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REVIEW ARTICLE

Investigation of the influence of lineaments, lineament intersections and geology on groundwater yield in the basement complex terrain of Ondo State, Southwestern Nigeria

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Abstract

The influence of lineaments, lineament intersections and geology on the groundwater yield of the basement terrain of Ondo State was investigated using optical remote sensing data, Aster DEM, geology, and borehole yield data. Landsat-7 ETM+ and Aster DEM were processed to generate composite lineament map. The study area was traversed by five (5) main lineament populations trending N–S, NE–SW, E–W, ENE–WSW, NNW–SSE. Boreholes sited on lineament exhibited a yield range of between 0.8 and 1.28 l/s with an average yield of 1.04 l/s. Boreholes sited close to lineament gave groundwater yield values of between 0.5 and 1.28 l/s and an average yield of 1 l/s, while boreholes located outside lineament gave groundwater yield range of between 0.2 and 1.26 l/s with an average yield of 0.98 l/s. The investigation of the hydrogeological characteristics of the lithologies by superimposing the yield data showed average yield of 0.98 l/s for migmatite gneiss biotite granite undifferentiated (M), 1.01 l/s for porphyritic granite (OGp), 1.03 l/s for medium- to coarse-grained (OGe), 1.17 l/s for pelitic schist undifferentiated (Su), 1.24 l/s for quartz schist and quartzite (Eq), 1.12 l/s for older granite undifferentiated (OGu), 0.5 l/s for slightly migmatised medium-grained granite-gneiss (gg) and 1.23 l/s for fine-grained flaggy quartzite and schists (Sf). The study concluded that borehole data located on or near lineaments or at intersection of lineaments gave higher yields more than those located before lineaments or outside lineaments, while quartz schist and quartzite exhibited the highest average groundwater yield of all the lithological units.

Keywords Lineament · Lineament intersection · Lithology · Groundwater yield · Crystalline basement complex

Introduction

Basement aquifers constitute relevant sources of water in the hard rock terrain of Ondo State in which groundwater occurs mainly in fractured zones, with or without saturated weathered zones (Olorunfemi and Olorunniwo 1985; Olorunfemi 1990; Olorunfemi et al. 1991; Olorunfemi and Okhue 1992; Idornigie and Olorunfemi 1992; Olorunfemi and Fasuyi 1993; Olorunfemi 2007; Ekwe et al. 2010; Bayowa et al. 2014; Akinlalu et al. 2017). However, the development of crystalline bedrock aquifers is highly complex, and groundwater occurrence is spatially variable due to many factors (Satpathy and Kanungo 1976; Mabee et al. 1994; Mabee 1999; Mabee et al. 2002; Ojo et al. 2015; Aladejana et al. 2016). Though tectonic history, geomorphology and climatic conditions play prominent role in the development of weathered and fractured aquifer systems, in this kind of terrain, water percolation and accumulation is essentially controlled by fractures and other rock discontinuities (Lattman et al. 1964; Siddiqui and Parizek 1971; Edet et al. 1994; Edet 1996; Sander 1997; Taylor and Howard 2002, Anifowose et al. 2012; Akinlalu et al. 2017). Therefore, knowledge of some surficial features such as lineament (originated possibly by faults, fractures, joints, foliation, etc.) in an area

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underlie by Basement Complex rocks for site selection prior to localized geophysical surveys could maximize search for developing productive-well representing positions of potential deformation zones in bedrocks. Hence, the surficial features can be used as surface indicators to the sub-surface fracturing and weathering which are essential for high yielding productive aquifers in hard rocks.

Optical remote sensing with the availability of multispectral and progressive development in the image processing techniques provides the opportunity to prepare relatively more reliable and comprehensive lineament maps. The wide ground coverage and relative high resolution with respect to scale presented by the satellite images, also enables regional and local lineament analysis (Masoud and Koike 2006; Nag et al. 2011; Adiat et al. 2012; Dasho et al. 2017). Although there have been significant approaches for the evaluation and automatic detection of the lineaments and curvilinear features from satellite images (Cross 1988; Taud and Parrot 1992; Hardcastle 1995; Odeyemi et al. 1999; Henriksen and Braathen 2005, Yene et al. 2015; Lobatskaya and Strelchenko 2016, Ilugbo et al. 2017), however, semi-automatic extraction combining the expert human nature and computer algorithm is an asset for lineament detection and interpretation (Mallast et al. 2011; Vaz et al. 2012; Vasuki et al. 2014; Middleton et al. 2015; Bonetto et al. 2017).

This study intends to investigate the influence of lineaments, lineament intersections and geology on the groundwater yield in the Basement Complex terrain of Ondo State. The result will provide enhanced knowledge and improved understanding of the hydrogeological characteristics for evaluating groundwater potentiality in the study area and the world as a whole.

The study area and geological setting

The study area (Fig. 1) lies between latitudes 5°27′ and 8°09′ N and longitudes 4°00′ and 6°00′ E. It covers a geographic area of approximately 105, 239.49 sq km. It is bounded in the East by the Edo State, in the West by Ogun, and Osun and in the North by Ekiti and Kogi States. It is composed of some prominent hills found in Idanre and Akoko which rise to over 250 m above sea level (m.a.s.l).

Ondo State is underlain by both Precambrian rocks and sedimentary formations (Fig. 2). The Basement Complex underlies the northern part (60%) of the state. The Precambrian crystalline rocks consist of metamorphic and igneous rocks with isotopic ages greater than 300–450 Ma (Ajibade and Fitches 1988). They are mainly composed of biotite granites, porphyritic granites, gneisses, schists, pelitic schists, quartzites, schistose quartzites and charnockites. Some of the metasediments are also intruded by pegmatites. The granites are part of the older granites of the Dahomeyan Embayment. The Basement rocks outcrop in many localities

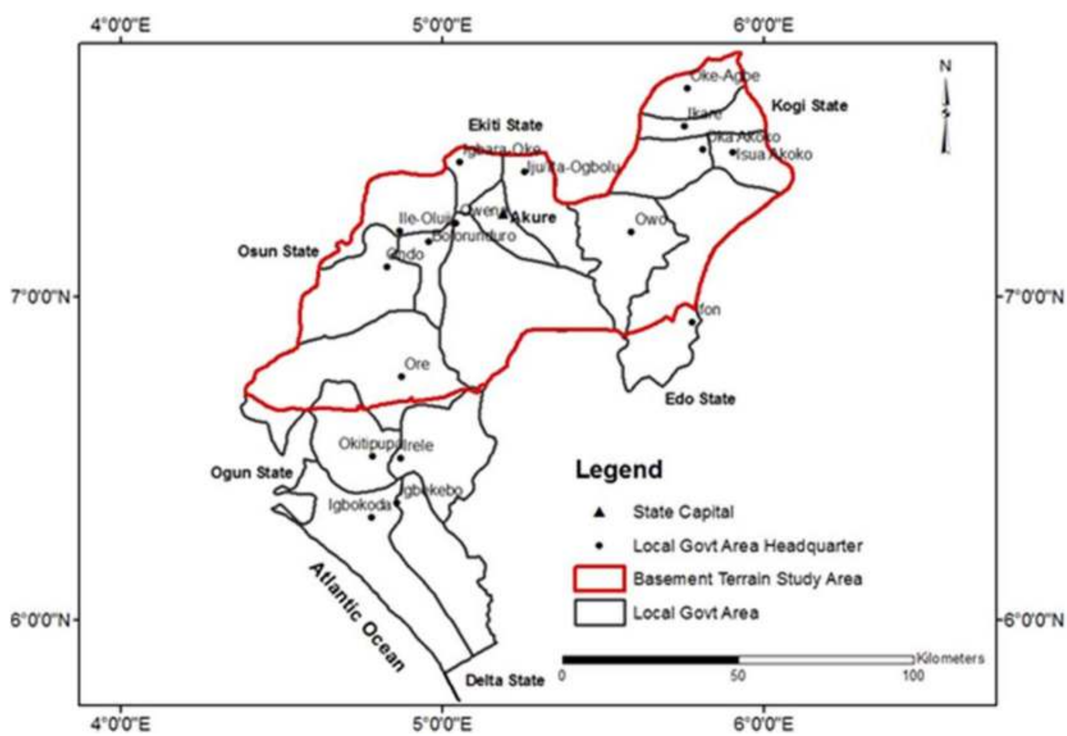

Fig. 1 Administrative map of Ondo State (modified from administrative map of Ondo State published by the office of the surveyor-general of the State, 1998)

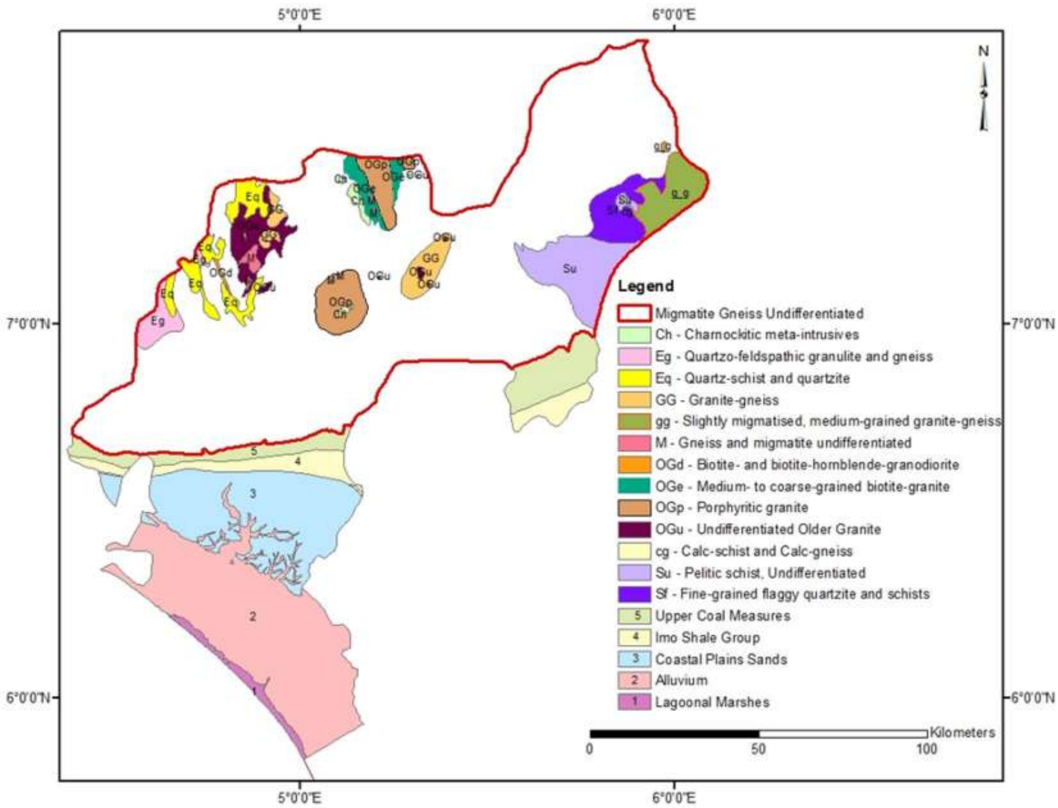

Fig. 2 Digitized generalized geology of Ondo State (adapted from the nigerian geological survey agency (NGSA) map, 1966)

in the state. They occur as isolated hills and inselbergs which stand out against low-lying surroundings. The granite rocks are mostly made up of feldspathic porphyries that are generally aligned along the N–S direction at Idanre and Ikare, where they assume batholithic dimensions.

Materials and methods

Three Landsat ETM+ scenes of paths/rows: 189/055, 190/055 and 190/056, Aster DEM, Ondo State administrative and topographical maps at 1:250,000 scales were acquired. In order to reduce processing and computational time during digital image processing, a vector map representing the geomerty of the study area was created to subset all the acquired data and Landsat ETM+ was pre-processed for haze reduction, noise filtering, re-sampling and orthorectification. For maximum utilization of multi-spectral Landsat ETM+, optimum index factor (OIF) was carried out using Ilwis 3.7.2 to select the optimum combination of three bands out of all possible 3-band combinations to create a color composite. Bands 457 contain the highest OIF and used to create false colour composite while band 7 being a geologic band was subjected to linear stretching and spatial enhancement filters, spectral enhancement of Landsat ETM+ bands (principal components analysis, PCA), the Aster DEM to topographic analysis such as sink fill, shielded relief and image fusion. All of these processes were then integrated to generate lineament map. The extracted lineaments were validated by overlaying the lineaments on high resolution Google Earth image and topographical maps to expunge anthropogenic linear/curvilinear features of non-geologic origin. The output of the corrected lineaments from high resolution Google Earth image and topographical maps was further processed for hydrogeological analysis whereby non-hydrogeologic significant lineaments lying on DEM highs were removed. Hydro-lineament and hydro-intersection maps were then sub-mapped from the general lineament map. Hydrogeologic characteristics of the generalized geology and hydro-lineament, intersection of the basement complex area were carried out using superimposition function with the groundwater yield data 92 borehole yield data that were used for this characterization.

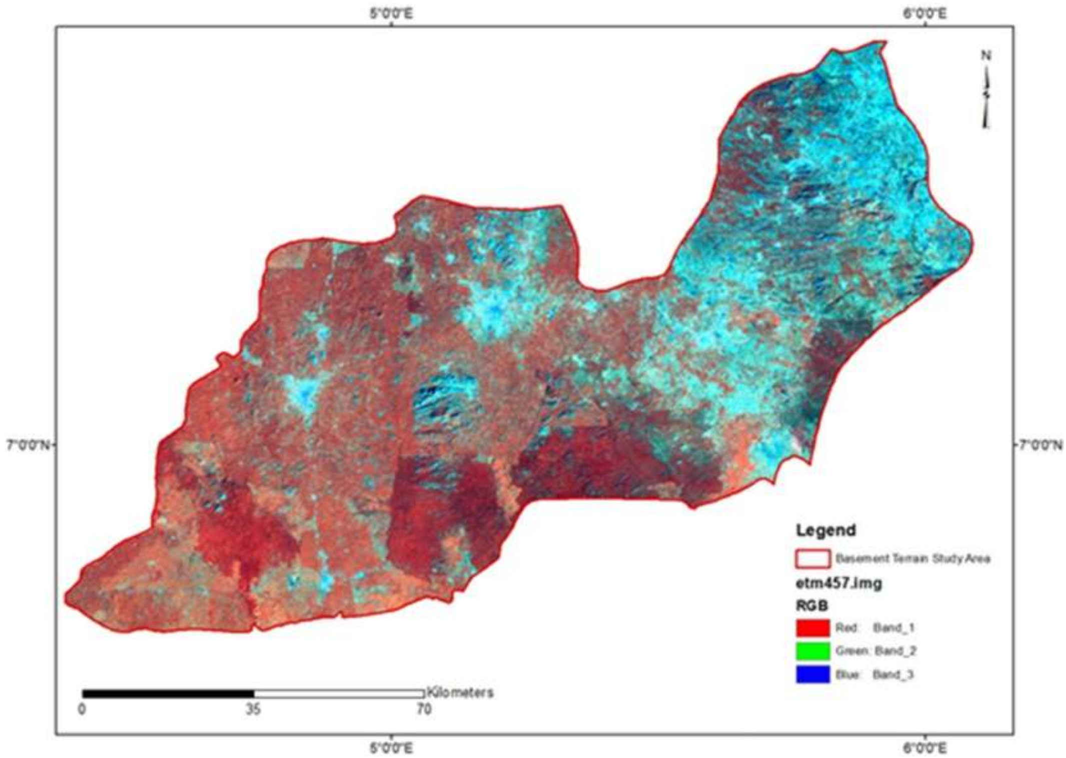

Fig. 3 Bands 457 false color composite of the study area

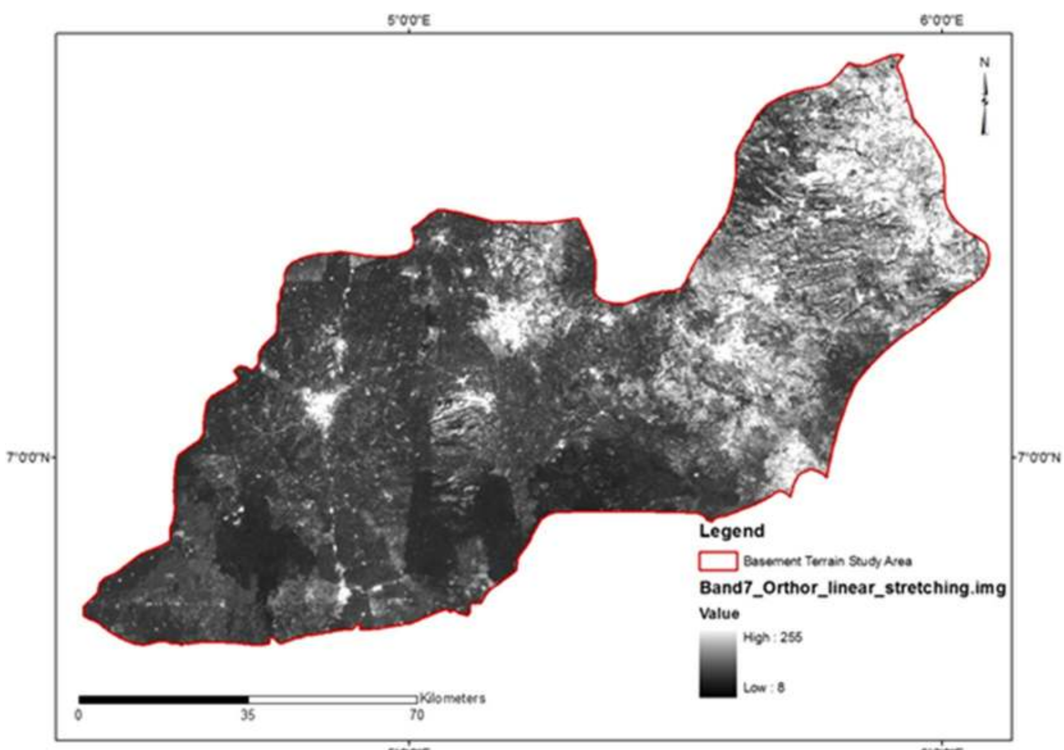

Fig. 4 Linear stretch of Band7 of landsat-7 ETM+

Results and discussion

Lineaments mapping

Figure 3 shows bands 754 color composite of Landsat-7. Visually, it reveals land cover classes ranging from vegetations, linear features, built-ups, roads, soil/rock outcrops, and aeroplane track. Linearly stretched gray scale band 7 ETM+ (Fig. 4) reveals some linear/curvilinear structures which are particularly visible in the centre and northwest of the study area. While Fig. 5a–f show kernels and output raster images of spatial filters. These arrays of spatial frequency filters (i.e., edge enhancement, high pass, Laplace, cross edge enhancement, vertical and low pass) suppress and emphasize structural appearance of topographic/geologically induced linear/curvilinear features. Principal components (PC1 to PC6) are shown in Figs. 6a–f. It depicts varying degrees of spectral information content inherent in bands 1, 2, 3, 4, 5, and 7 (Table 1).

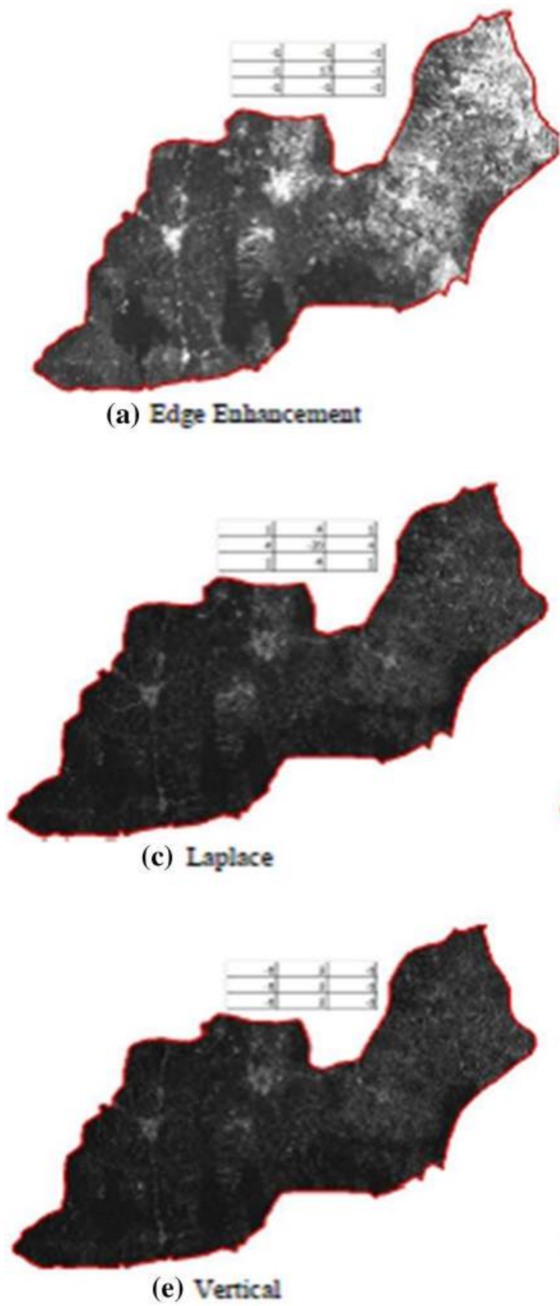

Fig. 5 **a–f** Shows kernels and output raster images of anthropogenic and topographic structures

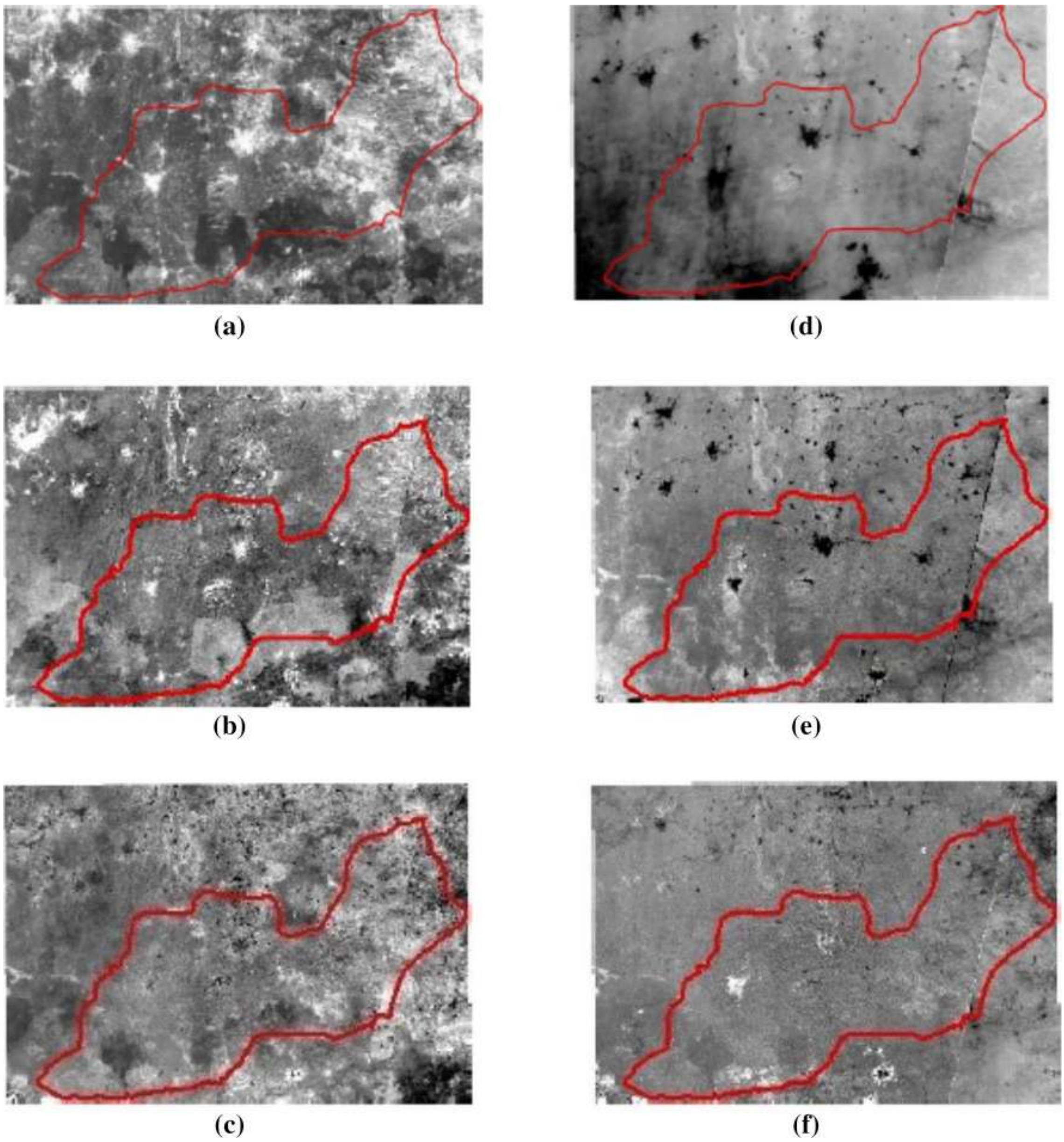

Fig. 6 a–f Decreasing quality of principal component images of basement complex

Table 1 Eigenvectors of principal component analysis results

	Eigenvectors					
	P1	P2	P3	P4	P5	P6
Band 1	0.0927	− 0.7969	0.2293	0.5440	− 0.0536	− 0.0706
Band 2	0.1401	− 0.3929	0.0664	− 0.5152	0.1866	0.7220
Band 3	0.2652	− 0.2539	0.2183	− 0.5777	0.1863	− 0.6701
Band 4	− 0.1166	− 0.3355	− 0.7609	− 0.2140	− 0.4851	− 0.1173
Band 5	0.6336	0.0559	− 0.5188	0.2429	0.5169	− 0.0051
Band 6	0.6974	0.1745	0.2173	− 0.0055	− 0.6520	0.1041

Table 2 Eigenvalues of principal component analysis results

Components	1	2	3	4	5	6
Value	341.27	72.41	25.02	8.28	4.31	1.94
Eigenvalues (%)	75.30	15.98	5.52	1.83	0.95	0.43

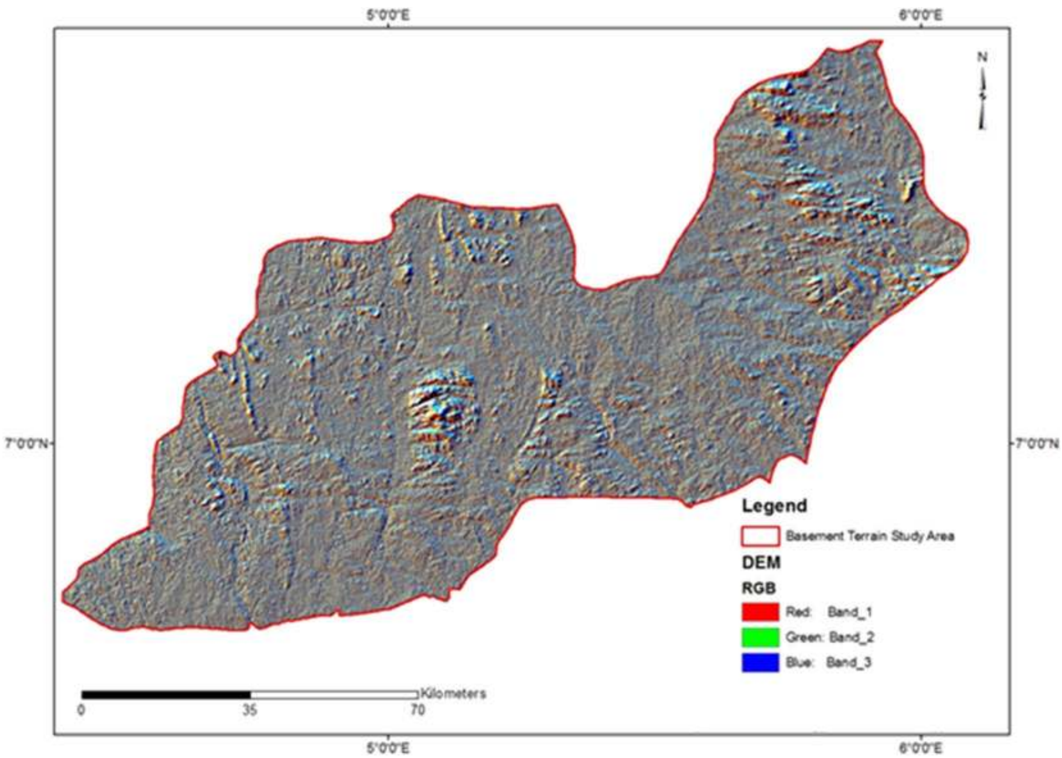

Fig. 7 Hill-shaded relief map of the study area

Table 1 shows the transformation coefficients of the set of input bands. The columns correspond to the six principal components and the rows correspond to the six bands. It depicts the factor score (eigenvector) contributed to the individual components. Higher values indicate a greater factor loading, i.e., that band is contributing more to that component. This is the same regardless of sign, i.e., a high negative value also indicates a high factor loading. Table 2 shows the decreasing variance in successive principal components. As can be seen from the eigenvalues (Table 2), the first three components made 96.79% of the available variance and carry most of the spectral information in the total data set available for analysis while the other shows noise in the data. For geomorphic linear features, generated Hill-shaded map is shown in Fig. 7. It reveals lows and highs of different geomorphic linear features. This represents both natural and man-made linear features. Ambiguities in the interpretation of hill-shaded relief map for verifying and discarding geologic and non-geologic linear features were reduced by comparing it with other images generated and fused image results. Figure 8 shows the general lineament map in the basement terrain study area of Ondo State. The spatial distribution of lineaments expresses itself in terms of topography in the study area, which manifested as straight stream valley, sudden changes in flow direction of drainage patterns, contrasting tone, straight/curvilinear ridges and alignment of vegetation (Mabee et al. 1994; Masoud and Koike 2006; Ekwe et al. 2010; Adiat et al. 2012; Akinluyi 2013; Dasho et al. 2017). Figure 8 depicts a characteristic feature of the occurrence of underlying structures in the basement complex of Ondo State. It shows the fracture distribution and pattern in the study area on a scale of 1:200,000 as exhibited in each of the sixteen (16) local government areas (LGA). The central and north-eastern parts of the study area present a structurally complex landscape around the Idanre (Owena), Oke Agbe, Ikare, Ido-ani, Oba and Isua Akoko. High concentration of lineaments of topographic highs origin is evident in the rugged terrain of Idanre local government area (LGA) and Akoko area particularly in Akoko northwest local government area (LGA). Therefore, Fig. 8 play a significant role as one of the criteria used

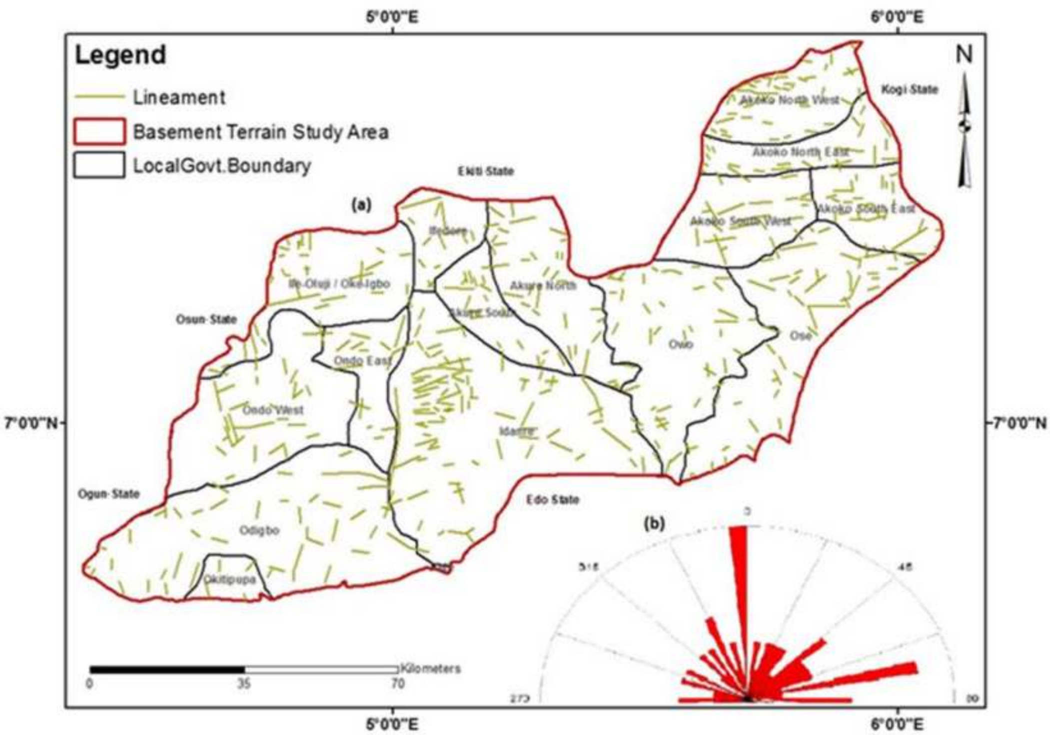

Fig. 8 **a** Lineament map and **b** rose diagram of the study area

during evaluation of groundwater potential, engineering studies, erosion risk mapping, landfill characterization, etc. The Rose diagram (Fig. 8b) shows that the study area is traversed by five (5) main lineament populations trending N–S, NE–SW, E–W, ENE–WSW, NNW–SSE. The large spread in the azimuths of the lineaments is due to the polycyclic history as well as the brittle nature of the migmatites, gneisses and quartzites which together constitute the major lithology of the basement complex rocks of Ondo State. The N–S lineament trend pattern coincided with the general N–S foliation strike emplacement in the basement complex of Nigeria. This invariably implies that these lineaments might have resulted from plate movements and tectonics in the region.

Geology, hydro-lineament/intersection and groundwater yield in the basement complex area of Ondo state

Figure 9 shows the spatial distribution of the borehole yield data on the generalized geological map of the study area. The ninety-two groundwater yield data fall on eight lithological units as shown in Fig. 9 and Table 3. These lithological units and the range of borehole yield (in bracket) are migmatite gneiss undifferentiated (*M*: 0.2–1.28 l/s), porphyritic granite (OGp: 0.6–1.28 l/s), medium-to-coarse-grained biotite granite (OGe: 0.5–1.24 l/s), pelitic schist undifferentiated (Su: 1.1–1.2 l/s), quartz bschist and quartzite (Eq: 1.23–1.24 l/s), older granite undifferentiated (OGu: 0.74–1.26 l/s), slightly migmatised medium-grained granite-gneiss (gg: 0.5 l/s) and fine-grained flaggy quartzite and schists (Sf: 1.23 l/s). Within the limits of the groundwater yield data, quartz schist and quartzite and flaggy quartzite have the highest average groundwater yield followed by older granite/pelitic schist (which is suspected to be pegmatitic); porphyritic/coarse-grained granite and lastly by migmatite/granite-gneiss. The relatively high groundwater yield observed on quartzite is not unconnected with the relatively high fracture (lineament) density with consequently high permeability. Figure 10 shows the overlay of borehole location on the hydro-lineament map. Table 4 presents groundwater yield characteristics on lineament, close to lineament and outside lineament obtained on a scale of 1:100,000. Boreholes sited on lineament exhibit a yield range between 0.8 and 1.28 l/s with an average yield of 1.04 l/s. Boreholes sited close to lineament gave groundwater yield values between 0.5 and 1.28 l/s and an average yield of 1 l/s, while boreholes located outside lineament gave groundwater yield range between 0.2 and 1.26 l/s with an average yield of 0.98 l/s. This shows that boreholes located on lineaments are expected to give relatively high groundwater yield due to the enhanced groundwater flow through the lineaments. Similar experiences have been reported by Edet et al. (1994), Edet (1996), Adiat et al. 2012, Yene et al. (2015), Aladejana et al. (2016). Figure 11

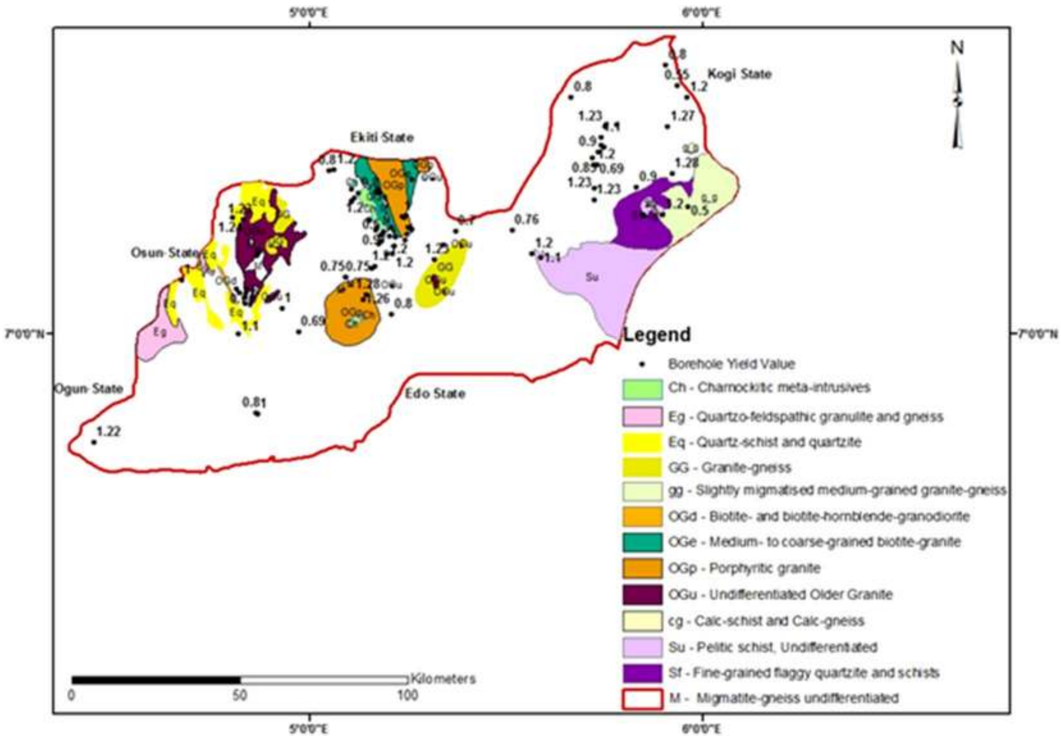

Fig. 9 Overlay of yield data on generalized geology of the study area (adapted from the nigerian geological survey agency (NGSA) map, 1966)

Table 3 Hydraulic characteristics of some lithological units

Lithology	Percentage distribution of yield data on lithology (%)	Yield range (l/s)	Average yield (l/s)
Migmatite gneiss undifferentiated (M)	72	0.2–1.28	0.98
Porphyritic granite (OGp)	8	0.6–1.28	1.01
Medium- to coarse-grained biotite granite (OGe)	5	0.5–1.24	1.03
Pelitic schist undifferentiated (Su)	3	1.1–1.2	1.17
Quartz schist and quartzite (Eq)	2	1.23–1.24	1.24
Older granite undifferentiated (OGu)	5	0.74–1.26	1.12
Slightly migmatised medium-grained granite-gneiss (gg)	1	0.5	0.5
Fine-grained flaggy quartzite and schists (Sf)	1	1.23	1.23

shows the spatial distribution of boreholes on the hydro-intersection map. Table 5 shows groundwater yield characteristics of hydro-lineament intersection with respect to on intersection, close to intersection and outside intersection. The borehole located on lineament intersection gave the highest average yield of 1.28 l/s. The next highest average groundwater yield of 1.01 l/s was recorded from boreholes located close to lineament intersections, while those located outside the lineament intersections gave the lowest average of 1 l/s. The analysis in Tables 4 and 5 corroborated the works of Lattman and Parizek (1964), Sander 1997, Mabee et al. (2002), Bayowa et al. 2014, Dasho et al. (2017), that wells located on or near lineaments or at the intersection of lineaments gave yields greater than wells placed between lineaments and outside lineaments. Siddigui and Parizek (1971), Mabee (1999), Bayowa et al. (2014), Adiat et al. (2012), Yene et al. (2015) and Ilugbo et al. (2017) also found that wells sited on lineament had productivity greater than randomly located wells.

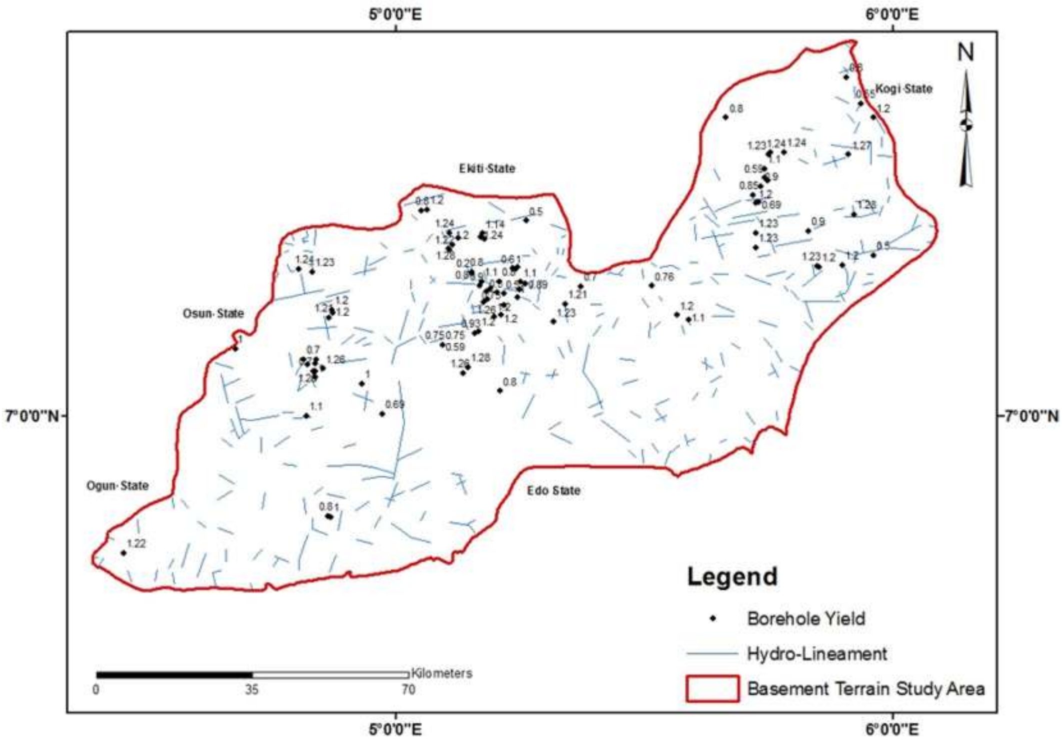

Fig. 10 Overlay of yield data on hydro-lineament map

Conclusions

This study evolved a systematic remote sensing and GIS-based methodology for mapping lineaments and sub-mapped it into hydro-lineament and hydro-intersection maps. It related lineament and lineament intersection and geology to groundwater yield in the basement complex terrain of Ondo State.

The remote sensing offers a synoptic view to study the large geographical areas. In our study, spatial statistical application for optimal band selection, multi-sensor data analysis and image fuse were demonstrated for mapping reliable geologically induced lineament patterns. The Ondo State basement complex area was characterized by five (5) main lineament populations trending N–S, NE–SW, E–W, ENE–WSW, NNW–SSE. The azimuths of the lineaments are due to the polycyclic history as well as the brittle nature of the migmatites, gneisses and quartzites which together constitute major lithology of the basement complex rocks of Ondo State. This result agrees with the N–S lineament trend pattern coinciding with the general N–S foliation strike emplacement in the basement complex of Nigeria.

Ninety-two borehole yield data overlaid on eight lithological units exhibit variable yield. These lithological units and the range of borehole yield are migmatite gneiss undifferentiated (*M*: 0.2–1.28 l/s), porphyritic granite (OGp: 0.6–1.28 l/s), medium-to-coarse-grained biotite granite (OGe: 0.5–1.24 l/s), politic schist undifferentiated (Su: 1.1–1.2 l/s), quartz schist and quartzite (Eq: 1.23–1.24 l/s), older granite undifferentiated (OGu: 0.74–1.26 l/s), slightly migmatised medium-grained granite-geniss (gg: 0.5 l/s) and fine-grained flaggy quartzite and schists (Sf: 1.23 l/s).

Table 4 Hydraulic characteristics of hydro-lineament map

Borehole location	Yield range (l/s)	Mean yield (l/s)
On lineaments	0.8–1.28	1.04
Close to lineaments	0.5–1.28	1
Outside lineaments	0.2–1.26	0.98

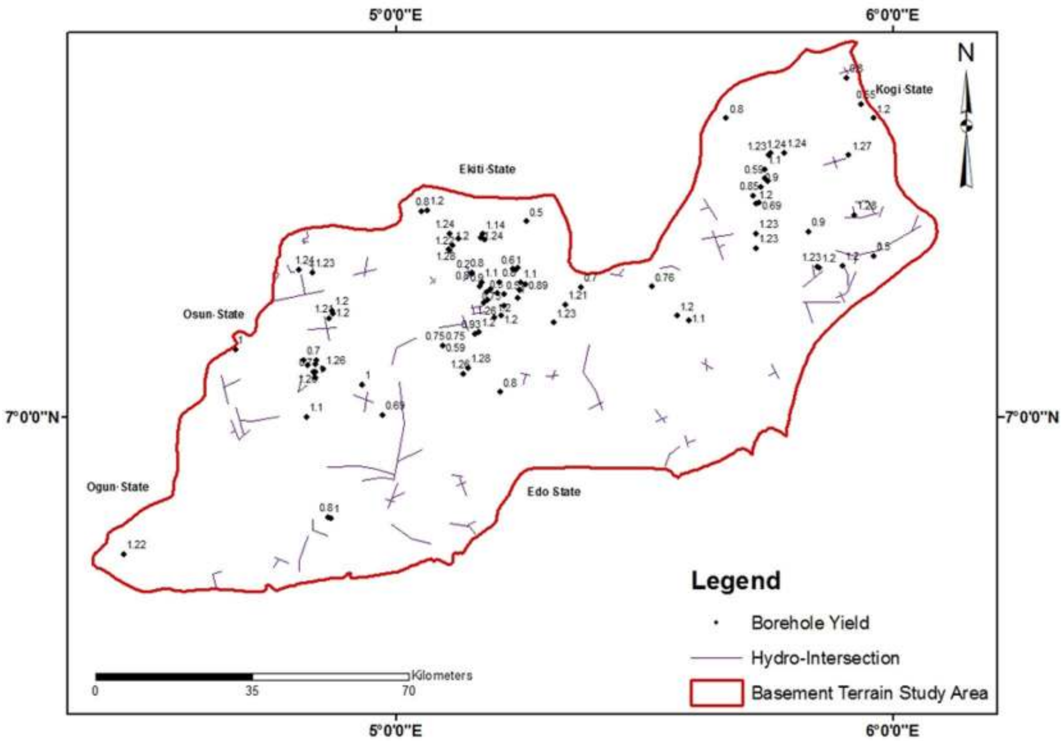

Fig. 11 Overlay of yield data on hydro-intersection map

Table 5 Hydraulic characteristics of hydro-lineament intersection map

Borehole location	Yield range (l/s)	Mean yield (l/s)
On intersections	1.28	1.28
Close to intersections	0.50–1.27	1.01
Outside intersections	0.20–1.28	1.00

Boreholes sited on lineament exhibit yield range between 0.8 and 1.28 l/s with an average yield of 1.04 l/s. Boreholes sited close to lineament gave groundwater yield values between 0.5 and 1.28 l/s and an average yield of 1 l/s, while boreholes located outside lineament gave groundwater yield range between 0.2 and 1.26 l/s with an average yield of 0.98 l/s.

This study concluded that boreholes located on or near lineaments or at intersection of lineaments gave yields more than those located before lineaments or outside lineaments, while quartz schist and quartzite exhibited the highest average groundwater yield of all the lithological units. It, therefore, optimizes the hydrogeological investigation for predicting groundwater potential in terms of proximity to structural lineaments and hydro-lithological characteristics as a guide to siting productive boreholes and invariably reduces considerably the rate of failure during exploitation.

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Compliance with ethical standards

Informed consent Informed consent was obtained from all individual authors included in this study titled Investigation of the Influence of Lineaments, Lineament Intersections and Geology on Groundwater Yield in the Basement Complex Terrain of Ondo State, Southwestern Nigeria. We all agreed to every component of the manuscript.

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