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ORIGINAL ARTICLE

Use of remote sensing and GIS techniques for groundwater exploration in the basement complex terrain of Ado-Ekiti, SW Nigeria

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Abstract
Integrated investigations involving remote sensing and GIS have been conducted with the objective of achieving optimal results in sustainable groundwater development in Ado-Ekiti, south-western Nigeria. The hard rock terrain in the region presents challenges in groundwater exploration. Landsat imageries were used for landuse/landcover mapping and lineament analysis for groundwater prospecting. Shuttle Radar Topographic Mission Digital Elevation Model was used for drainage network extraction, slope and geomorphological analysis. Thematic maps were generated, analysed in terms of hydrogeological importance and reclassified for integration using appropriate software. The groundwater potential maps generated were validated against the existing groundwater yield data. The light vegetation and bare soil area cover was 110.9 km^2, with the rock outcrops covering a total area of 14.9 km^2. Hydrogeomorphic units delineated included hills, pediments, pediplains, alluvium and valley fills. The lineaments showed predominantly NNW–SSE, ENE–WSW and NNE–SSW orientations and subsidiary NW–SE and W–E trends. Application of geospatial techniques has been recognized. The methodology provides improvements in the understanding of the hydrogeological characteristics of the basement terrain. These will aid planning and management of groundwater resources in the crystalline basement terrain.

Keywords Basement complex · Geomorphology · Groundwater potential · Lineament extraction

Introduction

Ado-Ekiti metropolis is underlain by the hydrogeologically challenging crystalline basement rocks whose hydraulic properties are characterized by extreme variations over short distances which often limit groundwater development to low-yielding well. High borehole failure rate has been reported in the area (Olayinka 1992; Fashae et al. 2014; Ojo et al. 2015).

Ogundana et al. (2015) reported high borehole failure of ten (representing 71%) out of fourteen boreholes studied at ABUAD in the metropolis. These boreholes exhibit low groundwater yield as the holes could not support continuous flow of water beyond 5 min. Bayowa et al. (2014) attributed the high borehole failure rate in the area to inadequate knowledge of the hydrogeological characteristics of the hard rock terrain. Forkuor et al. (2013) emphasized the need for thorough pre-drilling hydrogeological investigations. These and similar studies underlined the need for improvements in the conventional methodology to ensure optimum results in groundwater development.

The occurrence and circulation of groundwater is controlled by geological factors. The crystalline basement rocks only possess secondary porosity arising from joints, fissures/fractures and intergranular porosity (Olayinka 1992; Amadi and Olasehinde 2010; Ojo et al. 2015). Satellite-based remote sensing data are capable of revealing structural features including faults, fractures and different landforms. Singh et al. (2013), Ndatuwong and Yadav (2014) and Badamasi et al. (2016) emphasized the usefulness of remote sensing as a rapid assessment tool in groundwater exploration. The integrated approach is particularly fascinating as it is applicable even in inaccessible areas. Groundwater is expected to form a significant part of the water resources of Ado-Ekiti and its environs.

The thrust of this work is to apply geospatial techniques to provide information on the hydrogeological regime of a

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typical hard rock terrain with a view to achieving optimal result in sustainable groundwater development in Ado-Ekiti.

Description and geology of the study area

Ado-Ekiti, south-western Nigeria, lies within latitudes 7°33′ and 7°42′N and longitudes 5°11′ and 5°20′E (Fig. 1). The topography of the area is fairly rugged (Fig. 2). The area falls within the basement complex of south-western Nigeria (Rahaman 1988). The rock sequence includes granitite rocks, charnockitic rocks, the quartzite series, gneisses and migmatites (Fig. 3).

The region experiences a tropical climate with mean annual temperature of 27 °C and distinct wet and dry seasons. About 75% of all rainfall events are of moderate to high intensities. Light showers of less than 10 mm/h account for only 25%. The major rivers draining the area include Alamoji, Elemi and Ireje (Olajuyigbe 2010; Bankole 2010).

Materials and methods

Landsat enhanced thematic mapper (ETM+) sensor of path 190 and row 055 acquired in 2005 was used for lineament extraction. PCI Geomatica 2013 was used for automatic lineament extraction with ArcGIS 10.2.2. Rockware 15 was used for generating lineament statistics.

Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) was used for drainage network extraction, slope and geomorphological analysis. ArcHydro module was employed for drainage network extraction. Geomorphological and slope maps were prepared. Topographic analyses were carried out on the DEM including sink fill, flow direction, flow accumulation, stream order and stream to feature. The fill tool in the spatial analyst of Arcmap was used to fill the sink and remove peaks within the data (Hung et al. 2005; Singh et al. 2013).

Landuse/landcover (LULC) map of the study area was produced using Landsat 8 imagery of path 190 and row 055 acquired in 2015. Ecognition Developer software was used for image classification.

Other data inputs are Geological map 3300/6/66/3289/OS prepared by the British Government Ministry of Overseas Development on 1:250,000 scale and Topographical sheet 1000/404/6.68 compiled and drawn by Federal Survey from photo reduction 244 (Ado-Ekiti), 245 (Ikole), 264 (Akure) and 265 (Owo).

Data preparation (mainly digitizing), data pre-processing (georeferencing and resampling), data processing [edge detection and principal components analysis (PCA)], data analysis and integration (lineament extraction and statistics, geostatistical analysis, IDW) formed the basic methodology of this study (Hung et al. 2005; Prasad et al. 2013).

The thematic layers of the extracted features including lithology, geomorphology, drainage density, slope, lineaments and landuse/landcover were generated and reclassified in terms of hydrogeological importance. Weightage factors were assigned to themes and their corresponding categories according to the groundwater prospects. The reclassified layers were integrated in a GIS environment to produce a composite groundwater potential map of the study area. The generated groundwater potential zones were validated with field checks and the existing groundwater yield data (Hammouri et al. 2012; Singh et al. 2013; Fashae et al. 2014). The flow chart is presented in Fig. 4.

Results and discussion

The results are presented as maps and tables. Six parameters were evaluated, namely lithology, lineament density, drainage density, geomorphology, slope and LULC.

Geology/lithology

The dominant lithologies in the study area include migmatites, gneisses, granite, quartzite and charnockite (Fig. 3). The granitic rocks occupy the western and north-central parts, the charnockitic rocks are found in the central, while the gneisses and migmatites occur in the western and eastern flanks. The quartzite occurrences are located in the western and central portion as elongated bodies within the granitic and coarse-grained charnockitic rocks (Ayodele and Aturamu 2011; Rahaman 1988).

Lineament analysis

The results of the lineament analysis are presented as the lineament map (Fig. 5) and lineament density map (Fig. 6). Lineaments are indicative of zones of localized weathering which are known for high permeability and porosity. These features enhance groundwater accumulation (Prasad et al. 2008; Prabu and Rajagopalan 2013; Fashae et al. 2014).

The lineaments show mainly NNW–SSE, ENE–WSW and NNE–SSW orientations with subsidiaries along NW–SE and W–E. The orientation of the fractures is indicative of the preferential flow path (Talabi and Tijani 2011; Ojo et al. 2015). The majority of the lineaments/fractures are located on the migmatized biotite-hornblende gneiss with the minorities on the charnockites. The distribution of lineaments suggests geologic control. The granites and gneisses are more responsive to stress by fracturing than charnockites.

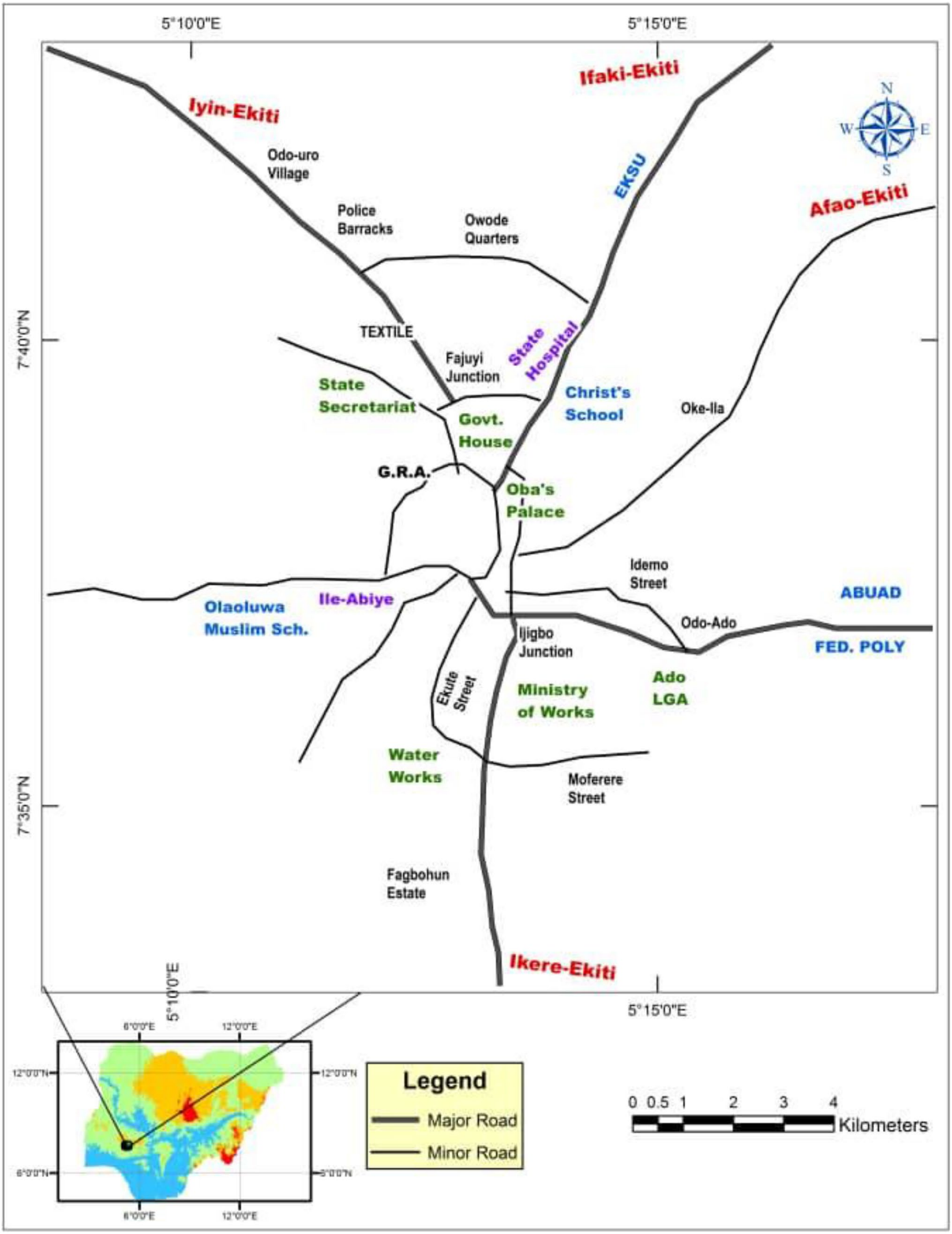


Fig. 1 Location map of Ado-Ekiti—the study area. Adapted from Google map

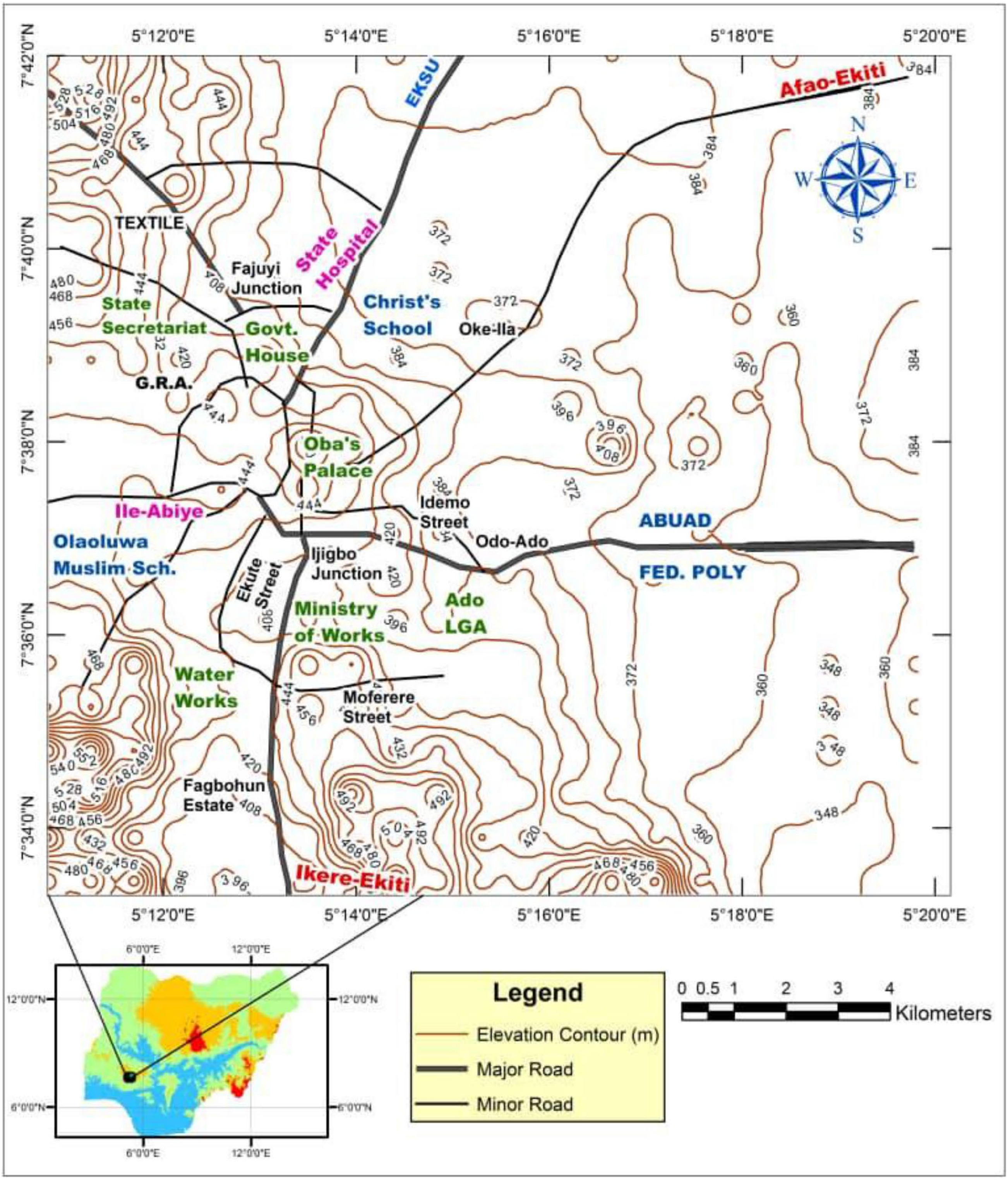


Fig. 2 Topographical map of Ado-Ekiti. Adapted from Google map

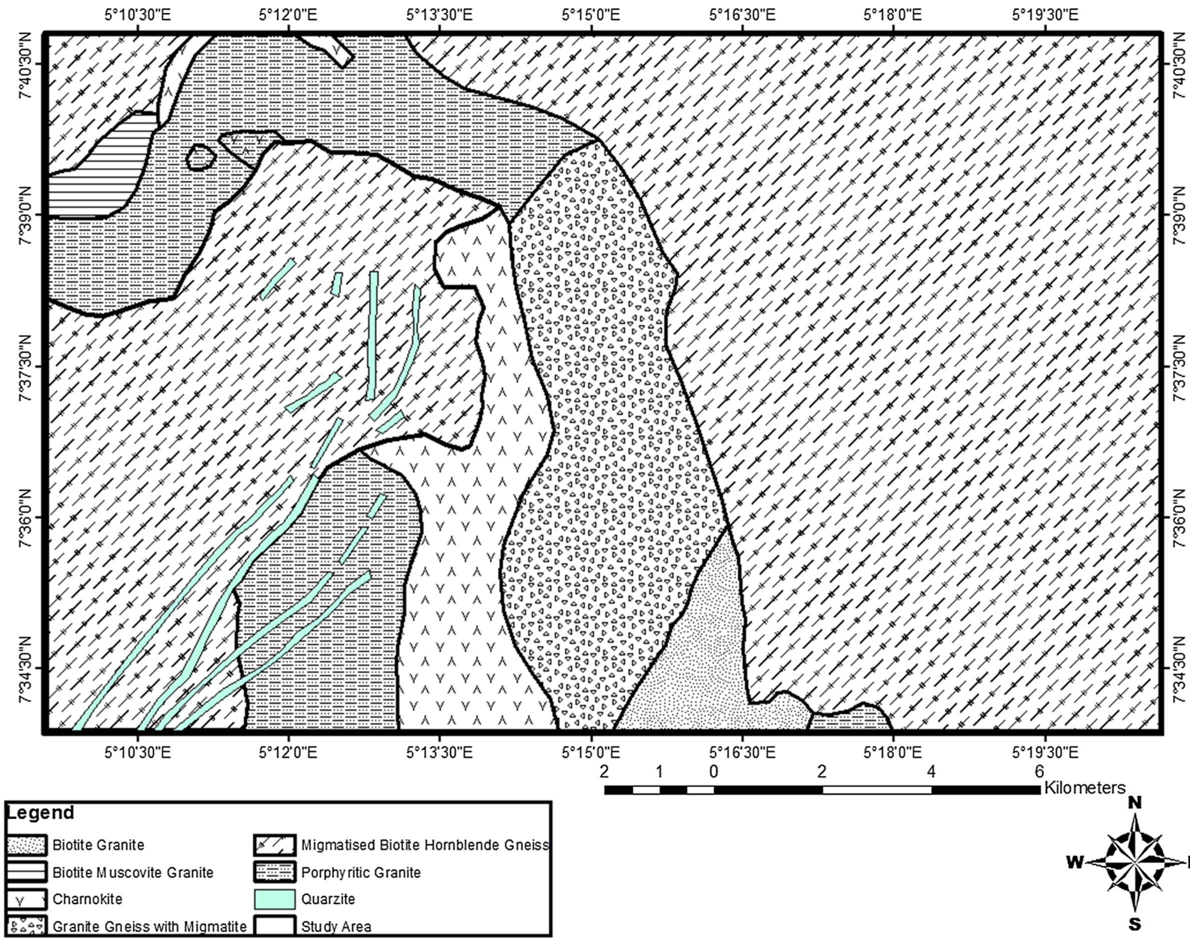
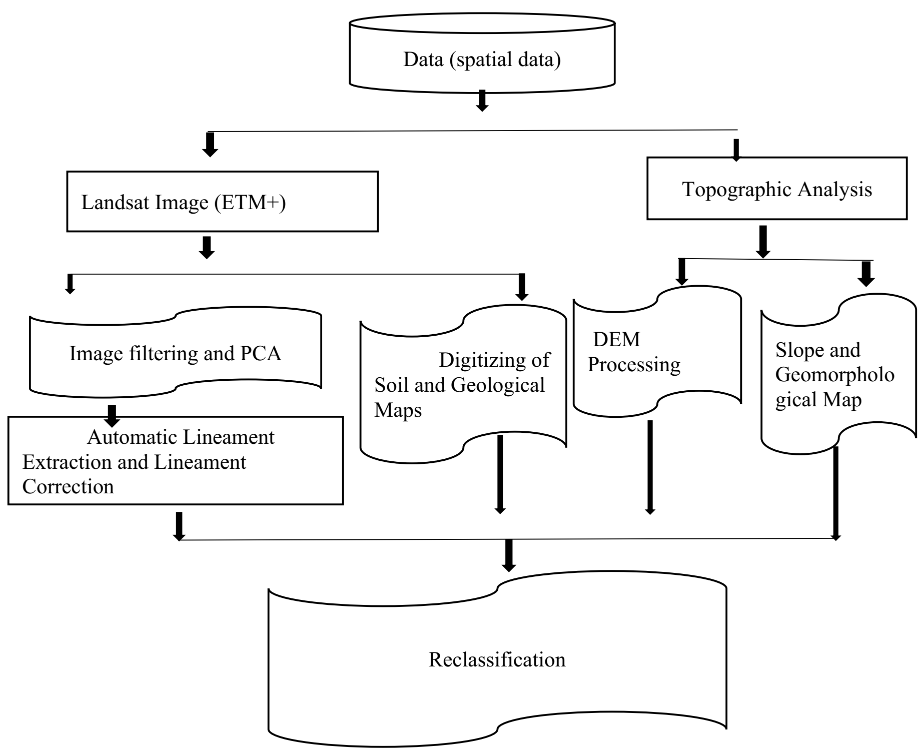


Fig. 3 Geological map of Ado-Ekiti. After NGSA; Geological map of Akure Sheet 56, 1966

Fig. 4 The processing flow chart



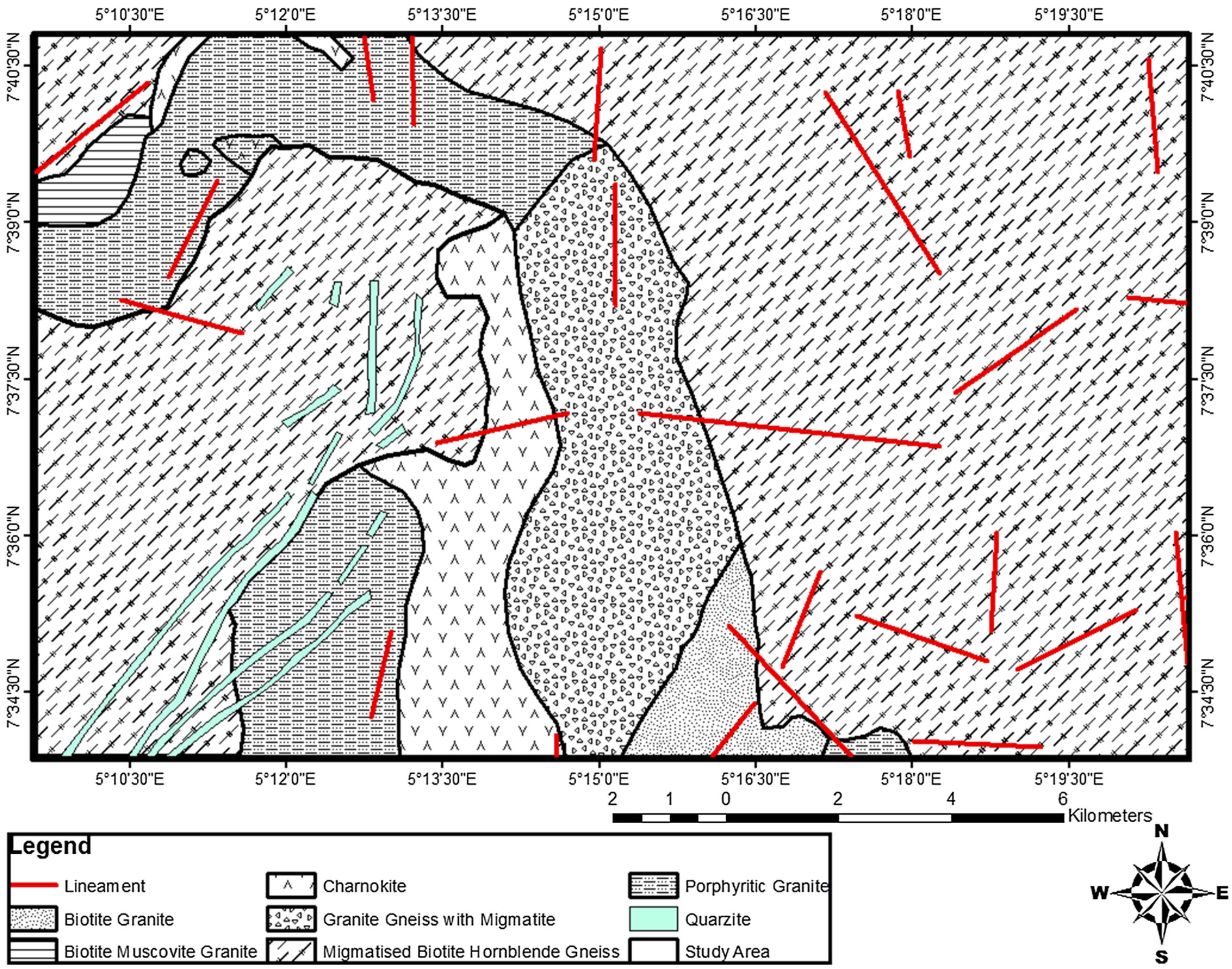


Fig. 5 Lineament map of the study area

High groundwater potentials are thus envisaged from areas underlain by gneisses and granites (Olorunfemi et al. 1999; Chuma et al. 2013).

Groundwater potential could be inferred from lineament density of an area (Ghosh et al. 2016). The lineaments density map shows the lineament numbers to be in the range of 0.00 and 0.24 km/km^2. The result is consistent with Fashae et al. (2014) which observed lineament density varying from less than 0.04 to 0.35 km/km^2 across the Basement Complex terrain of south-western Nigeria. High lineaments density suggests high groundwater potential (Chuma et al. 2013; Prabu and Rajagopalan 2013; Ojo et al. 2015).

The hydrogeomorphological map

Geomorphology reflects various landforms and topographical features in the area of study. These include hills, ridges, pediments, pediplains, pediplain with alluvium and valley fills (Fig. 7). The characteristics and groundwater prospects of the units are given in Table 1. The hills in the area are mainly made up of quartzites, gneisses, granites and charnockites. Groundwater occurs under unconfined conditions in shallow, moderately weathered zones of the pediplain and in semi-confined conditions in joints, fissures, and fractures that extend beyond the weathered zones (Jayeoba and

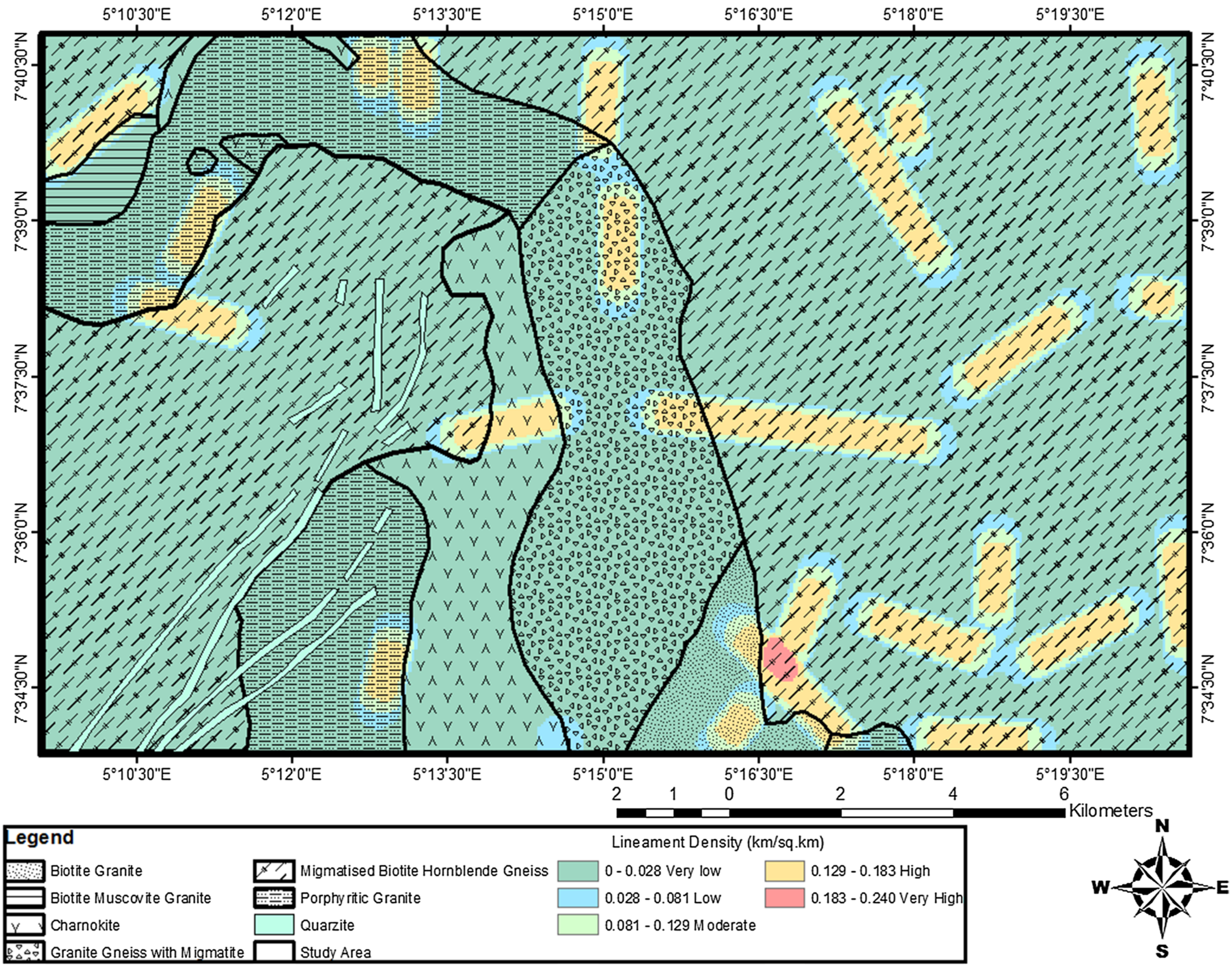


Fig. 6 Lineament density map of the study area

Oladunjoye 2013). Areas within the valley fills, the pediplain with alluvium, pediplains, pediment and hills and ridges portend very high, high, moderate, low and very low groundwater prospect, respectively (Rao and Jugran 2003; Bayowa et al. 2014; Ojo et al. 2015).

Slope

Surface gradients ranging from 0° to 49° observed in the study area (Fig. 8) yielded topographic slopes classes of nearly level, very gentle, gentle, moderate, strong, moderately steep to steep and very steep. The relationship with groundwater potential is presented in Table 2. Steep slope areas are characterized by high run-off, with less residence time for rainwater and less infiltration, while gentle slopes facilitate more time for rainwater infiltration (Prasad et al. 2008; Talabi and Tijani 2011; Bagyaraj et al. 2013).

Landuse/landcover

Spatial variation in the amount of groundwater storage occurs due to changes in landuse and vegetation cover. Landuse/landcover thus plays a significant role in the recharge process (Fashae et al. 2014; Selvam et al. 2014; Ghosh et al. 2016).

The landuse/landcover classes in the study area are vegetation, water body, built-up and outcrops as shown in Fig. 9. Built-up land (dense, medium and sparse residential areas) comprises 68.6 km^2 of the total study area. Coverage of 52.4 km^2, 13.5 km^2 and 2.7 km^2 is recorded for dense,

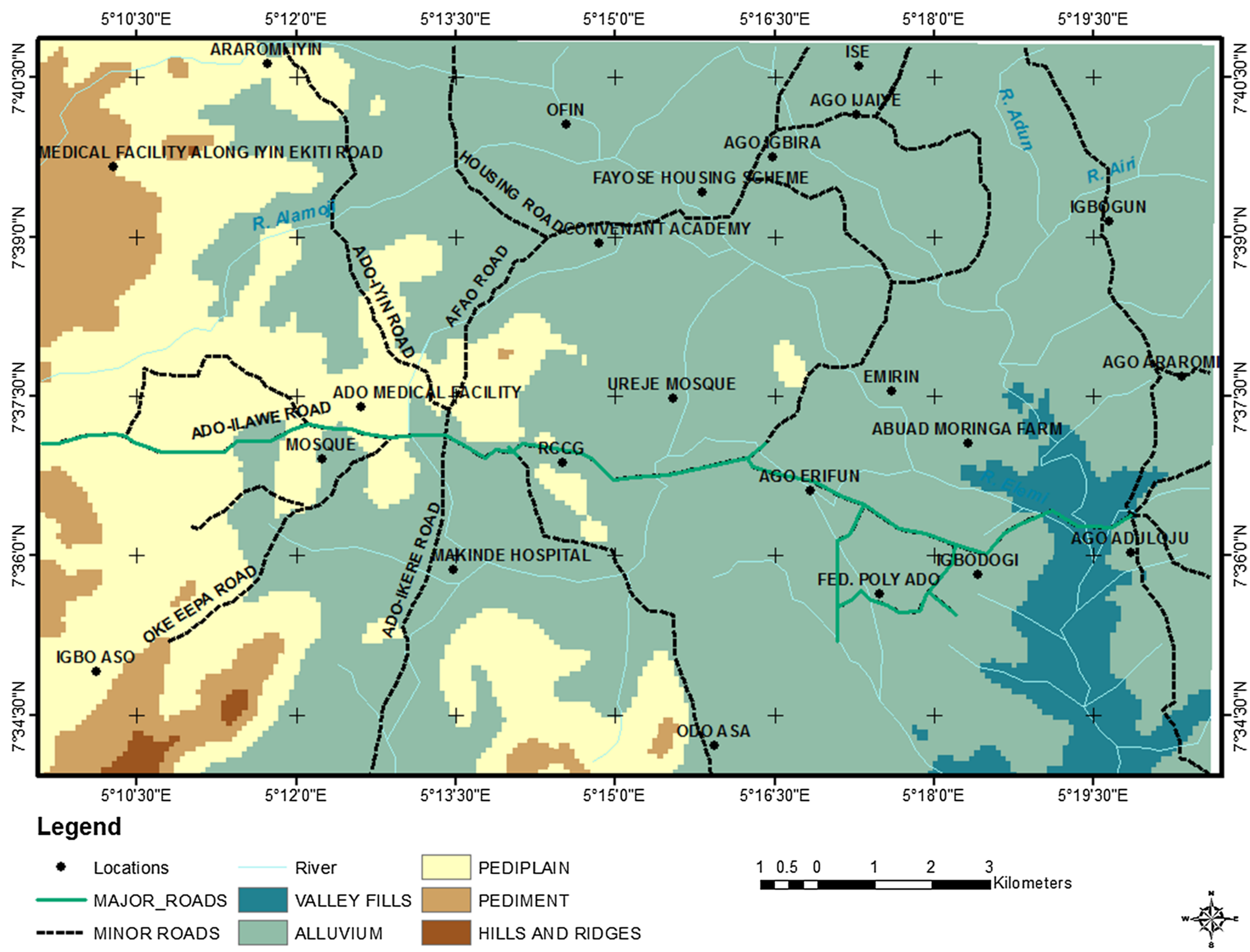


Fig. 7 Hydrogeomorphological map of the study area

Table 1 Hydrogeomorphological characteristics in Ado-Ekiti (Rao and Jugran 2003; Talabi and Tijani 2011)

Units	Characteristics	Groundwater prospects
Alluvium	Nearly level surface adjoining river courses with intercalations of gravel, coarse–fine sand, clay, etc.	Very good to excellent
Moderately weathered pediplain	Occurring away from hills with gentle slopes and appreciable vegetation cover. The potentials are increased when underlain by fractures with increased weathered zone thickness	Good to very good
Shallow weathered pediplain	Gentle to medium slope with sparse vegetation; possess only medium groundwater prospect unless when underlain by fractures	Medium to good
Inselberg, residual hill and denudational hill	characterized by medium to high relief/steep slopes with varying area extent or dimensions	Nil
The valley fills	Consist of weathered materials and in-filling of unconsolidated materials in the valley areas; usually underlain by fractures	Very good

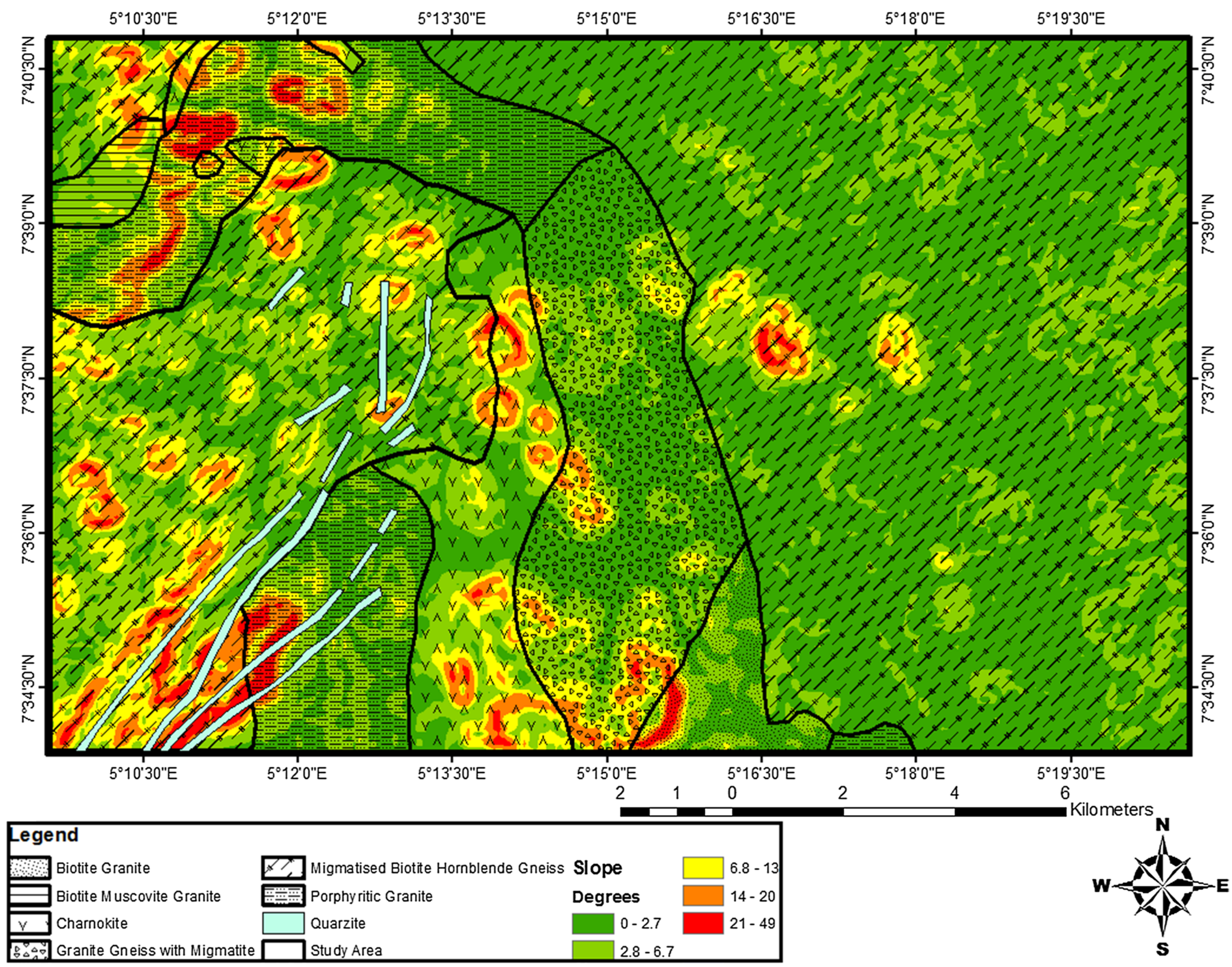


Fig. 8 Slope map of the study area

Table 2 Classification of slope in the study area (Talabi and Tijani 2011)

Classes	Attributes	Groundwater prospect
0°–2.7°	Gently sloping	Very high
2.8°–6.7°	Moderately sloping	High
6.8°–13°	Moderate steep sloping	Medium
14°–20°	Steep sloping	Low
> 20°	Very steeply sloping	Very low

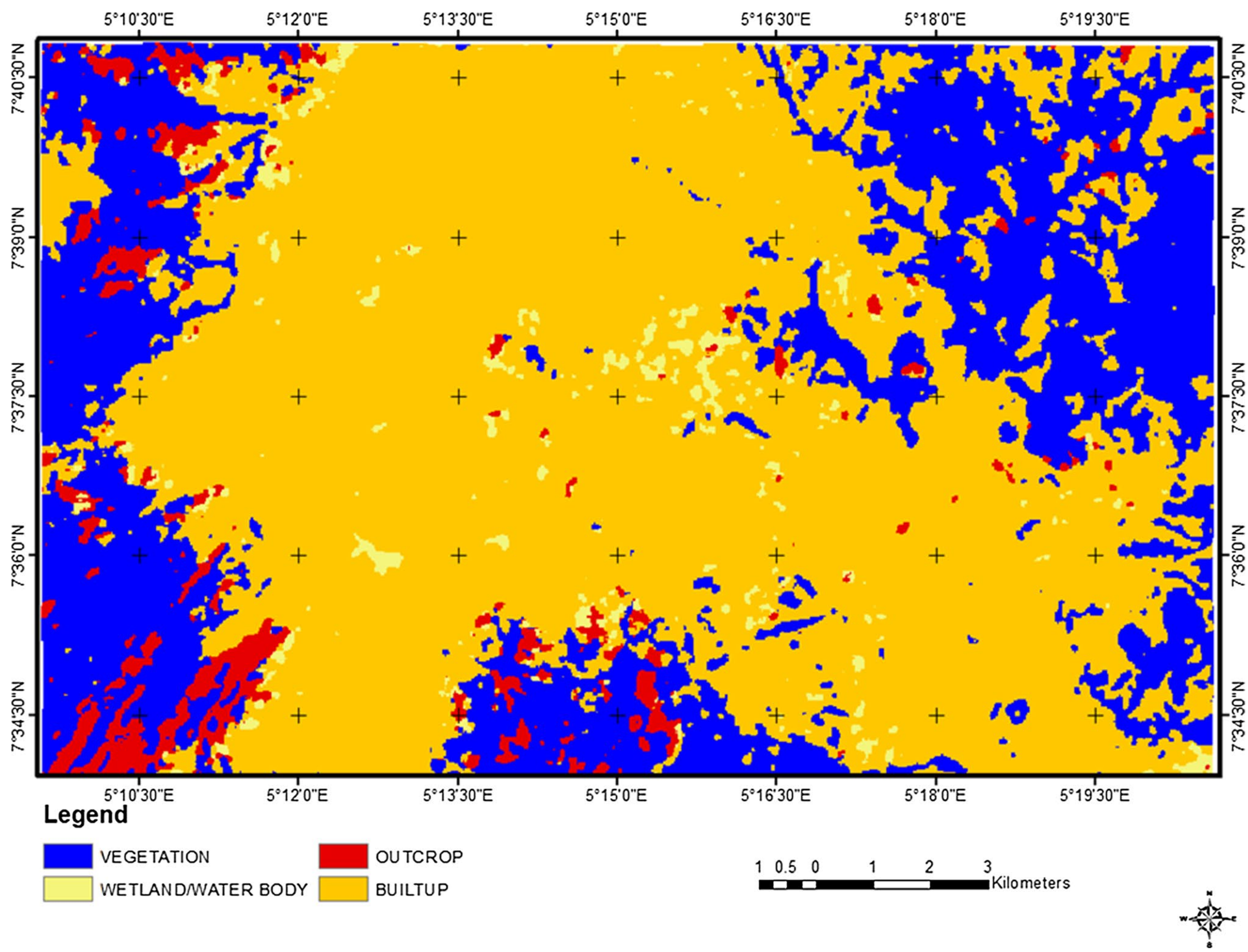


Fig. 9 Landuse/landcover map of the study area

medium and sparse residential areas, respectively. The light vegetation/bare soil has an area extent of 110.9 km^2 with the outcrops located in the north-western and south-western parts covering a total area of 14.9 km^2. The barren/fallow lands and settlements would have poor water-holding capacity unlike the wet/water bodies and cultivated lands (Selvam et al. 2014; Badamasi et al. 2016; Ghosh et al. 2016).

Drainage network/density

The drainage pattern, in general, is dendritic, typical of a granitic terrain. The drainage network analysis is germane to evaluate the recharge property. It is indicative of the rate of water percolation. The drainage density is proportional to surface run-off. Low drainage density enhances recharge and groundwater prospects (Shaban et al. 2006; Prasad et al. 2008; Selvam et al. 2014). On the stand point of recharge/groundwater prospect, more weightage has been assigned to regions of very low drainage density, while low weightage was assigned to regions of very high drainage density.

Groundwater potential evaluation (based on RS–GIS)

The spatial analysis and modelling involves integration of lithology, lineament density, drainage density, geomorphology, slope and LULC thematic layers. Weights ranging from 1 to 5 were assigned to the classes with respect to groundwater prospect in ascending order. The thematic maps were

Table 3 Weighting combination for groundwater potential zonation

Parameters	Classes	Scale value	Rank
Lineament density	Very low	1	20
	Low	2	
	Medium	3	
	High	4	
	Very high	5	
Drainage density	Very low	5	15
	Low	4	
	Medium	3	
	High	2	
	Very high	1	
Geomorphology	Valley fills	5	15
	Alluvium	4	
	Pediplain	3	
	Pediment	2	
	Hill and ridges	1	
Geology	Variably migmatized undifferentiated biotite-hornblende-gneiss	1	20
	Charnockite meta intrusive	1	
	Undifferentiated older granite mainly granitized gneiss	3	
	Coarse porphyritic biotite and biotite-hornblende	3	
	Fine- to medium-grained biotite and biotite-muscovite granite	3	
	Medium- to coarse-grained biotite granite	3	
	Quartzite vein	5	
Slope	Very gentle	5	15
	Gentle	4	
	Medium	3	
	Steep	2	
	Very steep	1	
Landuse/landcover	Outcrop	3	15
	Wetland/waterbody	1	
	Built-up	3	
	Vegetation	5	

synthesized in a GIS environment using weighted indices for groundwater potential map development according to the works of Rao and Jugran (2003), Talabi and Tijani (2011) and Fashae et al. (2014). The resulting groundwater potential possibility maps were subjected to validation against the existing borehole yield data. The weighting combination (Table 3) which gave the highest correlation was subsequently adopted, thereby producing the groundwater potential map (Fig. 10). The map classifies the study area into very low, low, moderate and high groundwater potential zones.

The marked variability and the unpredictability of the nature of basement aquifers suggest that precision is essential as a location error of less than 5 m can make all the difference between a productive borehole and a dry hole. Tube wells drilled without sequential hydrogeological and geophysical study often fail to meet the quest for groundwater and justify the overall cost (Olayinka 1992; Fashae et al. 2014).

The integrated RS–GIS analysis offers an approach that narrows down the target areas for detailed hydrogeophysical exploration (Bagyaraj et al. 2013; Prabu and Rajagopalan 2013; Ndatuwong and Yadav 2014). Site-specific ground geophysical methods such as the very low frequency electromagnetic (VLF-EM) profiling and vertical electrical sounding (VES) could then be deployed for site characterization and selection for sustainable groundwater development.

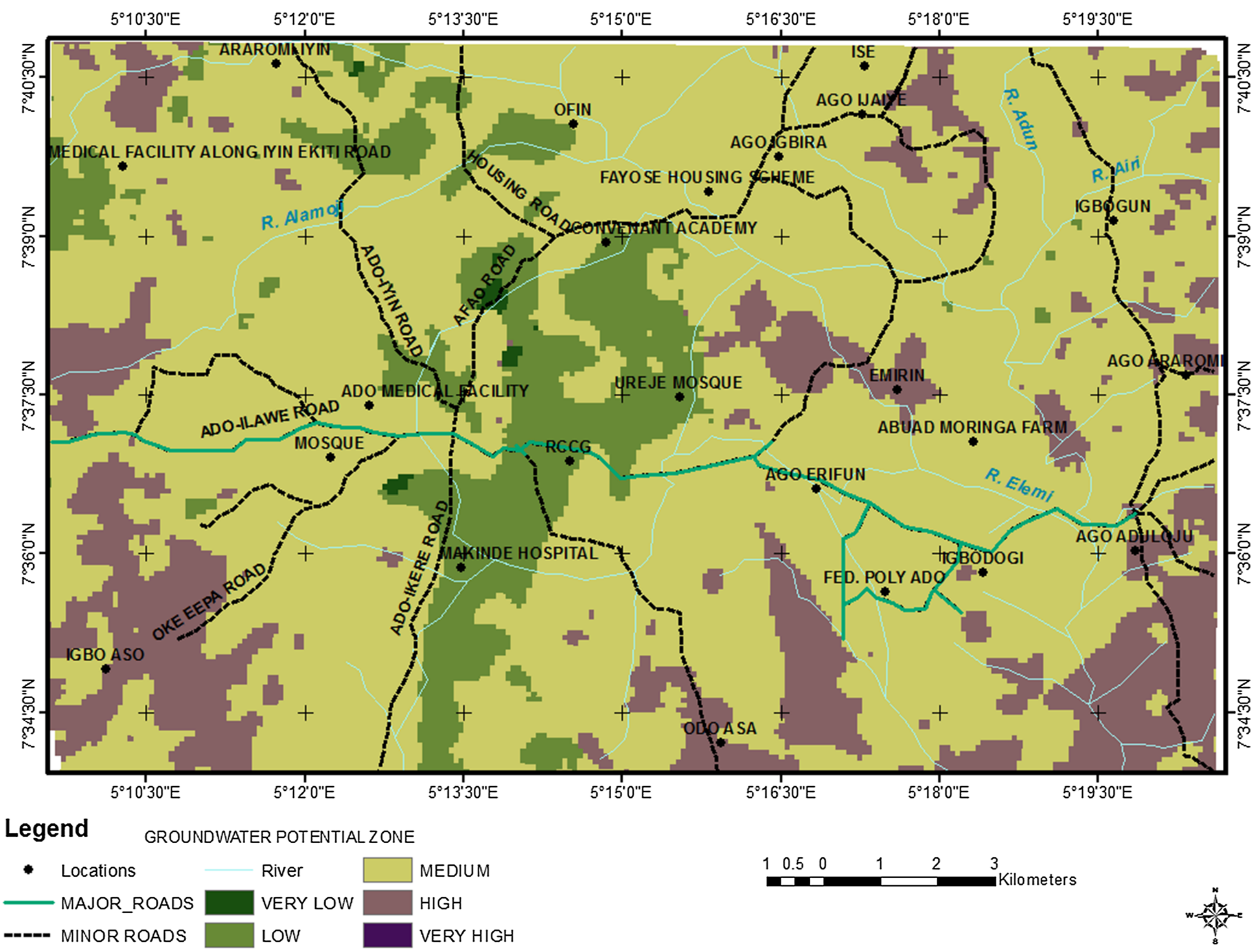


Fig. 10 Groundwater potential map of the Ado-Ekiti area, SW, Nigeria

Conclusions

The study delineated very low, low, moderate and high groundwater potential zones. The groundwater resources in hard rock terrain are limited and commonly restricted to diastrophic features. Groundwater exploration in the terrain demands precise determination of the attributes of these features. Remote sensing–GIS approach would serve as the preliminary inventory method to understand groundwater potential index and facilitate delineation of zones adjudged suitable for further hydrogeophysical investigations.

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Compliance with ethical standards

Conflict of interest I hereby state that there is no conflict of interest of any sort on this work. Potential conflicts do not exist regarding the work.

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