

# Lineament Mapping and Groundwater Occurrence within the Vicinity of Osara Dam, Itakpe-Okene area, North Central Nigeria, Using Landsat Data

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**Abstract** The implementation of geographic information systems (GIS) tools and remote sensing data for exploration of groundwater in area with scarce water resources saves time and money. Digital layers of topographic, drainage, lithology, and geological structure maps were prepared and analyzed using remote sensing data and GIS tools; to identify the most promising sites for groundwater exploration in the studied area. Lineament analysis of Osara area using LandSat MSS data was performed to identify linear geologic features and lineament density. Directional edge enhancement techniques using convolution kernel were applied to Band 5 to enhance lineament in NW, N-S and E-W compass directions which act as conduit for ground water recharge. The result indicates that NE-SW is the most predominant lineament trend and a few along NW-SE direction. The hydrogeomorphologic and groundwater potentiality of the area were studied using ILWIS 3.2 and Surfer 8 workstations. Hydrogeomorphological analyses of the area was also carried out using visual interpretation of true and false colour composite (FCC) imagery and field observations. A weightage is assigned to each theme depending on its influence on the storage and movement of groundwater. A knowledge based ranking is assigned to each unit in every theme map, depending on its significance to groundwater occurrence. The cumulative scores have been worked out and the scored pattern has been contoured in preparing the final potential map and classified into five groundwater prospect categories which are further justified by hydrological studies. Based on groundwater potentiality zones, the study reveals that about 13% of the area has good potential; about 58% is moderately good while about 31% of the area has poor ground water potential. The central part reveals favourable environment for higher water yield as well as favourable discharge area for groundwater prospect. The study showed that remote sensing and GIS is an efficient tools for mapping an area for groundwater exploration.

**Keywords:** *lineament, remote sensing, Nigeria, groundwater prospect, GIS*

**Cite This Article:** Kolawole M.S, Ishaku J.M, Daniel A, and Owonipa O.D, "Lineament Mapping and Groundwater Occurrence within the Vicinity of Osara Dam, Itakpe-Okene area, North Central Nigeria, Using Landsat Data." *Journal of Geosciences and Geomatics*, vol. 4, no. 3 (2016): 42-52. doi: 10.12691/jgg-4-3-1.

## 1. Introduction

The potentiality for groundwater occurrence in hard rock areas is influenced by the presence of lineaments [21]. Presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and therefore, can serve as groundwater potential zone [16]. According to Acharya and Nag [1] that the problem of groundwater supply in areas underlain by crystalline rocks still exists and no proper solution has been found so far. The authors went further to stress that water supplying wells have commonly been located on the basin of local geological studies followed by drilling into crystalline rocks with little success rate. Sustainable groundwater supply in basement areas therefore requires lineament analysis for proper sitting of boreholes [14]. Generally, producing wells are located in areas of greater lineament density,

lineament intersection, and degree of lineament connectivity. Lineament analysis has been used extensively for geologic interpretation, particularly since the 1930s with the advent of photogeology [13]; besides satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater like geology, lithology/structural, geomorphology, soils, land use/cover and lineaments. With the advent of remote sensing techniques, identification of the occurrence of groundwater has become a rapid and cost effective procedure [1]. Lineaments that may act as conduits for fluid flow are of particular importance in this investigation.

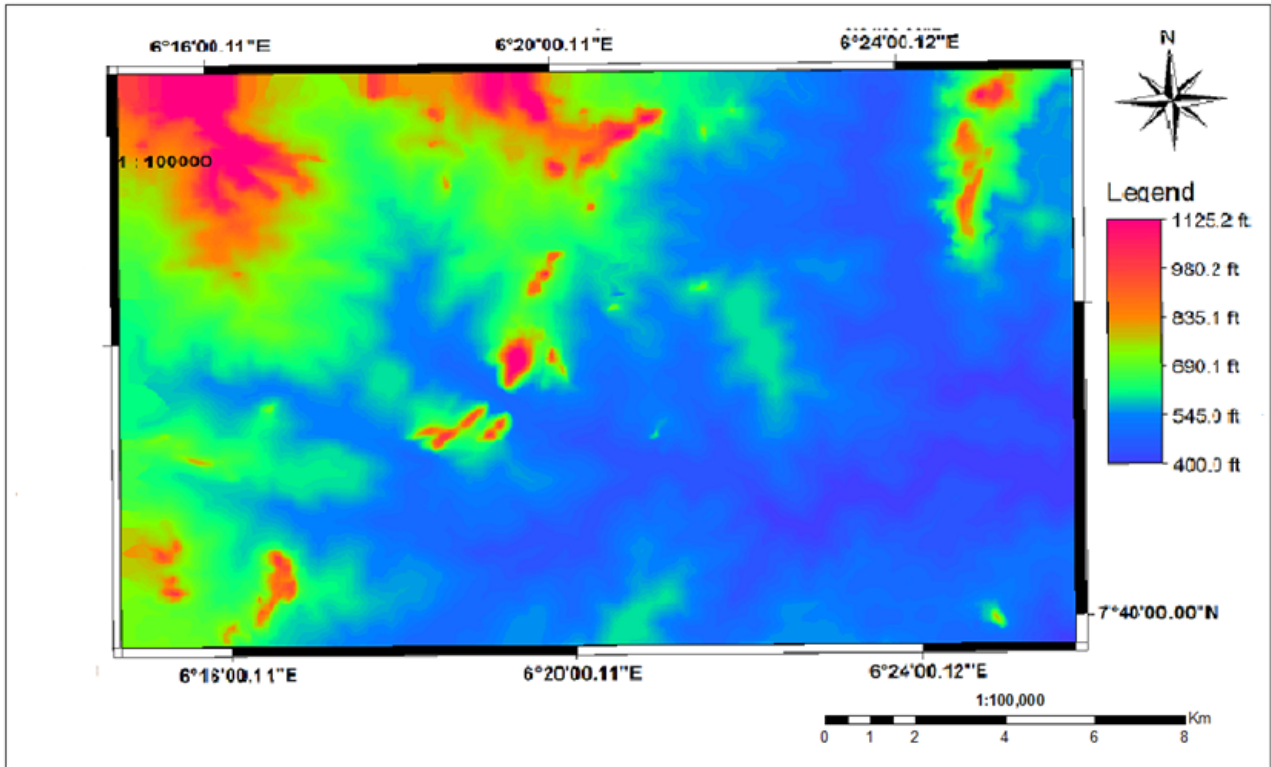
In this study, several image processing procedures and visual interpretation of Landsat MSS imagery were used to delineate geologic lineaments, hydrogeomorphological units, lineament density and ground water potentiality in the vicinity of Osara Dam built to supply water to Nigeria Iron Ore Mining Company (NIOMCO), Itakpe in an ILWIS 3.2 and Surfer 8 workstations.

## 2. Study Area

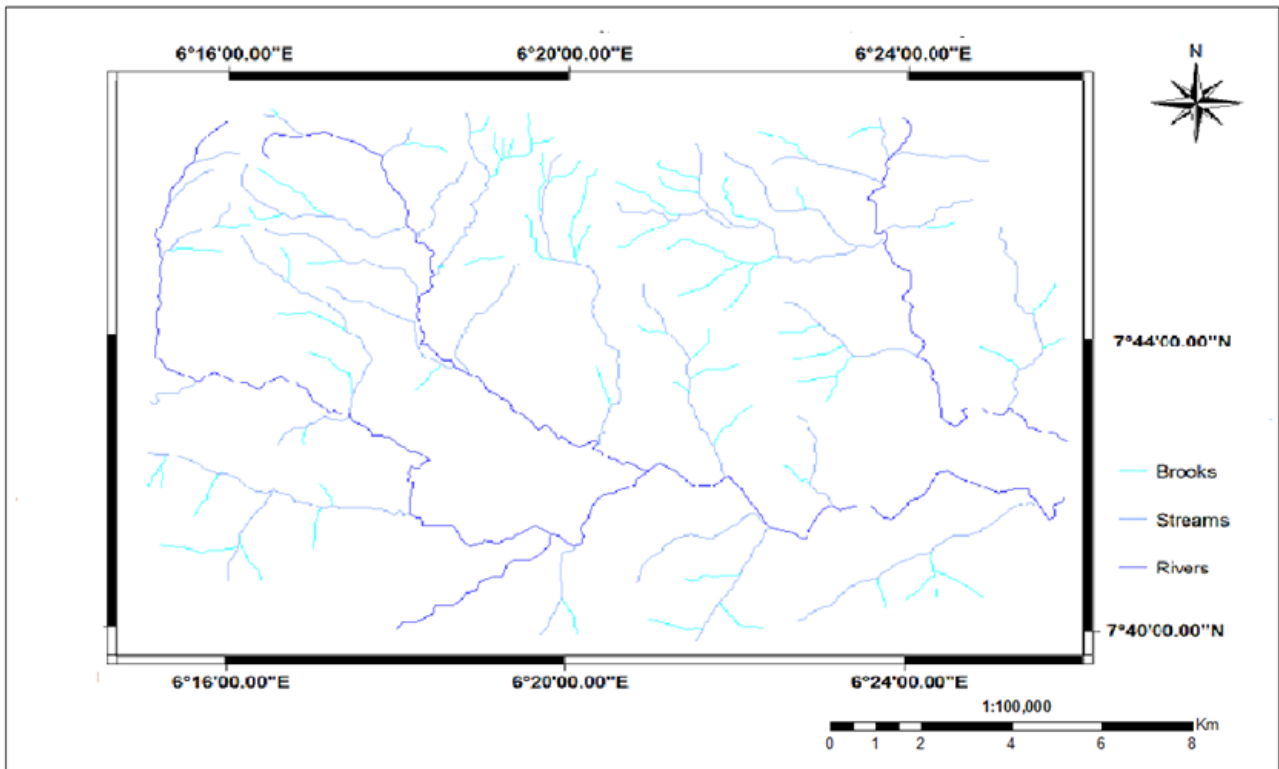
### 2.1. Location and Geomorphology of the Study Area

The Osara dam is located in Okehi Local Government area of Kogi State in the north central part of Nigeria. The study area is bounded between Latitudes  $7^{\circ} 40'$  and  $7^{\circ} 47'$

North of equator and longitudes  $6^{\circ} 15'$  and  $6^{\circ} 26'$  East of the Prime Meridian and contains the dam site (Figure 1). The Dam site is situated about 6km north of the NIOMCO and it is accessible through Lokoja-Okene highway and Abobo-Dam untarred road. The outcrops in this area were accessed through these routes and cattle tracks, footpaths, and river and stream channels.



a.



b.

Figure 1. Showing (a) DEM map from digitized topographic map and (b) Drainage pattern map of the study area

The iron ore deposit mined by this company forms prominent ridges that is approximately 1 km wide and 5km long and reaches a maximum elevation of about 500m above the surrounding lowland which is 200 m above sea level (Figure 1a) and dendritic drainage pattern (Figure 1b). The granitic rocks and gneisses in the area also occur as inselberg or low lying. The vegetation is typically a southern savanna with long grasses and shrubs. Annual rainfall in the area ranges from 1524 to 1916 mm in May to October, with surface temperature of about 27°C [18].

## 2.2. Geological Setting

The study area is located within the southwestern Basement Complex of Nigerian which forms part of the Pan- African mobile belt that is situated between the east of the West African Craton, north-west of the Congo cratons and south of the Tuareg Shield as defined by Black et al [5]. The basement rocks comprise of

crystalline complex of gneisses, migmatites and quartzites (>2000 m.y.), overlain by sequence of low-grade metamorphic rocks (~800m.y. old), and intruded by a suite of granitic and charnockitic rocks (~600 m.y. old). The geology of the area consists of strongly foliated gneiss of granodiorite composition with alternating dark (biotitic and/or hornblende) and light (quartzo-feldspathic) bands [18]. Other varieties of gneisses mapped in the area, according to him, are of granite compositions that contain either biotite or biotite-hornblende as the dominant mafic minerals consisting of fine-grained leucocratic gneiss that consist of about 70% of quartz, 25% of microcline and 5% of biotite that forms a major topographic feature and structural marker unit in the area (Figure 2). The iron – bearing rocks in the area can in part be considered as ferruginous quartzites that comprise alternating bands of quartz and iron oxides. Intrusive rocks include gabbro, biotite-hornblende granites, pegmatites and numerous lamprophyre dykes [18].

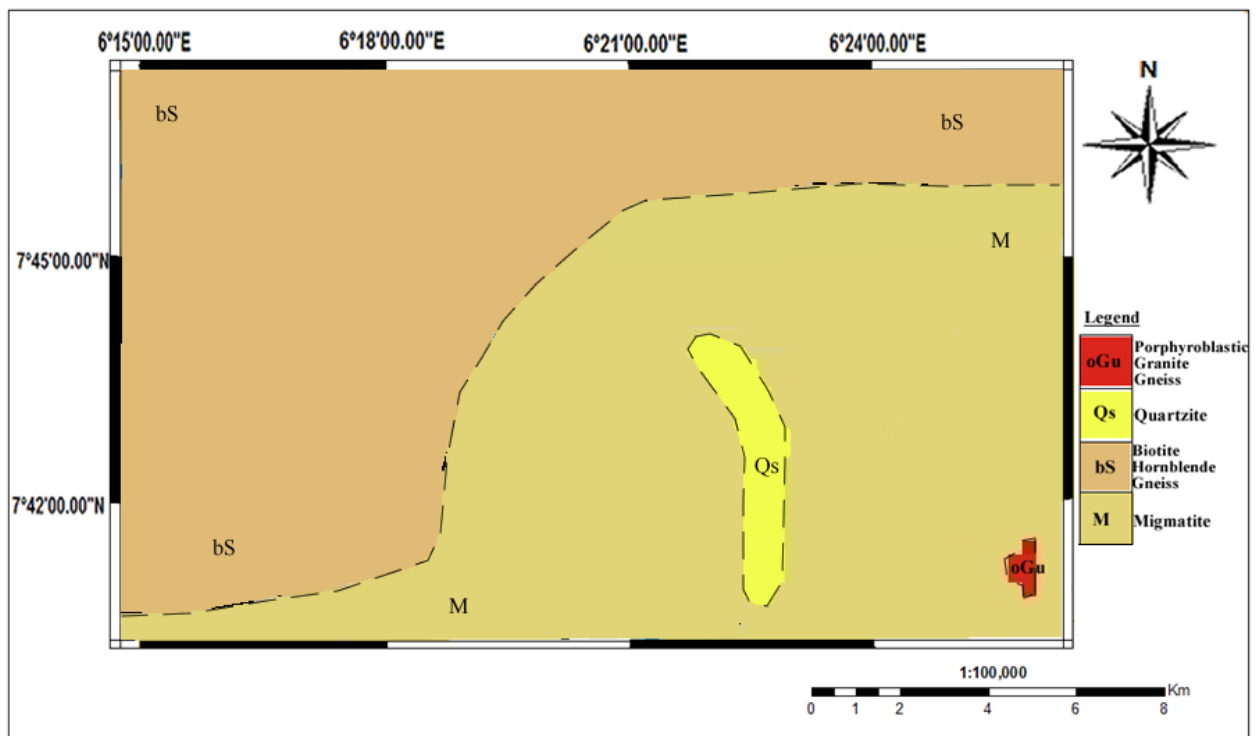


Figure 2. Geology Map of the Study Area

## 3. Materials and Methods

The Landsat MSS image of the area used was acquired on 21<sup>st</sup> April, 1992 and processed at National Remote Sensing Centre, Jos Nigeria. This data was used due to data available as at the time of this study and because the aspect in which the data was applied is independent of the time the data was acquired. The sub-scene covers approximately 1000km<sup>2</sup> including the dam site that occur at the southern portion of the area.

The methodology used was based on GIS approach; where digital layers of topographic, drainage, lithology, and geological structure maps were used to derive the sites with high prospect for groundwater exploration, and on DIP approach; i.e. digital Image processing of remote

sensing data to identify the spectral class that was highly correlated with the sites identified by the GIS tools.

### 3.1. Data Preparation

The hard copy of the topographic, drainage, lithology, and geological structure maps covering the study area were scanned at a scale of 1:100,000 and geo-referenced using GIS tool.

### 3.2. Hydrogeomorphological Study

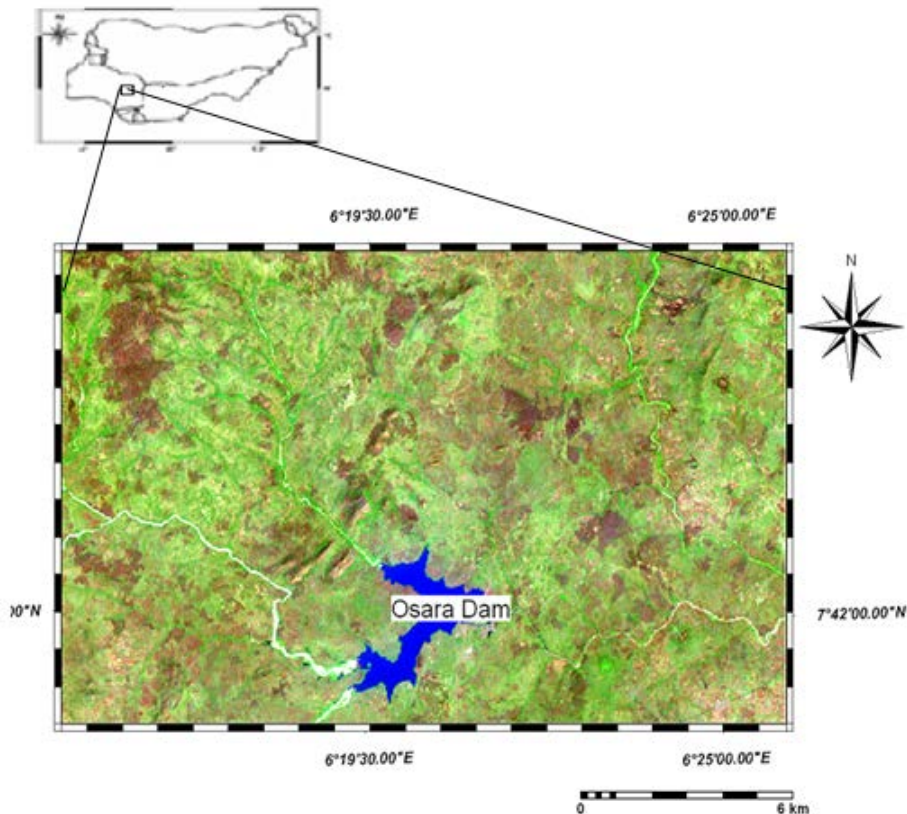
The lithology and structures of the underlying formations has a great influence on the hydrogeomorphology. The study area is dominantly a rocky terrain and is characterized by a number of erosional and depositional hydrogeomorphic features manifested by uplands and undulating surfaces. Visual interpretation of satellite,

using FCC (Figure 4) image classification reveals several lighter, intermediate and darker tones indicating the significantly identified hydrogeomorphic units i.e. alluvial plain, valley fills, plateau, buried pediments, pediments,

Intermontane valley etc (Table 1). The weathered pediments, buried under soil-cover, represent the features formed by erosional process while the depositional processes have developed landform as valley fill.

**Table 1. The weightage criterion for groundwater potentiality.**

Hydrogeomorphic Units	Description (Field Observation)	Image characteristics on FCC image (Figure 3)	Ground water
<b>Alluvial Plain (Ap)</b>	Gently sloping tract produced by deposition of alluvial material consisting of gravel, sand, silt and clay of varying lithology.	<b>Tone;</b> Bright red for cropland to white/grey for fallow. Smooth texture, irregular shape, curvilinear outline, contiguous pattern. Extensive cultivation as land use, drainage development negligible. Sharp contact with pediment/buried pediment.	<b>Moderate to good</b>
<b>Valley fills (Vf)</b>	Accumulation zone of colluvial materials derived from surrounding uplands; shallow to deep; fine loamy to clayey soils.	<b>Tone;</b> Light grayish for moisture to dark for natural vegetation. Fine texture, irregular shape and linear, elongated pattern, occupying low-lying area associated with vegetation.	<b>Good to very good</b>
<b>Plateau (Pl)</b>	Flat topped with arcute, showing definite trends. Comprises thin veneer of soil, which varies from place to place. Lineaments are present and quarrying activity at few places	<b>Tone:</b> dark green for rock exposure to white for rock quarrying, coarse texture, irregular shape, linear and contiguous pattern, dominated by linear features. The prominent fracture here are lineament with general trend NE-SW, while few trending NW-SE. sparse vegetation, presence of quarry activity, parallel to subparallel drainage of 1st order channel follow linear fractures.	<b>Poor to moderate</b>
<b>Buried Pediment (Bp)</b>	Unconsolidated alluvial materials fill irregularities on the surface. Mostly vegetated or cultivated lying at foot hills	<b>Tone;</b> light red for cultivated land to red for natural vegetation, fine texture, irregular shape and elongated contiguous pattern. Drainage is sub parallel.	<b>Moderate to good</b>
<b>Pediment (Pe)</b>	Gently sloping surface covered with thin layer of soil at places and have natural vegetation.	<b>Tone;</b> light grey to medium grey, coarse to medium texture, irregular shapes, gently sloping pattern.	
<b>Intermontane valley (Iv)</b>	Depression between the mountains, generally narrow and linear, filled with colluvial and fluvial deposits of varying grain size.	<b>Tone:</b> light for uncultivated land to dark reds for cropland, coarse texture, irregular shape, linear and contiguous pattern, drainage is radial	<b>v. poor to poor</b>
<b>Residual hills (Rh)</b>	Relict hills which have undergone the processes of denudation and acts as run off.	<b>Tone;</b> light grayish to green for rock exposure, coarse texture, shape and size irregular and rounded, contiguous pattern drainage is radial	<b>v. poor to poor</b>
<b>Linear ridge (Lr)</b>	Acts as barrier as well as carrier for ground water flow which represents areas of high runoff.	<b>Tone:</b> Brown to dark, coarse texture, with linear shape and contiguous pattern. Development of 1st order drainage.	<b>v. poor to poor</b>



**Figure 3.** LandSat MSS 642 (RGB) true color composite image of the study area

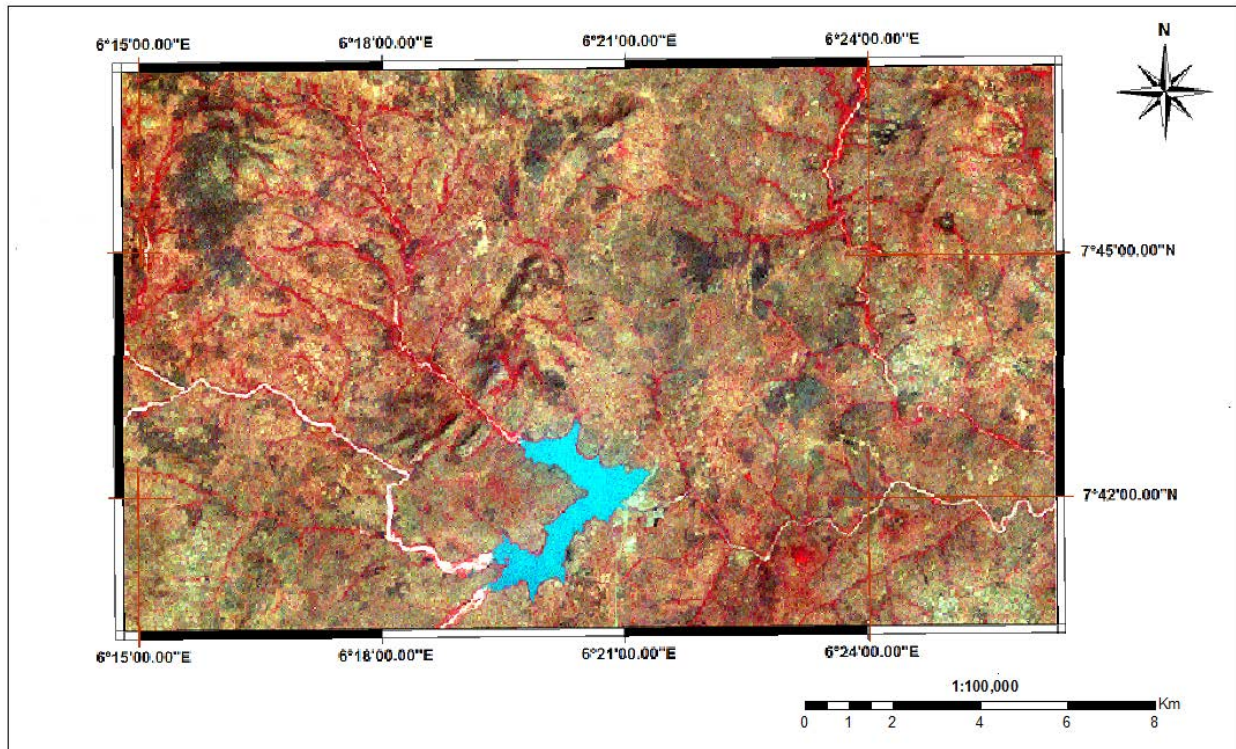


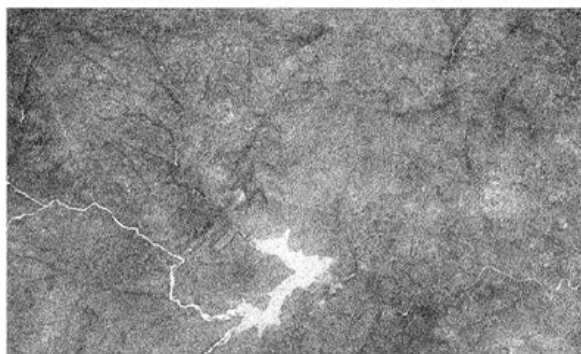
Figure 4. LandSat MSS 432 (RGB) false color composite of study area

### 3.3. Lineament Study

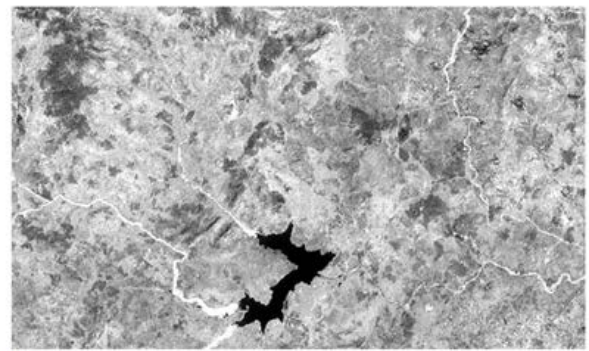
#### 3.3.1. Visual and Composite Images Interpretations

To detect lineaments from Landsat MSS data, two procedures were carried out. Visual (manual) interpretations

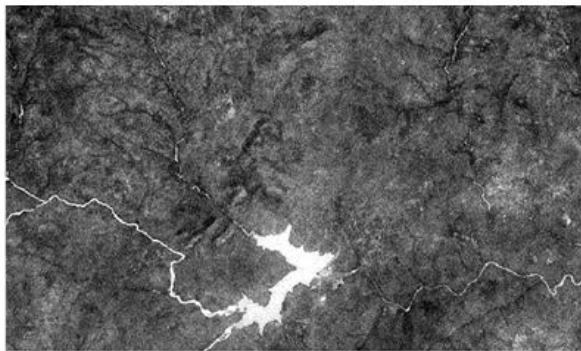
were used to extract geologic lineament using true and false colour composites of bands 6, 4, 2 and 4, 3, 2 of the imagery respectively (Figure 3 and Figure 4), and on individual bands of 1, 2, 4 and 6 (Figure 5).



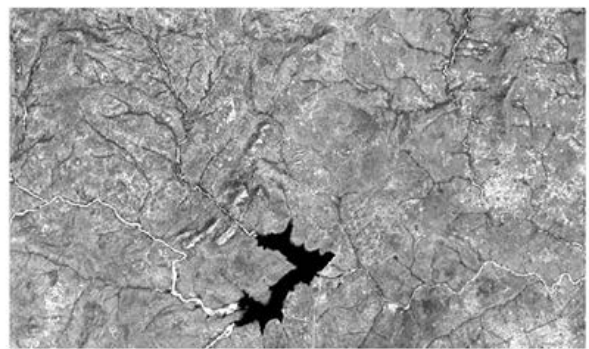
a.



c.



b.



d.

Figure 5. Individual bands of LandSat MSS (bands 1, 2, 4 and, 6 marked a, b, c and d respectively) of the study area

The imagery of the area was also evaluated using various digital image processing techniques. Image

processing techniques used are edge enhancement techniques which include contrast stretching and

directional filtering. Colour bands ratio of 5/6, 5/4, 4/1 (Figure 6a-c) and their composite (Figure 6d) which according to Kavak and Cetin [11] are good in enhancing geological features and to extract structural lineaments. The band ratio image of the scene effectively compensates for the brightness variation caused by the differences in

topography and calculates the slope of the line that passes from the origin of the multispectral space through a particular pixel (ILWIS 3.2 user guide 2001). Lineament recognition criteria such as geomorphologic trends, rectangular, trellis and collinear drainage system patterns and distinct contrast differences were used in this analysis.

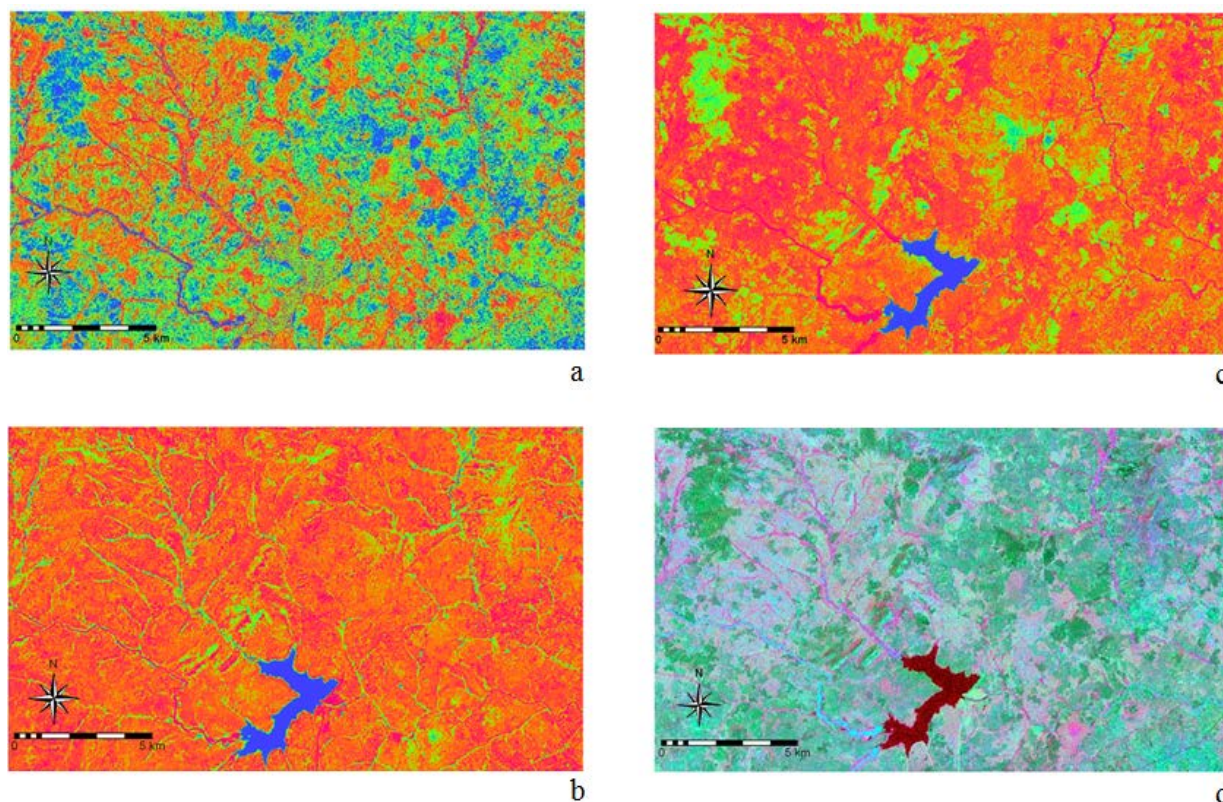


Figure 6. Ratio color composites (5/6, 5/4, 4/1, and RGB marked a, b, c and d respectively) of the study area

### 3.3.2. Rationing Effect to the Determination of Geologic Lineaments:

Figure 5 shows the individual bands, 1, 2, 4 and 6, of the Landsat MSS data set of the region. Several analysis techniques such as visual interpretation and compass gradient enhancement are routinely used for lineament studies. In this study, ratio colour composite subscene images of the region were also used to enhance the lineament systems that were not clearly enhanced by other methods. Ratio images generally enhance different lithologies and features of a region. For example, various kinds of land-cover types such as rocks, vegetation and water are represented in different colours in ratio colour composite images. Geological contacts can be enhanced using different colours that can help researchers interpret lineament systems easily. Figure 6 shows a ratio colour composite image using Landsat MSS 5/6 (red), 5/4 (green) and 4/1 (blue) ratios in RGB form.

### 3.3.3. Directional Filtering

Edge enhancement filters are used in geological applications to highlight faults and lineaments that occur in specific azimuths [11]. The band 5 of the Landsat MSS dataset is one of the best bands showing most of the features in the area and different filter types which enhance particular spatial directions [11]. To enhance such edges, filters are designed to map the contrast gradient

orthogonal to the preferred direction [4] that will detect and highlight diagonal, horizontal and vertical edges in digital images [21]. Directional filters are very useful for producing artificial effects suggesting tectonically controlled linear features [9]. The characteristic of kernel weighted directional filtering is that the distribution of nonzero weighting factors is parallel to the direction and therefore ideal for lineament analysis studies [11].

Table 2. Weighted Kernel Types of Directional Filters Used in this Study (after Kavak and Cetin [11])

.....NW.....			.....N-S.....			.....E-W.....		
-1	-1	0	-1	-1	-1	-1	0	1
-1	0	1	0	0	0	-1	0	1
0	1	1	1	1	1	1	-1	1

For this study, several directional filters, NW, N-S and E-W compass filters were selected. Table 2 shows the size and weight of kernels used for the study area. The filters that have been used in this study had 3×3 kernel size which provides a better visual interpretation for every filtering type. Contrast enhancement procedure was also applied to three different edge detection filters. Later, filtered images taken from NW, N-S and E-W were displayed in RGB color space mode Fig. 7. Visual interpretation and digital image processing methods had very high correlation in this lineament analysis based study. Filtering directions were selected according to the features of the thermotectonic events that dominate in the area.

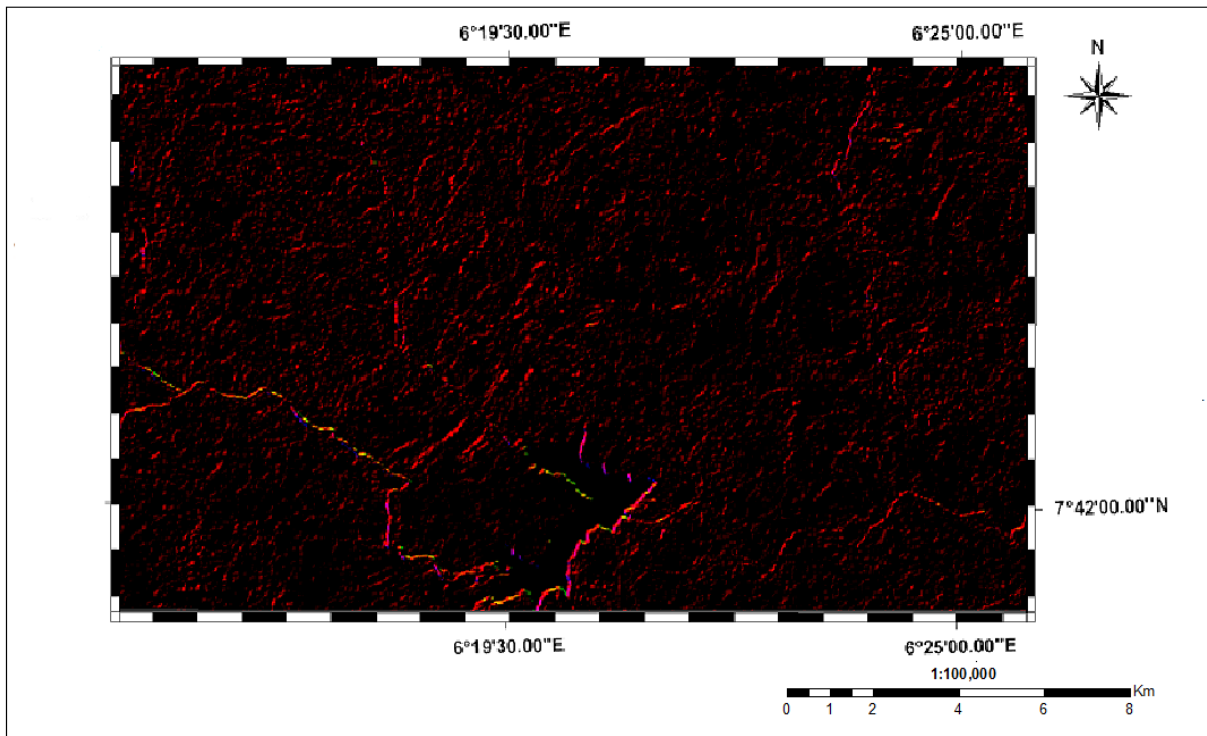


Figure 7. RGB (NW, N-S, E-W) color composite image of directional edge detection filtering on Band 5

### 3.3.4. Lineament Density Map

The lineament map was rasterized to derive the lineament count (per km<sup>2</sup>), the length density (m/km<sup>2</sup>) and thereafter used to draw the lineament density map.

The lineament map of the study area was subdivided into a number of grids of dimension 1 km x 1 km. Each grid cells having an area of 1 sq km and containing approximately 1811 pixels. The density of the lineaments of a single grid was obtained from the values of the total length of the lineaments in a single grid ( $\sum L$ ) and the area of that single grid (A).  $\sum L/A$  are located at the centre of the corresponding grid to prepare the lineament density map [1].

### 3.4. Data Integration

The main objective of this work is to find the suitable groundwater potential zones by overlaying the geomorphologic map, lineament map, lineament density map and lithological map of the study area, using weighted index overlay analysis [15]. Weighted Index Overlay Analysis (WIOA) [1] is a simple and straightforward method for a combined analysis of multi-class maps. A weight represents the relative importance of a theme vis-à-vis the objective. WIOA method takes into

consideration the relative importance of the themes and the classes within each theme [1]. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each theme should be assigned importance [23]. Determination of weightage of each theme is the most crucial in integrated analysis, as output is largely dependent on the assignment of appropriate weightage [1].

The equation used for calculation of groundwater potentiality index at any location of the area is given below: Groundwater potentiality index = weightage% x (Rank of the hydrogeomorphological unit) + weightage% x (Rank of the lineament density) + weightage% x (Rank of the lithological unit) (adapted from Acharya and Nag [1] and Nag [15]). The groundwater potentiality index is calculated for each grid of dimension 1 km x 1 km in the study area. Therefore, the study area has been classified into grid cells, each having a unique groundwater potentiality index value, revealing a contour map from those values showing groundwater potentiality of the area using the Surfer software, good zones (occupying 10% of the total area) which is again surrounded by an area of moderately good zone (occupying 70% of the total area) and poor zone (occupying about 25% of the area).

Table 3. The weightage criterion for groundwater potentiality

Theme	Rank								Weightage %
	4		3	2		1			
Hydrogeomorphology	Ap	Vf	Bp	Pd	Pe	Iv	Rh	Lr	50%
Lineament Density	H		M	L		V.L			40%
Lithology	oGu	Qs	M	bS					10%

H-High, M-Moderate, L-Low, V.L-Very low.

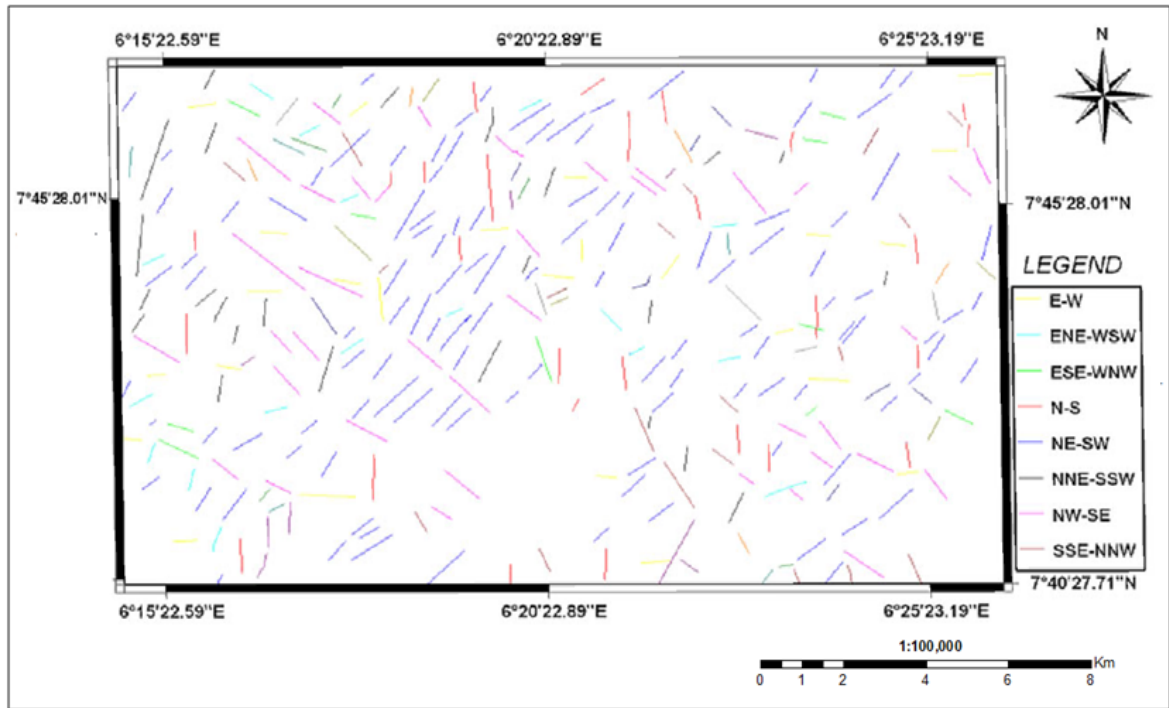
## 4. Results

Four main rock units were identified in the study area, namely granite gneiss, quartzite, mica gneiss and

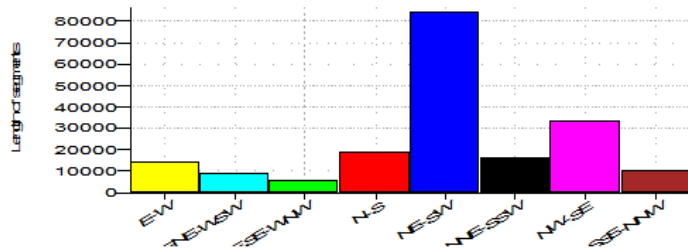
migmatite (Figure 2). These rock units shows different structural elements like foliations, lineaments etc.

From the remote sensing imageries processed about 320 geologic lineaments were extracted and interpreted visually using the RGB colour composite ratio bands and RGB directional filter band in the study area (Figure 8a).

Another approach that has been used by Qari [20] is shown using an azimuthally histogram bar (Figure 8b).

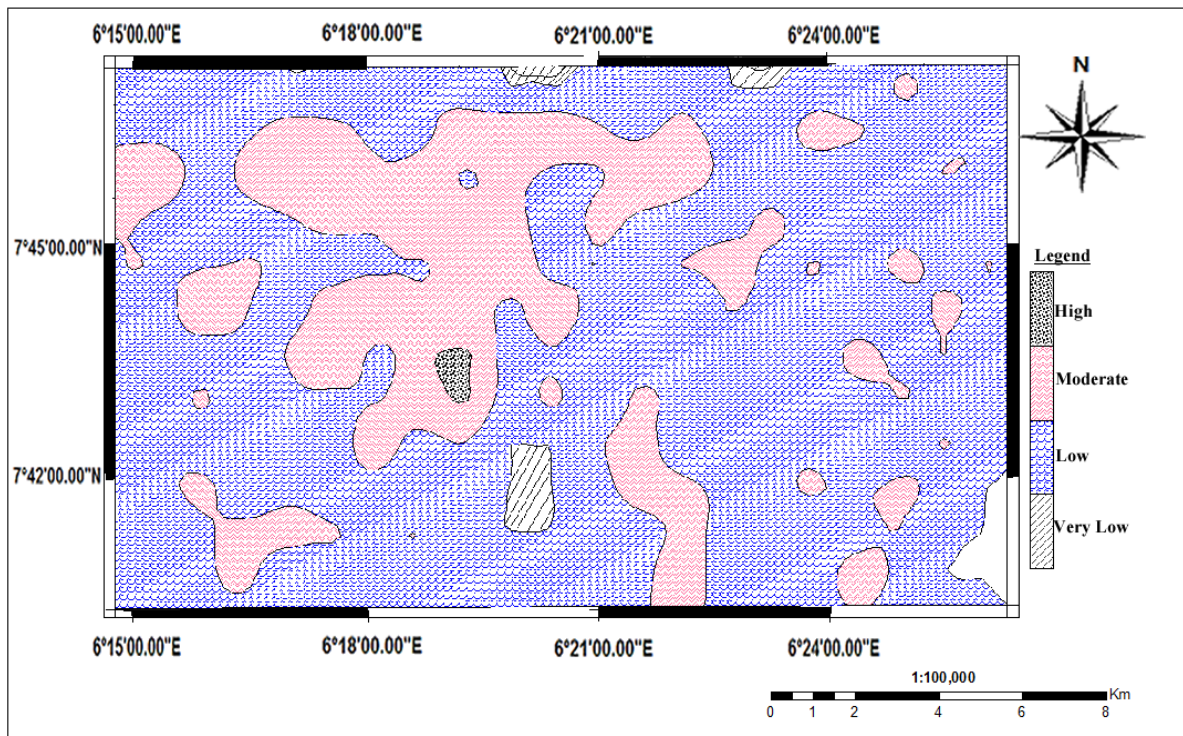


(a)



(b)

**Figure 8.** Derived lineament system from these imageries (a) and bar histogram showing the distribution of lineaments based on length of segments and azimuthal direction (b)



**Figure 9.** The lineament density map



The values of lineament density are designated as very low (< 3), low (3-6), moderate (6-9) and high (9-12). These values were plotted as a contour map representing the lineament density map, using surfer 8 (Figure 9).

Based on the visual interpretation of FCC satellite imagery using Table 1, the hydrogeomorphological map of the area is presented in Figure 10.

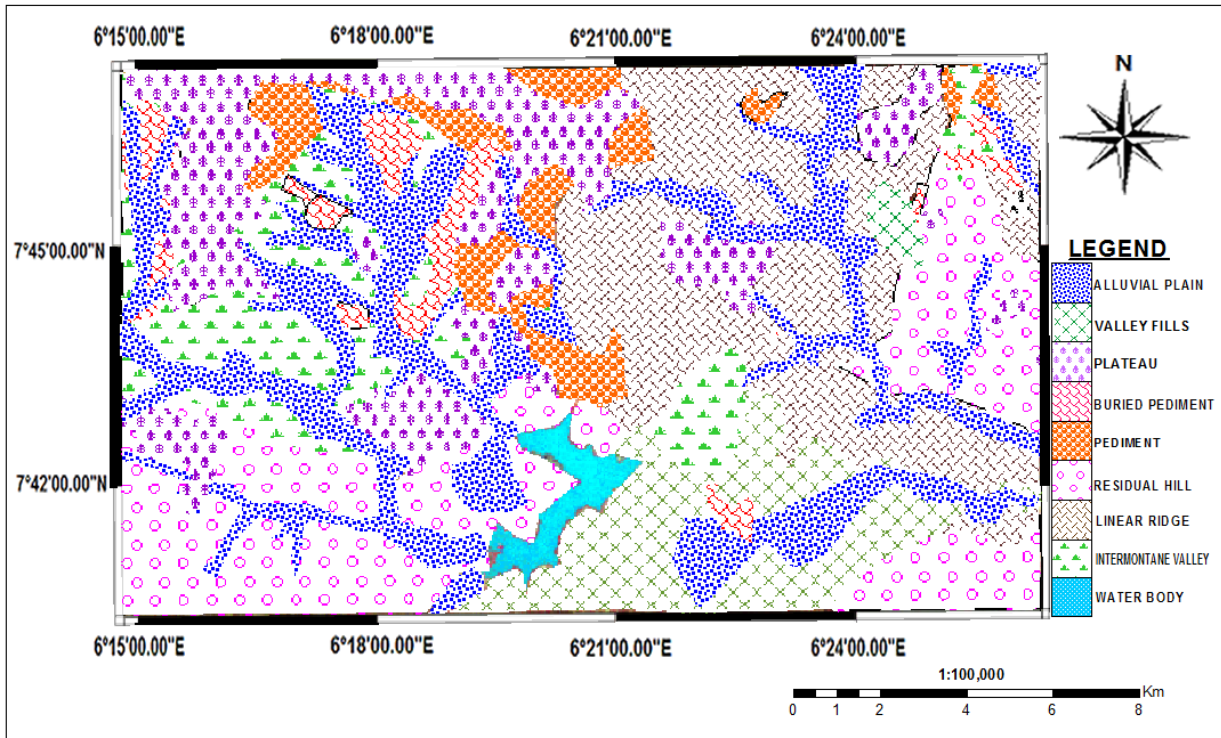


Figure 10. The hydrogeomorphological map of the area

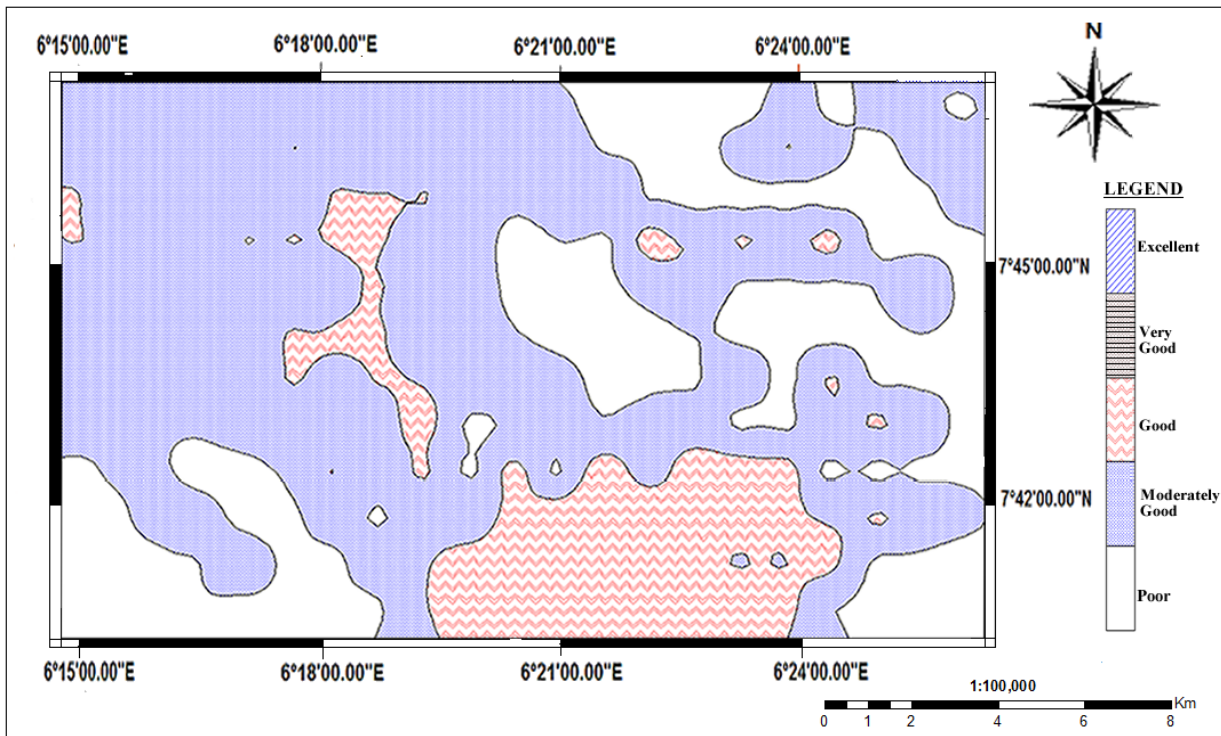


Figure 11. The groundwater potentiality map of the study area

The groundwater potentiality map drawn by contouring of the values obtained from the integration of data (by overlaying of the three thematic maps presented above (Figure 2, Figure 9 and Figure 10)) and application of the equation using Table 3 is presented in Figure 11.

## 5. Discussion

The groundwater yield of these crystalline rocks is directly dependent on the degree to which the rocks has

been fractured. Presence of weak planes in the rocks makes them susceptible to develop secondary porosity. Contact zones between crystalline-rock types are also favorable places for the location of wells yielding large volumes of water. Wells that penetrate no fractures will yield little or no water. Wells that penetrate only a few small, shallow fractures initially may have an adequate yield; however, after the fractures are drained, well yield can suddenly decrease and the sustained yield may be small. Wells that penetrate only one large fracture have similar yield characteristics. Wells that penetrate several small fractures as well as one large one probably will have a large sustained yield. Wells that penetrate intensely fractured rock will be the most dependable in terms of sustained yield. Steeply inclined fractures are commonly expressed at the land surface as lineaments, Wells drilled along such lineaments or along known fracture traces, consistently yield more water than randomly located wells.

Most of the lineament clusters in the central part of the area and are N 20°-30° E and N 60°-70° E trending lineaments. In this study, NE-SW dominates the structural trend followed by NW-SE and N-S (Figure 8b). This can be an indication of the directions of groundwater movement in the area. The research findings of Owoade and Moffat (1989) in determining the groundwater prospects in South-Western Nigeria corroborate the above hydrogeological deduction which emphasized that groundwater movement and its accumulation always explored the fissures/fractural/weathered column of the basement rocks.

From Table 3 and the hydrogeomorphological map (Figure 10) alluvial plain and valley fills have moderate to very good groundwater potential that occur all over the study area. Proximity of the regolith varies greatly, but it is everywhere more porous than the underlying, unweathered bedrock.

The porosity of the regolith is much greater than that of the bedrock, the regolith has the capacity to store a much larger volume of water. The regolith and bedrock fractures are directly connected to form an integrated ground-water flow system in which the regolith functions as a reservoir, providing water to the interconnecting fractures in the bedrock. Even though wells in crystalline-rock areas are ordinarily cased through the regolith, the fracture-regolith interconnection allows water stored in the regolith to move vertically into the fractured rock and then through the fractures to the well. The water table is at or near the land surface in valleys and adjacent to lakes, ponds, and wetlands.

Based on groundwater potentiality zones, the study reveals that about 13% of the area has good potential; about 58% is moderately good which corresponds to high to moderate lineament densities while about 31% of the area has poor ground water potential corresponding to low lineament density areas.

## 6. Conclusions

The study showed extensive NE-SW trending lineament systems most of which were clustered in the central part of the region corresponding to one of the imprints of Pan-African orogeny. Principal fractures directions in the area

are in the N-S, NNE-SSW, NNW-SSW and NW-SE and to a lesser extent E-W, with the N-S fractures.

The groundwater potential zones indicate that about 13% of the area has good potential; about 58% is moderately good which corresponds to high to moderate lineament densities while about 31% of the area has poor ground water potential corresponding to low lineament density areas. The central part reveals favourable environment for higher water yield as well as favourable discharge area as a consequence of high lineament density.

Results from this study showed that lithological, lineament density and hydrogeomorphological analysis are very effective in identifying promising sites for groundwater exploration using GIS and remote sensing technique. Therefore these tools and data sources would be recommended for groundwater exploration, as they would provide timely and cost effective tools for identifying and narrowing the target areas for groundwater exploration before carrying out further investigations.

## Acknowledgement

We thank the National Remote Sensing Centre, Jos Nigeria for making the imageries available for this work. We gratefully acknowledge the reviewers for their critical and constructive comments on the manuscript.

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