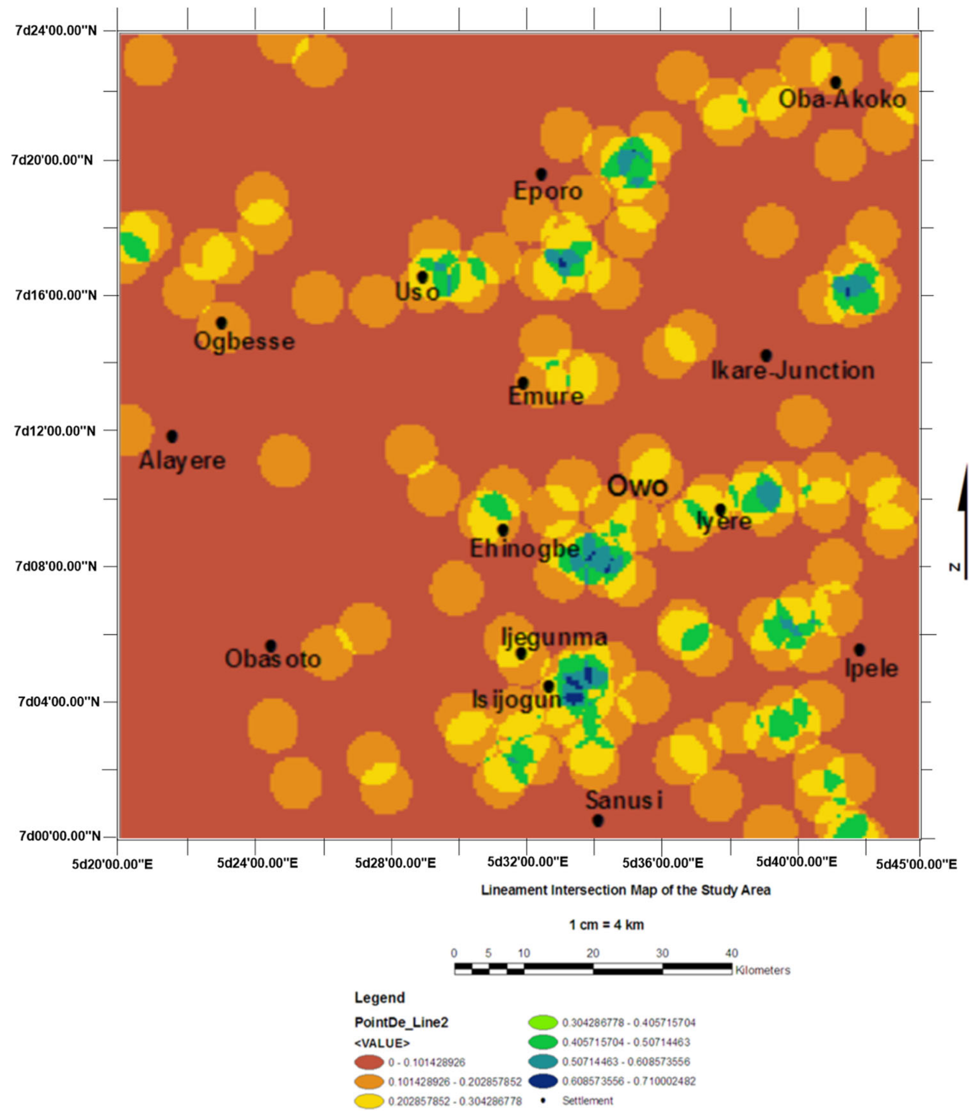


Fig. 5 Lineament intersection map of the study area

areas covered with flood plains would hold more groundwater. In this study, floodplains are found around Ogbese and Isijogun. Valley flats are low linear areas occurring between hills. These units occupy the lowest reaches in topography with nearly level slope. The valley flat deposits are colluvium fluvial origin derived from weathering and deposited by the action of streams at the floor of valleys (Sedhuraman et al. 2014). In the study area, these features are identified between the hills in the northern part of the study area.

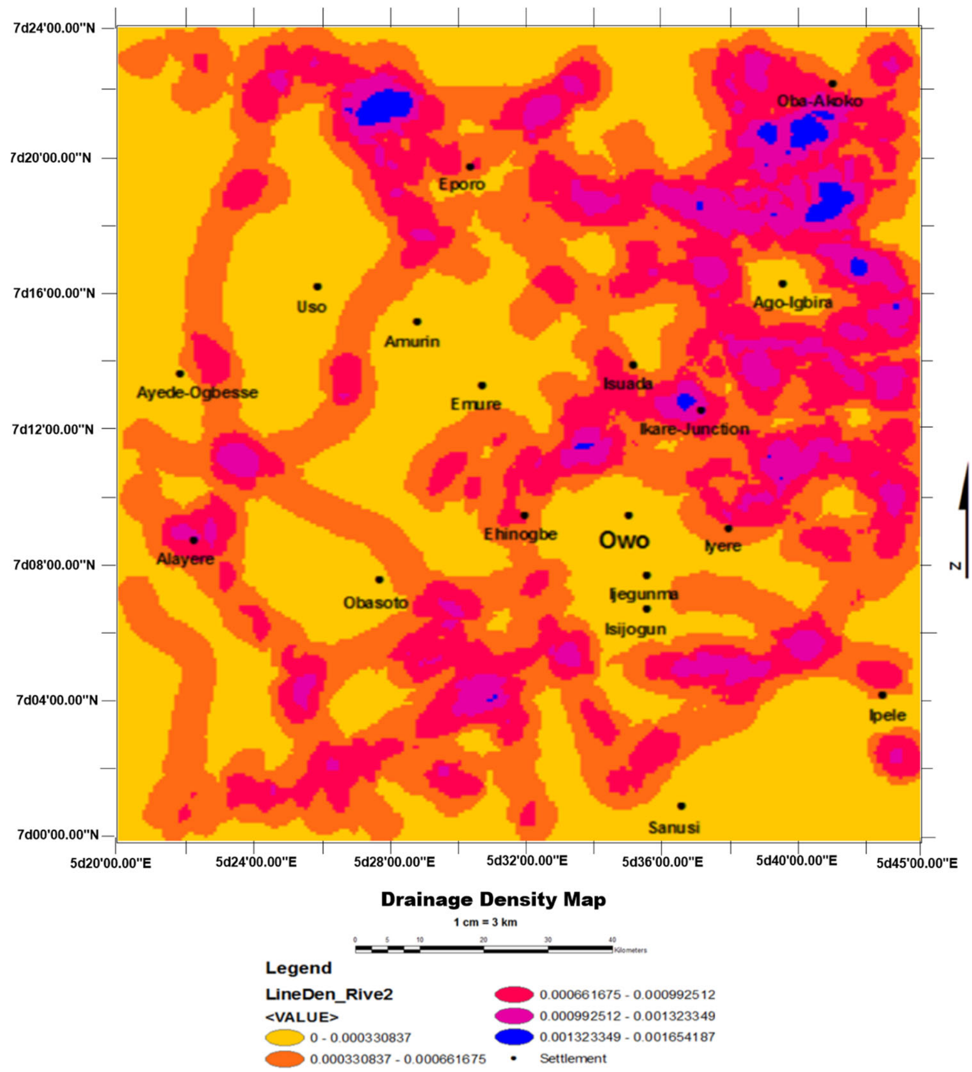
Lithology

The study area is underlain by crystalline Basement Complex rocks of Precambrian age. Migmatite gneissic, quartzite, granite, and granite gneisses were observed in the area. Around 60% of the total area is covered with migmatite gneiss followed by quartzite. Groundwater is expected to be low in granite and higher in quartzite (Fig. 2).

Land use/land cover

The major land-use type in the study area are wetlands, water bodies (Rivers), forested vegetations, less-forested vegetations, hilly rocks, and built-up areas. These land-use classes are delineated from LANDSAT ETM + data and ground verification (Fig. 8). Around 60% of the total area is covered by vegetated areas, while built-up areas make up 20% of the area. The implication of this is that areas with vegetation will have high groundwater potential than built-up areas that inhibits the infiltration of water into the subsurface.

Fig. 6 Drainage density map of the study area



Rainfall

The rate of groundwater recharge is dependent upon the rate of the addition of water to the system and the rate at which available water can infiltrate to a depth thus escaping evaporation (Theis 1940). The major source of groundwater recharge in Nigeria is mainly rainfall. Areas of high rainfall will have more groundwater potential, while areas with low rainfall will have less groundwater potential. This assumption is dependent on the land cover which inhibits infiltration, soil, and rock types. In this study, the minimum annual amount of rainfall is 950 mm, while the maximum is 1900 mm (Fig. 9). The implication of this is that groundwater will accumulate more and will definitely contribute to the groundwater resources in the area.

Groundwater potential of the study area

The groundwater potential map of the study area is as shown in Fig. 10. Table 1 shows the score value used in estimating the groundwater potential of the study area. In general, the groundwater potential of the study area is high. However, there is variation in the potential distribution. The southern parts of Owo Township have the highest groundwater potential than any other parts of the study area. This followed by the central part of Owo Township and Emure-Owo. Ipele-Owo has more groundwater potential than Oba-Akoko which in turn has more groundwater potential than Alayere area. Lesser groundwater potentials are observable in the northeastern and northwestern parts of Uso-Owo. This is also observable in the southern part of Alayere in the study area.

For any productive well to be dug, Owo Township, Ipele-Owo, Emure-Owo, and the southern part of Owo will

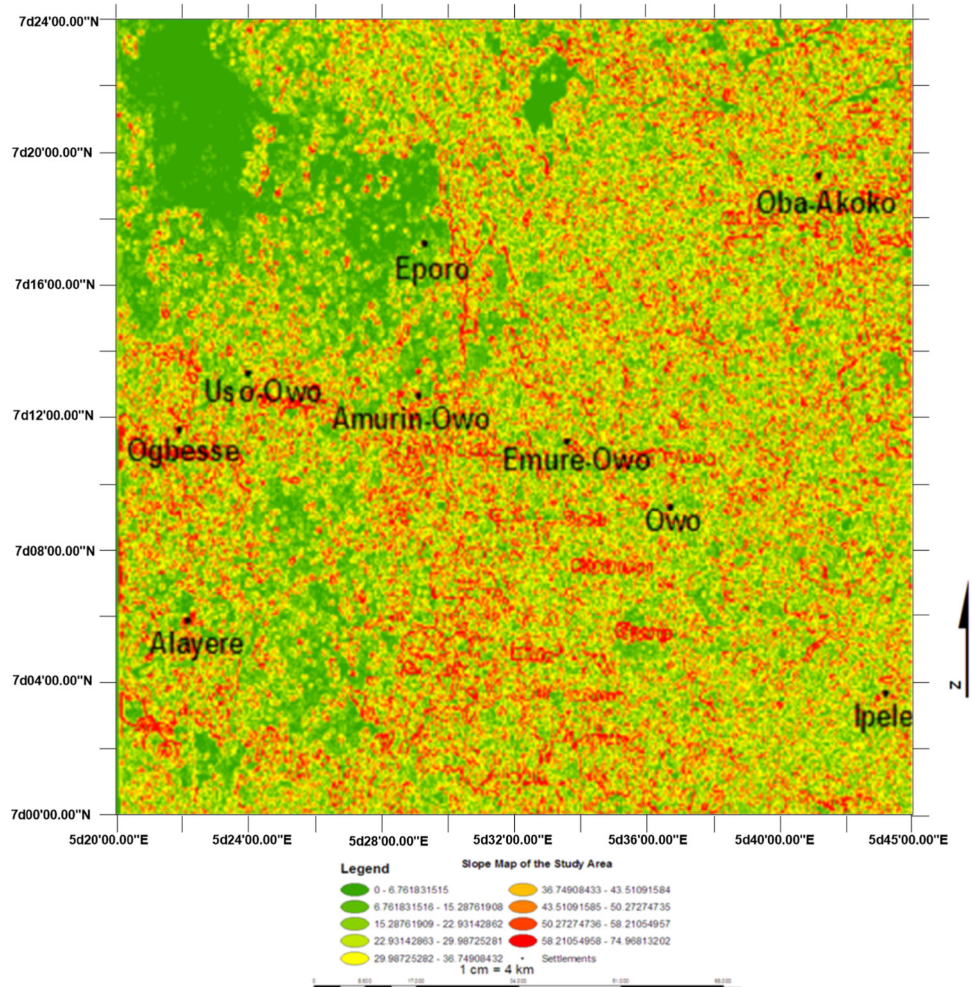


Fig. 7 Slope map of the study area

be the safest area to explore for groundwater due to its high potential to store and transmit underground water. This is followed by Ogbesse, Uso-Owo, Oba-Akoko, and Alayere areas, respectively. Over 50% of wells studied were found in areas with high-moderately high groundwater potential (Fig. 10). Over 30% of wells in the study area are found within the moderately high-to-moderate groundwater potential areas. About 20% of the wells studied were found within areas with low groundwater potential.

Conclusions

The importance of remote sensing and Geographic Information System (GIS) in hydrogeological characterization cannot be overestimated. In this research work, remote sensing and GIS techniques were employed to characterize the groundwater potential of Owo area, southwestern Nigeria. The NE–SW lineaments are the most prominent followed by NW–SE, NNW–SSE, NNE–SSW, and E–W. The lineament density around Owo (Ijegunmo, Isijogun and Sanusi) has higher lineament density in the study which is greater 0.85 km/km^2. There are more lineaments intersecting at the southeastern part of Owo Township around Iyere. The drainage density map generated for the study area reveals that there are more drainages around Emure-Owo than other parts of the study area. The groundwater flow pattern of the area showed that there are more recharge areas than discharge areas in the study area, which shows that the expected groundwater potential of the area is high. The study revealed that Owo Township has the highest groundwater potential than any other parts of the study area. Most of the wells in the study area are found within the moderately high–moderate groundwater potential areas. Thirty percent of the wells studied were found within areas with low groundwater potential. It was also observed that most of the wells studied are found close to or on a fracture zone.

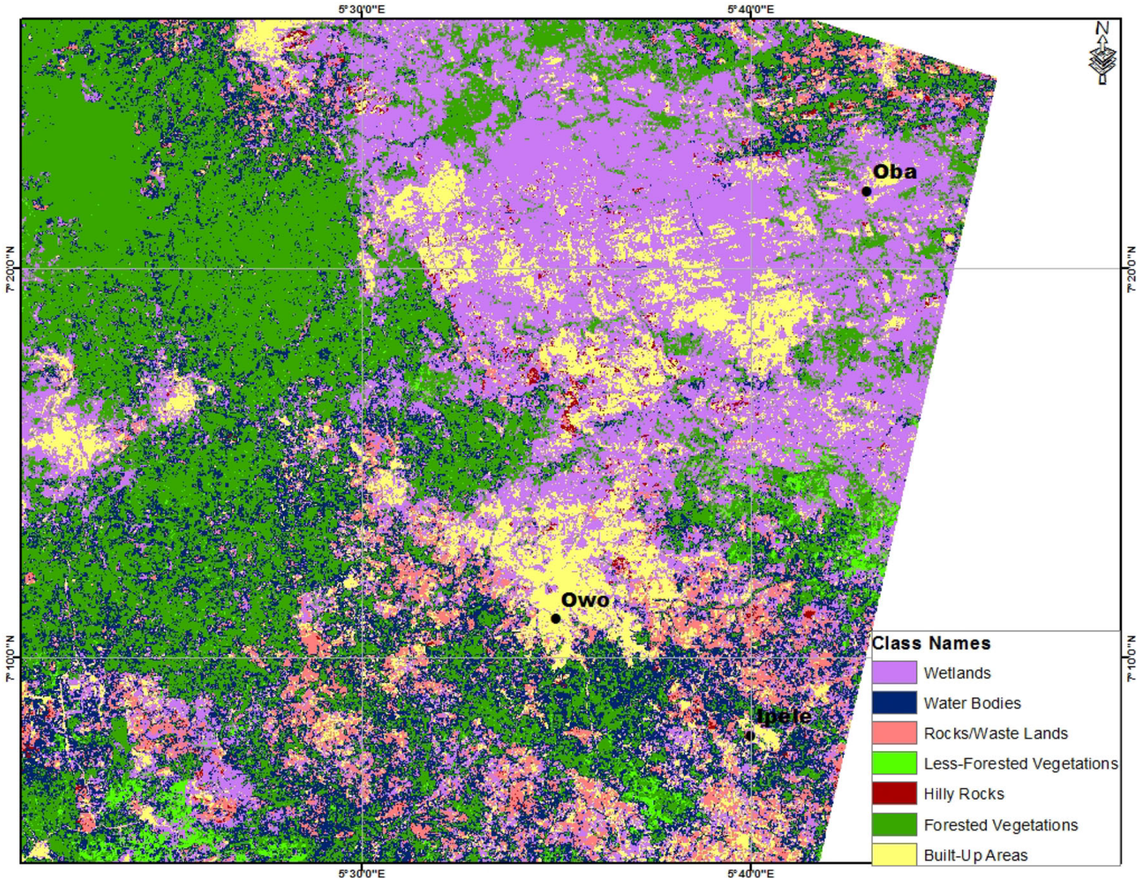


Fig. 8 Land-use and land-cover map of the study area

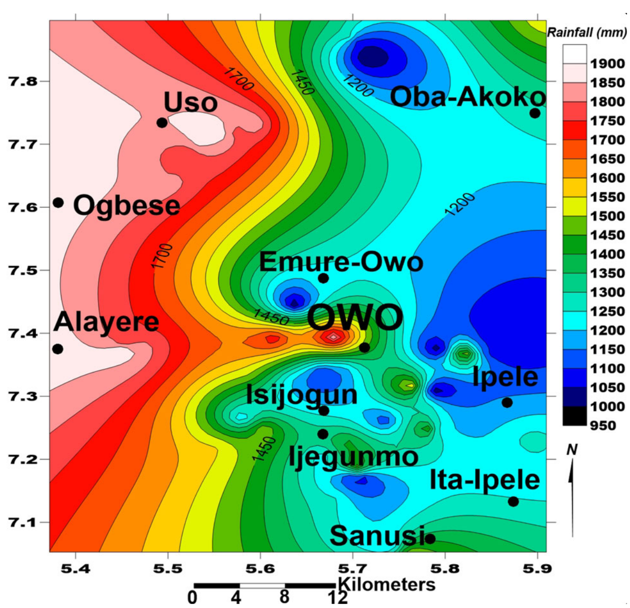


Fig. 9 Rainfall map of the study area

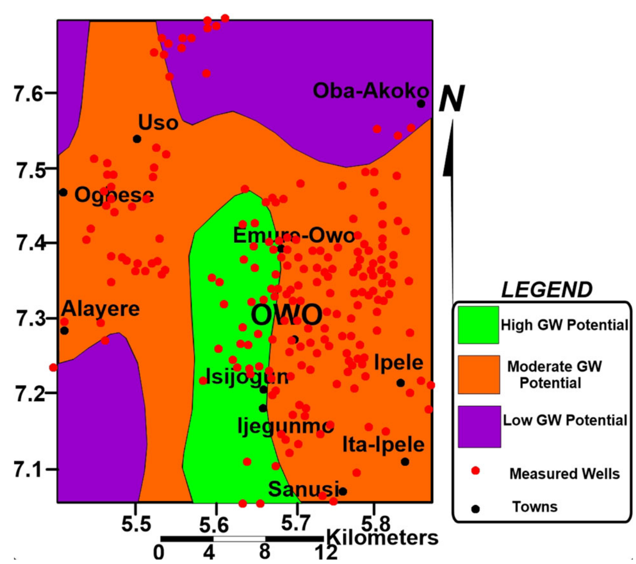


Fig. 10 Groundwater potential map of the study area

Table 1 Thematic layers, their categories, and their weights

S/N	Thematic layer	Rank	Map weight	Category	Category rank
1.	Geomorphology	5	$\frac{5}{6} = 0.833$	Hills	1
				Pediments	2
				Valley flats	3
2.	Slope (°)	5	0.833	<1° Nearly level	5
				1°–3° Very gentle	4
				3°–5° Gentle	3
				5°–10° Moderately steep	2
				10°–15° steep	1
				>15° V. steep	0
3.	Lineament Density	4	0.667	1.6–1.8 Highly dense	4
				1.2–1.6 Dense	3
				0.8–1.2 Moderately dense	2
				<0.8 Less	1
4.	Lineament intersection	4	0.667	0.50–0.70 High	4
				0.30–0.50 Dense	3
				0.20–0.30 Moderate	2
				<0.3 Low	1
5.	Lithology	3	0.500	Granite	1
				Gneiss	2
				Quartzite	3
6.	Rainfall (mm/year)	3	0.500	>2000	5
				1500–2000	4
				1000–1500	3
				500–1000	2
				<500	1
7.	Drainage density (km/km^2)	3	0.500	0.0013–0.0016 V. coarse	4
				0.0006–0.0009 Coarse	3
				0.0003–0.0006 Moderate	2
				0–0.00033 Fine	1
8.	Land cover/land use	2	0.333	Wetlands	5
				Water bodies	5
				Rocks/wastelands	1
				Less-forested vegetation	1
				Inselbergs	1
				Forested vegetation	2
				Built-up areas	1

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Compliance with ethical standards

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References

Adesida A, Anifowose AYB, Ojo JS (2012) A study of basement fracture pattern around Akoko area of southwestern Nigeria for groundwater potential using high-resolution satellite imagery and electrical resistivity. Glob J Geol Sci 10(1):59–69

Adewumi AJ (2016) Current status on the use of remote sensing and GIS techniques for groundwater mapping in Nigeria. Achiev J Sci Res 1(2):105–119

Anifowose AYB, Borode AM (2007) Photogeological study of the fold structure in Okemesi area, southwestern Nigeria. J Min Geol 43(2):125–130

Anudu GK, Essien BI, Onuba LN, Ikpokonte AE (2011) Lineament analysis and interpretation for assessment of groundwater potential of Wamba and adjoining areas, Nasarawa State, north-central Nigeria. J Appl Technol Environ Sanit 1(2):185–192

Arkoprovo B, Adarsa J, Animesh M (2013) Application of remote sensing, GIS and MIF technique for elucidation of groundwater potential zones from a part of Orissa coastal tract, eastern India. Res J Recent Sci 2(11):42–49

Badrinarayanan TS (2016) Ground water exploration-an introduction. https://www.researchgate.net/file.PostFileLoader.html?id…assetKey. Accessed 21 Jan 2016

Bera K, Bandyopadhyay J (2012) Ground water potential mapping in dulung watershed using remote sensing and GIS techniques, West Bengal, India. Int J Sci Res Publ 2(12):1–7

Bhunia GS, Samanta S, Pal DK, Pal B (2012) Assessment of groundwater potential zone in Paschim Medinipur District, West Bengal-a Meso-scale study using GIS and remote sensing approach. J Environ Earth Sci 2(5):41–59

Chatterjee RS, Bhattacharya AK (1995) Delineation of the drainage pattern of a coal basin-related inference using satellite remote sensing techniques. Asia Pac Remote Sens J 1:107–114

Chuma C, Orimoogunje OI, Hlatywayo DJ, Akinyede JO (2013) Application of remote sensing and geographical information systems in determining the groundwater potential in the crystalline basement of Bulawayo metropolitan Area, Zimbabwe. J Adv Remote Sens 2:149–161

Edet AE, Okereke CS, Teme SC, Esu EO (1998) Application of remote-sensing data to groundwater exploration: a case study of the Cross River State, southeastern Nigeria. Hydrogeol J 6:394. doi:10.1007/s100400050162

Eduvie MO (2006) Borehole failures in Nigeria. Paper presented at a national seminar held on the occasion of water africa exhibition

(Nigeria 2006) at Eko Hotels and Suites, Victoria Island, Lagos, on 15th November, 2006
Elbeih SF (2015) An overview of integrated remote sensing and GIS for groundwater mapping in Egypt. Ain Shams Eng J 6:1–15. doi:10.1016/j.asej.2014.08.008
El-Naqa A, Hammouri N, Ibrahim K, El-Taj M (2009) Integrated approach for groundwater exploration in Wadi Araba using remote sensing and GIS. Jordan J Civ Eng 3(3):229–243
Goudie AS (2004) Encyclopedia of geomorphology, vol 1. Routledge, New York. ISBN 0-415-32737-7
Graham S (1999) Remote Sensing. NASA Earth Observatory website: https://earthobservatory.nasa.gov/Features/RemoteSensing/. Accessed 21 Jan 2016
Hanidu JA (1990) National growth, water demand and supply strategies in Nigeria in the 1990s. Water Resour 2:1–6
Hernández-Mora N, Martínez-Cortina L, Fornés J (2003) Intensive groundwater aquifer over-exploitation. implications for water policy in Southern Europe. In: Dosi C (ed) Agricultural use of groundwater. Towards integration between agricultural policy and water resources management. Kluwer, Academic Publishers, pp 107–125
Horton RE (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geol Soc Am Bull 56:275–370
Kumar A, Srivastava SK (1991) Geomorphological unit, their geohydrological characteristics and vertical electrical sounding response near munger. Bihar J Indian Soc Remote Sens 19(4):205–215
Li J (2012) Application of remote sensing to water resources management in Arid regions of China. In: World water and environmental resources congress 2004, 27-July 1, 2004 Salt Lake City, Utah, United States. 10.1061/40737(2004)119
Lillesand TM, Kiefer RW (2000) Remote sensing and image interpretation. John Wiley and Sons, Toronto
Luczaj J (2016) Groundwater quantity and quality. Resources 5(10):1–4
Maness N (2015) 7 Reasons why you should care about floodplains. http://willamettepartnership.org/7-reasons-why-you-should-care-about-floodplains/. Accessed 25 Apr 2017
Meijerink AMJ, Bannert D, Batelaan O, Lubczynski MW, Pointet T (2007) Remote sensing applications to groundwater. IHP-VI, series on groundwater no. 16. United Nations Educational, Scientific and Cultural Organization, Paris, p 304
Mogaji KA, Aboyeji OS, Omosuyi GO (2011) Mapping of lineaments for groundwater targeting in the basement complex region of Ondo State, Nigeria, using remote sensing and geographic information system (GIS) techniques. Int J Water Resour Environ Eng 3(7):150–160
Nag SK (2008) Application of remote sensing and GIS in groundwater exploration. In: Ahmed S, Jayakumar R, Salih A (eds) Groundwater dynamics in hard rock aquifers. Springer, Netherlands, p 87–92. doi:10.1007/978-1-4020-6540-8_5
Nag SK, Amindita L (2011) Integrated approach using remote sensing and GIS techniques for delineating groundwater potential zones in Dwarakeswar watershed, Bankura district, West Bengal. Int J Geomat Geosci 2(2):430–442
Nag SK, Gosh P (2013) Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. J Environ Sci 70(5):2115–2127
Nwankwoala HO (2011) An integrated approach to sustainable groundwater development and management in Nigeria. J Geol Min Res 3(5):123–130
Nwankwoala HO (2015) Hydrogeology and groundwater resources of Nigeria. NY Sci J 8(1):89–100
Obiefuna GI, Adamolekun SS, Ishaku JM (2010) Determining potential areas of groundwater occurrences using remote sensing techniques: a case study of Mubi area, Northeast, Nigeria. Cont J Appl Sci 5:15–24
Odeyemi IB, Anifowose AYB, Asiwaju-Bello YA (1999) Multi-technique graphical analyses of fractures from remote sensing images of basement regions of Nigeria. J Min Geol 35(1):9–21
Okereke CN, Ikoro DO, Amadi C, Okorafor OO (2015) Groundwater accessibility using remote sensing technique: a case study of Orlu and Adjoining areas, Southeastern Nigeria. Sci Res J 3(3):12–20
Oluyide PO (1988) Structural Trends in the Nigerian Basement Complex. Precambrian Geology of Nigeria, Geological Survey of Nigeria, pp 93–98
Oyinloye AO (2011) Geology and geotectonic setting of the basement complex rocks in South Western Nigeria: implications on provenance and evolution, earth and environmental sciences, Imran Ahmad Dar (ed.), ISBN:978-953-307-468-9, InTech. http://www.intechopen.com/books/earthand-environmental-sciences/geology-and-geotectonic-setting-of-the-basement-complex-rocks-isouthwestern-nigeria-implications
Phukon P, Chetia D, Laskar AA (2012) Application of remote sensing and geographic information system for groundwater resource mapping: a preliminary appraisal in Guwahati City, Assam. Int J Comp Appl Eng Sci 2(2):107–113
Rahaman MA (1989) Review of the basement geology of South-Western Nigerian. In: Kogbe CA (ed) Geology of Nigeria. Rock View, Jos, pp 39–56
Ravindran KV (1997) Drainage morphometry analysis and its correlation with geology, geomorphology and groundwater prospects in Zuvari Basin, South Goa, using remote sensing and GIS. In: Proc. Nal Sym-remote sensing for natural resource with special emphasis on water management, held at Pune during Dec. 4–6, 1997, pp. 270–296
Rijswlk K (1981) Small community water supplies. IRC Technical Paper Series, No.18. The Netherlands
Sedhuraman M, Revathy SS, Babu SS (2014) Integration of geology and geomorphology for groundwater assessment using remote sensing and GIS techniques. Int J Innov Res Sci Eng Technol 3(3):10203–10211
Sharma D, Jugran DK (1992) Hydromorphological studies around Pinjaur-Kala Amb area, Ambala district (Haryana), and Sirmur district (Himachal Pradesh). J Indian Soc Remote Sens 29(4):281–286
Subba RN, Prakasa RJ, John DD, Srinivasa RK, Krishna C (2001) Multivariate analysis for identifying the governing factors of groundwater quality. J Environ Hydrol 9(16):1–9
Talab AO, Tijani MN (2011) Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area southwestern Nigeria. RMZ Mater Geoenviron 58(3):303–328
Teeuw RM (1995) Groundwater exploration using remote sensing and a low-cost geographical information system. Hydrogeol J 3(3):21–30
Theis CV (1940) The source of water derived from wells. Civ Eng 10:277–280
Tiwari A, Rai B (1996) Hydrogeomorphological mapping for groundwater prospecting using landsat-MSS images—a case study of part of Dhanbad District. J Indian Soc Remote Sens 24(4):281–285
Woakes M, Ajibade CA, Rahaman MA (1987) Some metallogenic features of the Nigerian Basement. J Afr Sci 5:655–664
Yenne EY, Anifowose AYB, Dibal HU, Nimchak RN (2015) An assessment of the relationship between lineament and groundwater productivity in a part of the basement complex, Southwestern Nigeria. IOSR J Environ Sci Toxicol Food Technol 9(6):23–35