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# Remote Sensing (RS) and Geographical Information System (GIS) for Detecting Groundwater Potential Zones at Wadi Elmilk Area, North Kordofan State, Sudan

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**Abstract:** Remote sensing and GIS technology are great important for use in groundwater potential analysis. The current study has applied techniques to delineate the groundwater potential zones besides improving the allocation of drilled boreholes in order to integrate water resources development and management for Wadi Elmilk, Sodari, North Kordofan state, Sudan. Five thematic layers were prepared they are geology, structure, topography, drainage density and slope, extracted and then classified according to their importance with respect to ground water occurrence and weight are assigned through geographic information system. Landsat 8 ETM+ images and Digital Elevation Models (DEMs) were used in this study. The geology of the area is composed of basement complex followed by Nubian Sandstone covered by sand sheets. Mosaic of four landsat images ETM+8 were obtained for the geological features. Drainage and lineaments were studied to recognized groundwater occurrence. The slope amount map was derived from the DEM. In the study area, mainly 5 lineaments density categories have been identified and mapped. Reclassified amount of slope, lineaments density, drainage density account maps and in addition to Rose diagram of the lineament frequency were obtained. The conclusion that the groundwater potential zone in the area is related to deep basement, have certain geologic structure and presence of faults, cracks, joints and lineaments and the two prominent lineament directions: NE from SW are the major structural trends in the central Sudan and is most likely related to the Central African Shear Zone. It is recommended that more detailed studies should be conducted in order to check all the information extracted from remote sensing data and Radar.

**Keywords:** GIS, Groundwater Occurrence and Potential, Lineaments or Fracture Zones Sudan

## 1. Introduction

Remote sensing and GIS technology are great important for use in groundwater potential analysis. Remote sensing, encompassing the study of satellite data and aerial photographs, is an extremely powerful technique for earth resources exploration, mapping and management. It involves measurements of electromagnetic (EM) radiation in the wavelength range of about 0.4 µm–1 m, from sensors flying on aerial or space platforms to characterize and infer properties of the terrain. Remote sensing has evolved primarily from the methods of aerial photography and photointerpretation used extensively in 1950s–1960s. The technique has grown rapidly during the last four to five decades. In the context of groundwater studies, remote sensing is of great value as a very first reconnaissance tool, the usual sequence of investigations being: satellite images—aerial photographs—geophysical survey— drilling. Geological interpretation derived from aerial photos/remote sensing has been extensively used for the purpose of identification of lineaments or fracture zones along which flow of groundwater may take place and for landform investigations suitable for groundwater prospecting particularly in hard rock's [4].

In the context of groundwater exploration, the various surface features or indicators can be grouped into two categories, the first order indicators are directly related to the groundwater regime, recharge zones (Rivers and Lakes), discharge zones (Springs, soil moisture and vegetation) [16]. The second order indicators are indirectly related to groundwater regime regionally such as rock types, structures, fractures, and landform and drainage patterns.

The distinct zones where lineament and fracture domains of similar. However, not all lineaments show a uniform correlation with fractures in the bedrock, therefore, only some can be considered fracture- correlated lineaments.

The chief advantages of remote sensing technique over other methods of data collection as following:

1. Synoptic overview: remote sensing permits delineation of regional features and trends.
2. Feasibility: in some inaccessible areas, remote sensing may be the only way to get the information.
3. Time saving: The technique saves time and manpower as information about a large area is quickly gathered.
4. Multidisciplinary applications: the same remote sensing data can be used by workers in different disciplines of natural sciences.

Groundwater is considered as one of the major source of water in the study area. GIS provided an excellent tool for the integration of various thematic and spatial layers for fast and economical detection of the groundwater potential zones.

## 2. The Study Area

The study area is located in Wadi Elmilk-Sodari area within North Kordofan State in North Western Sudan. It bonded by longitudes 28° 15` to 29° 15` E and latitudes 14° 15` to 15° 30` N and it covers an area of 14000 km2, (figure 1). Ground surface is generally low relief plain, undulated with stationary or mobile sand dunes and generally inclined from SW to NE. Many rocks outcrop of small heights in the area. Climate is predominantly semi-arid whereas the main monthly temperature ranges from 13°C to 47°C; annual rain fall 74 to 562 mm/y. According to the natural conditions in the area, drainage system is very poor; the rain percolate in sand dunes or gathers in some depression, so most of the water courses are temporary characters.

Groundwater is the only source of drinking water in the study area however; salinity is a problem that affects its usages.

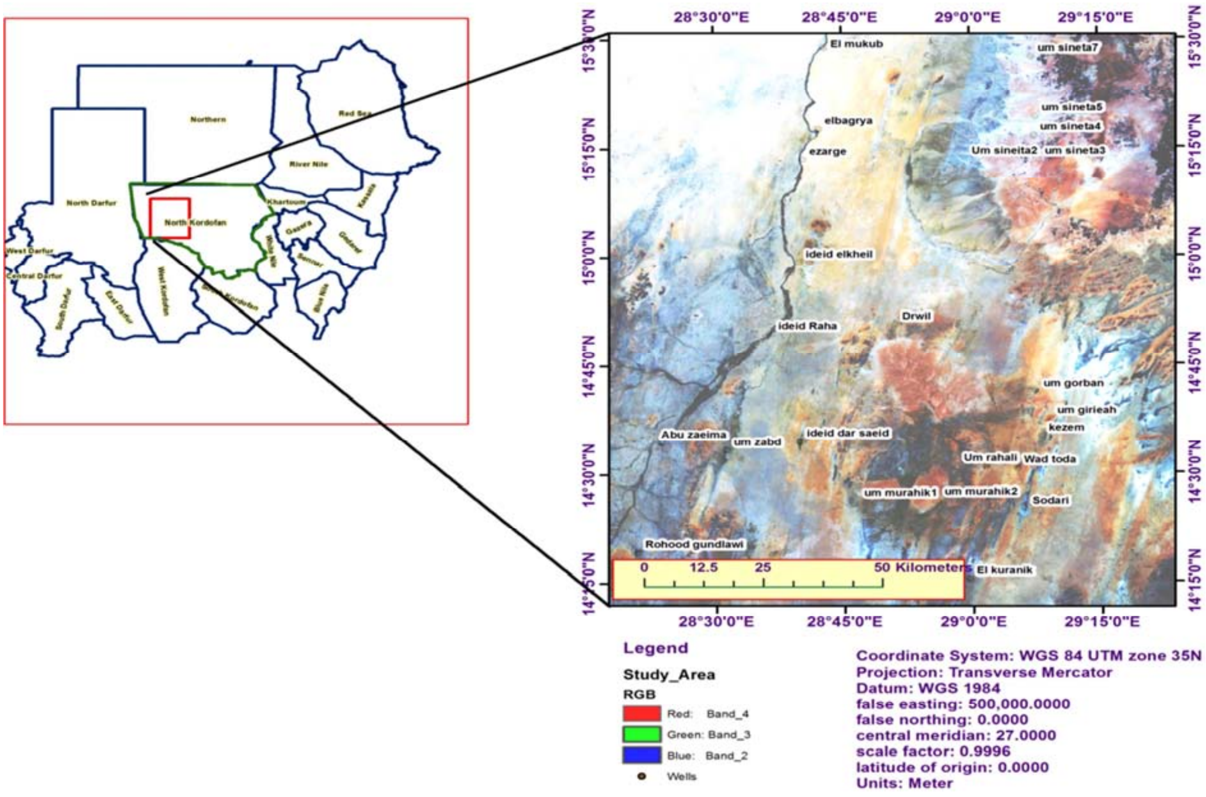



***Figure 1.*** *Location of the study area.*

## 3. Objectives of the Study

The main aim of the study for detecting the ground water in between the structure elements: Faults, Folds, Fractures and Joints. Studying drainage and lineaments to recognized groundwater occurrence. Studying surface topography and slopes to delineating the recharge rate.

## 4. Methodology

1. Landsat 8 ETM+ images with 30 m spatial resolution and Digital Elevation Model with one thermal band 60 m spatial resolution was used in this study and different thematic maps were prepared.

2. All the prepared primary input maps (lineation, geology and lineaments density) have been digitized in Arc GIS software package and the slop map, drainage system were prepared from the digital elevation model and Landsat 8 ETM+ images and the geological features were obtained from the Mosaic of four Landsat images 8 ETM+ [8].
3. Global Land Cover Facility web site was used to obtain Satellite mosaic image that covered the study area. In this study satellite images were processed by ENVI for data file preparations and digital image processing.
4. Digital Elevation Models (DEMs) was used to delineate the regional topography of the study area.

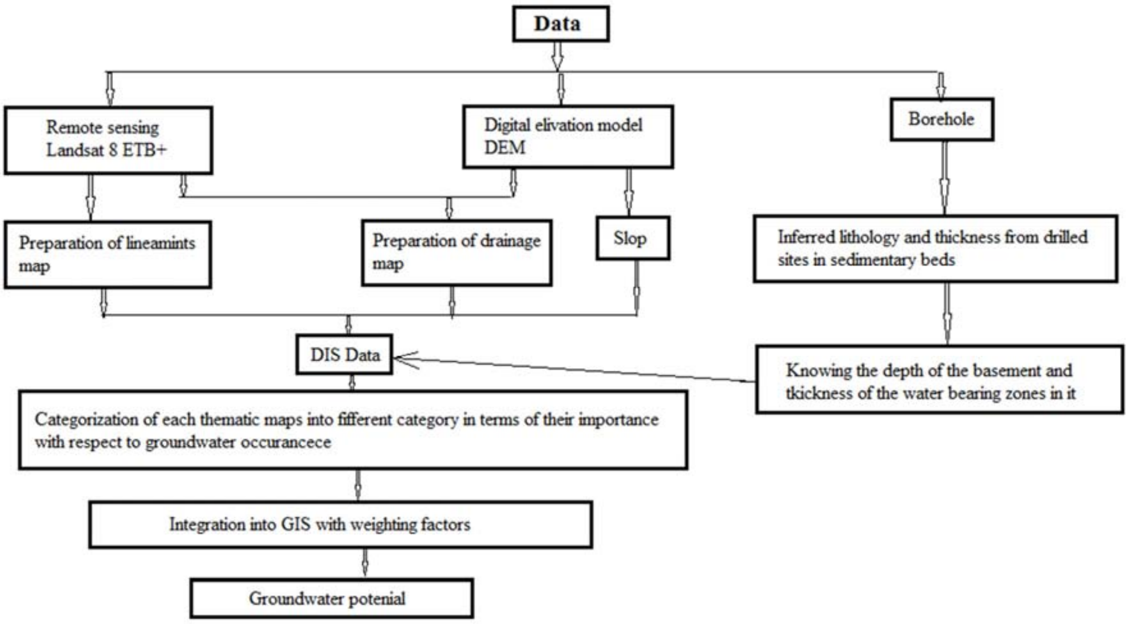



***Figure 2.*** *Flow chart showing data flow and different GIS analysis operations.*

# 5. Regional Geology of the Study Area

The main rock unites in the area from older to younger include:

### *5.1. The Basement Complex*

The Basement complex is oldest rock unit in the area (pre-Cambrian to Cambrian). It is formed of granitic gneisses, migmatite gneisses, quartzite and schist in some parts [15]. Jebel Kordofan represents an uplift block of Precambrian Basement rocks on the western side of the fault bounded block on the Umm Ruwaba Basin [5]. The Basement rocks consist of gneisses and schist intruded by fine to coarse – grained granites.

#### *5.1.1. Gneisses*

In the study area they are overlain by a thick cover of superficial deposits the oldest unite in the Basement complex. Locally augen gneisses were identified, particularly in khor ed domaya, umm badir area. They are occurring in small hillocks of weakly foliated grey biotite gneisses and grantitic gneisses in near the umm khirwa village south of J., and they are well exposed to the southwest of El Obeid town at J. Kordofan and east of El Obeid town at J. Kurbage [6].

#### *5.1.2. Metasediments*

The metasediments in the area exhibit well developed schistosity and regional trends compatible with those detected in the gneisses. Without elaboration the following Lithological units were identified within the metasedimentary sequence: graphitic schist, quartzite, mica schist, chlorite schist, phyllite, amphibolites and marbles. Marble are encountered only in the vicinity of El Mazroub village [1].

### *5.2. Nubain Sandstone Formation*

The Nubian outliers have been recorded in J. Karfis, J. Abu rataj (sodari area). the formation is composed of poorly sorted medium to coarse-grained sandstones containing quartz pebbles and feldspars. This formation is widely distributed in Sudan, and is defined as continental sedimentary deposits of late-Cretaceous age (Nubian Sandstone Formation) [14]. They comprise the most potential groundwater bearing formation in Sudan, containing oil bearing strata and are used as building materials [9]. In Sodari-Umm Badr area, these outliers are in the form of small in J. Umm Marahiek near Sodari, J. Meneidra north of Umm Khirwa village and J. El Hamra north of Hamarat Esh Shiekh town. The late –Cretaceous formation lies unconformable on the Basement rocks 70 km west of El Obeid area. In some locations, it is overlain by Umm Ruwaba formation.

### *5.3. Umm Rawaba Formation*

The Umm Ruwaba Formation cover about 20% of Sudan's area overlies unconformably on undulating Basement

Complex and in some cases it rest unconformably the Nubian Sandstone surfaces. The superficial deposits of qoz sand and fluvial deposits overlie this formation and completely cover it, so that its existence and lithology are known only from borehole data collected by the writer from the area. Andrew and Karkanis proposed the name Um Ruwaba Series for thick superficial deposits that occur on the central Sudan, which consist of unconsolidated sands, sometimes gravely, clayey sands, and clays [2]. The maximum thickness of saturated zone do not exceed 335m has been recorded. The writer believes that the increase or decrease in thickness of Umm Ruwaba Series sediments depends largely on the depth of basins and on the irregularity of the Basement erosion surface.

### *5.4. Superficial Deposits*

The processes of weathering of older deposits and erosion of their uncovered parts were active in the geological past as they are today.

The products of such processes cover the surface of the investigated area. The aeolian sand is the biggest part of these sediments and most important member of the superficial deposits according to [12]. It is called Kordofan sand or Qoz sand locally. It is a deposit of unconsolidated surface sand that is covers large areas. Most of the area under consideration is covered by unconsolidated sands which obscures the underlying rocks and impedes travel [7]. Alluvial deposits are found in many wadies and khors as wadi El milk, Khor Abu Gembiel, Khor Ed Domaya and wadi Umm Amad, these are consisting of sands, gravel and clay. Lacustrine deposits are found in El firga and south of J. Abu Asal mainly of calcareous fossil- bearing sediments.

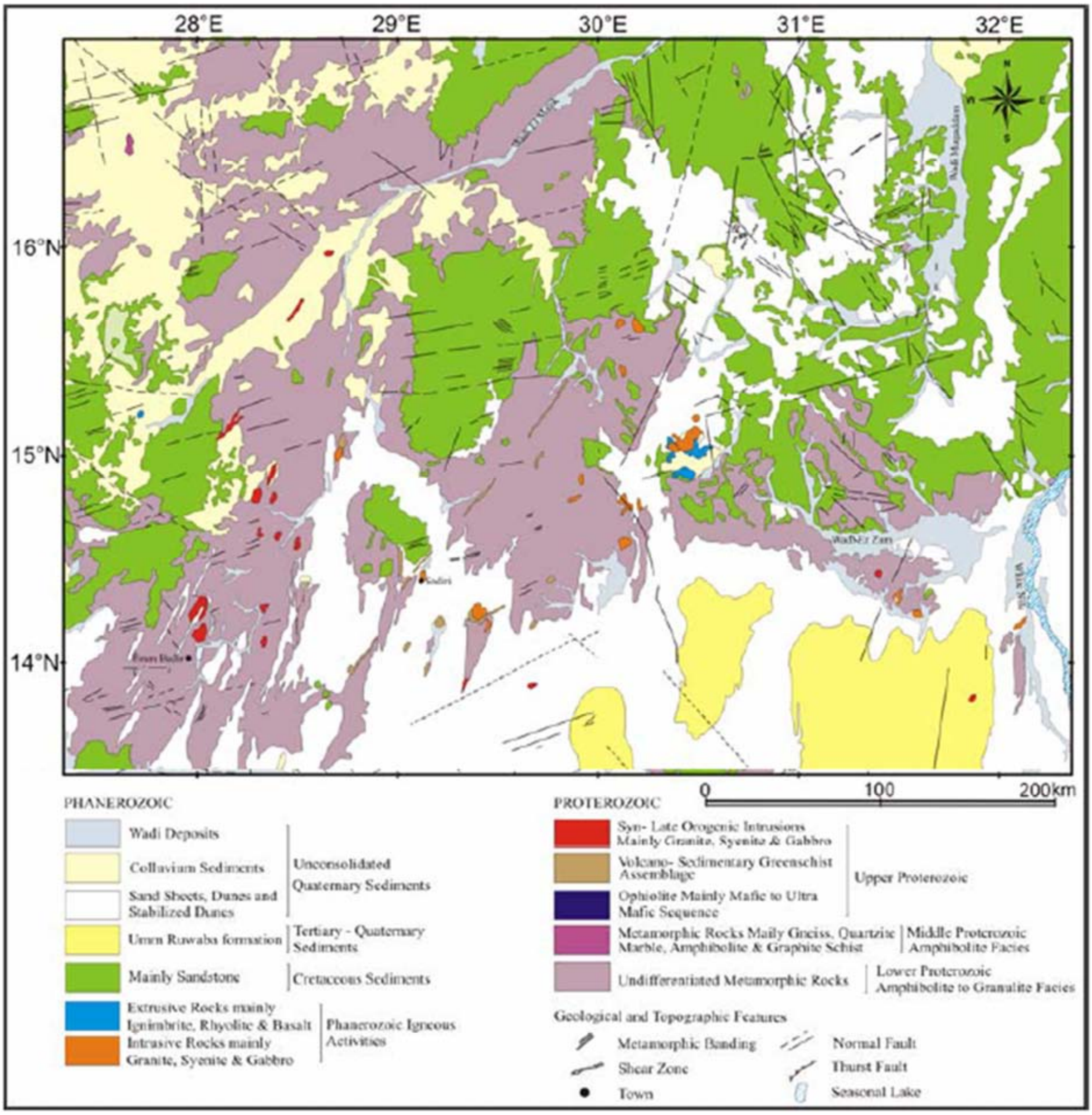



***Figure 3.*** *Geological map of the study area.*

*Table 1. Landsat ETM +8 Dataset.*

| Date of acquisition | Row | Path |
|---|---|---|
| 12/04/2021 | 49 | 175 |
| 12/04/2021 | 50 | 175 |
| 9/04/2021 | 49 | 176 |
| 9/04/2021 | 50 | 176 |

# 6. Results and Discussion

## *6.1. Remote Sensing Data*

Remotely sensed image data are digital representations of the Earth. Image data are stored in data files, also called image files, on magnetic tapes, computer disks, or other media. The data consist only of numbers. These representations form images when they are displayed on a screen or are output to hardcopy. In remotely sensed image data, each pixel represents an area of the Earth at a specific location. The data file value assigned to that pixel is the record of reflected radiation or emitted heat from the Earth's surface at that location. Data file values may also represent elevation, as in digital elevation models (DEMs). Four satellite imagery scene of landsat8 Enhanced Thematic Mapper +, were used in the current study as listed in Table 1.

## *6.2. Digital Mosaic and Subset*

Satellite mosaic image that covered the study area (Figures 4 and 5) were obtained from the Global Land Cover Facility web site, Landsat image digital format were preferred over other satellite data due to the availability of three near- to mid-infrared bands, extremely useful for terrain and lineaments analyses. Furthermore, as Landsat ETM provides eight co-registered spectral channels (one panchromatic with 15 m spatial resolution, six bands ranging from visible to mid-infrared with 30 m spatial resolution, and one thermal band with 60 m spatial resolution), this permitted a large spectrum of band combinations, useful in visual interpretation of different features.

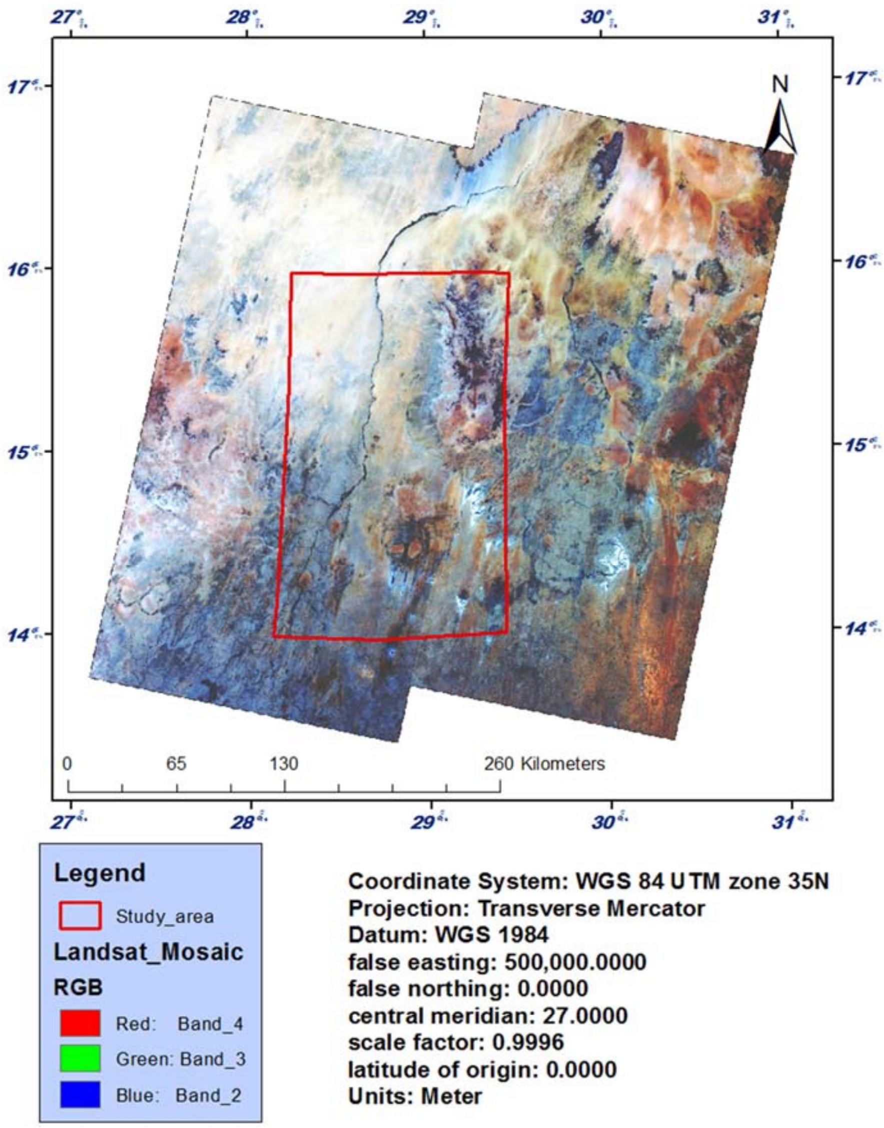



***Figure 4.*** *Mosaic of four landsat images ETM+8.*

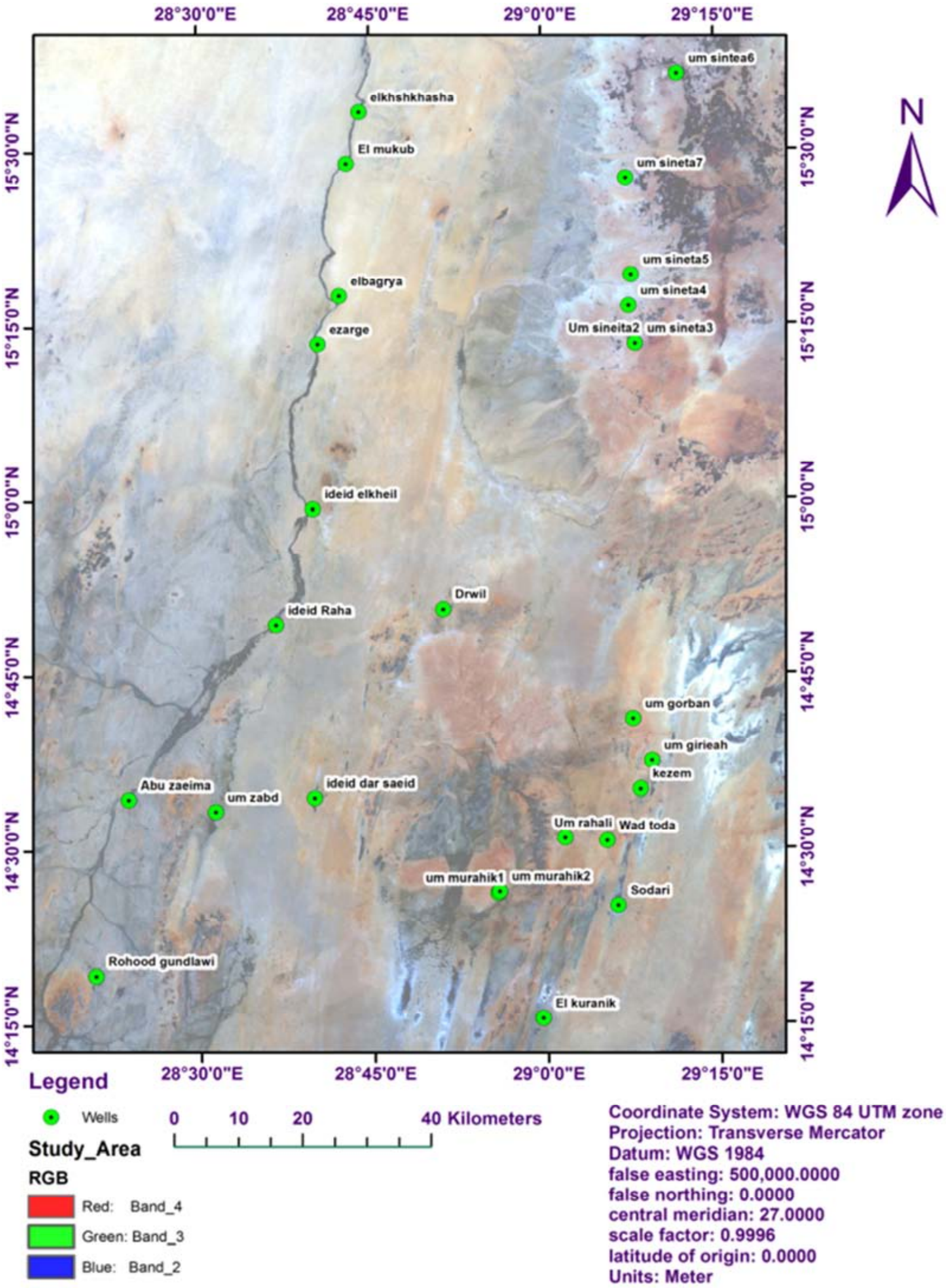



***Figure 5.*** *Subset mosaic of four landsat images.*

### *6.3. Geological Features*

The geological features of the study area are represented by the rock units and soil types, Figures 4 and 5 which enhanced the occurrence and distribution of groundwater. From the hydrogeological point of view, fractures and joints are the most important geological structures. Major fracture zones provide better targets for groundwater than joints because of their greater widths, greater lengths, and better interconnections with other fractures. On the other hand, some discontinuities such as faults and dykes may also act as barriers to groundwater flow [10].

The surface conditions in the study area (Basement complex in the southern, central and eastern part of the study area) are suitable for reconnaissance of structural features (faults, folds, fractures and joints).

### *6.4. Digital Elevation Models (DEMs)*

Surface topography has pronounced influence on groundwater occurrence. Topography also governs basin boundaries. The regional topography is best studied on stereo photographs/images. Besides, topographic maps, multispectral images and radar images are also useful for the study of topography figure 6. Digital Elevation Models (DEMs) forms a very basic and important input in any study of the earth's surface features. DEMs can be obtained in many ways. Digitization of topographic maps followed by interpolation has been a widely used practice for generating DEMs. However, the major short-comings of this are lower accuracy due to deformation of topographic map paper and many generalizations during topographic map preparation, [11]. Geographic projection with decimal degrees (DD) and a WGS-1984 datum was used as a spatial reference for the study area, grid were projected in Albers coordinate system in order to ensure that areas and distances are computed correctly later.

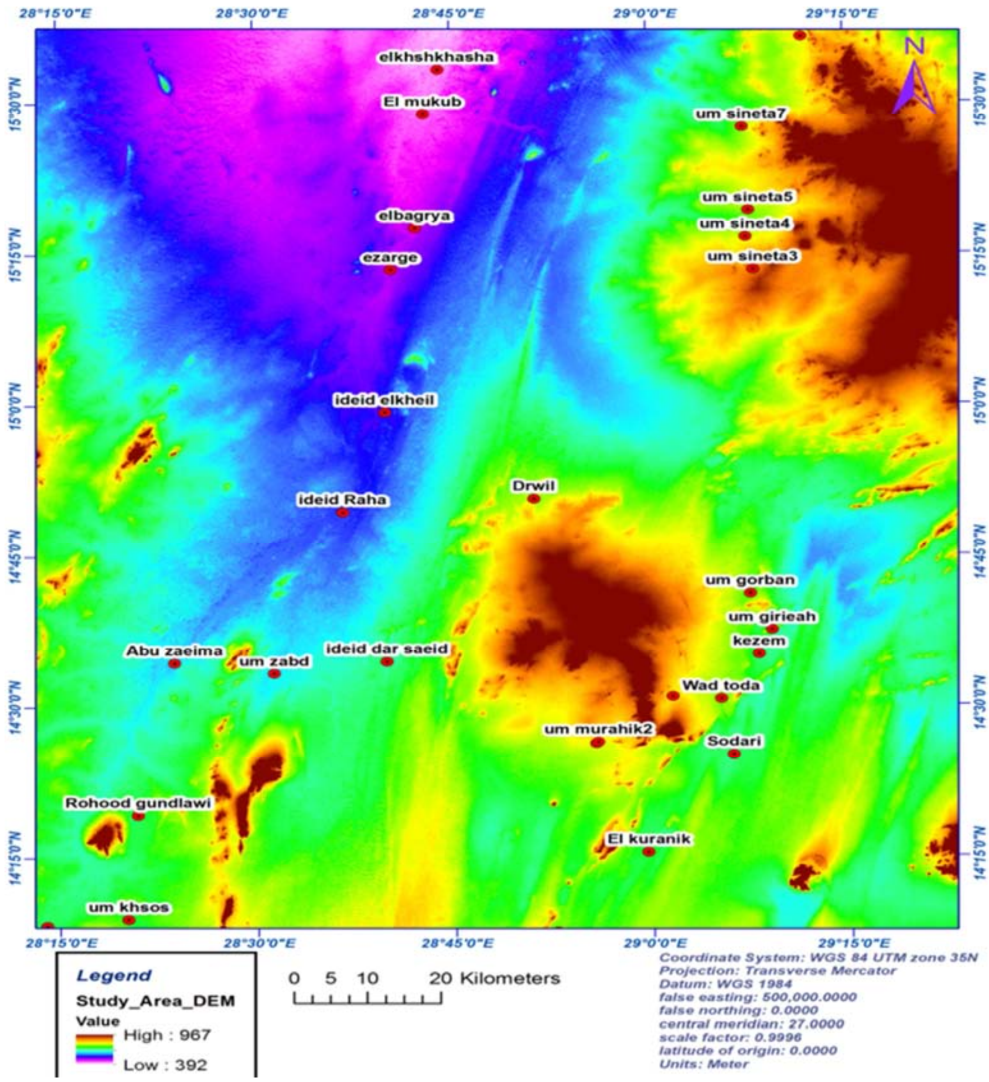



***Figure 6.*** *Digital Elevation Models (DEMs) of the study area.*

### *6.5. Lineaments and Drainage Studies*

The study area investigated, undulating, partly hilly country is mostly covered with shrubs, trees occur mainly on the plains and in valleys. The study of drainage and lineament pattern is passed on land-sat analysis of imagery in (Figure 6) and digital elevation models map in (Figure 6). The drainage system map was derived from STRM data using Archydro tool and screen digitization from Landsat8ETM+. Drainage and lineaments were studied to recognized groundwater occurrence. Drainage pattern is one of the most important indicators of hydrogeological features, because drainage pattern, texture, and density are controlled in a fundamental way by the underlying lithology [3]. In addition, the stream pattern is a reflection of the rate that precipitation infiltrates compared with the 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 surface bedrock. In combination, drainage-length density and drainage frequency reflect rock permeability.

### *6.6. Interpretation of Lineament and Drainage*

The study area was covered by sand dunes that make extraction of lineaments from Landsat 8 ETM+ difficult. Therefore, Lineaments were inferred from the drainage system which was derived from STRM (DEMs) data.

### *6.6.1. Surface Lineaments*

The drainage system, which develops in an area, strictly depends on the slope, the nature and attitude of bedrock and on the regional and local fracture pattern. According to drainage pattern type, three types of drainage patterns were identified, figure 7, namely:

A-Parallel pattern, major tributaries are parallel to major streams and join them at approximately the same angle [13]. It can occur in homogeneous, gentle and uniformly sloping surfaces whose main streams may indicate a fault or fracture zone (Figure 7).

B- Dendritique pattern, major tributaries are parallel to major streams and join them at approximately the 70° angle. It can occur in nonhomogeneous, gentle and uniformly sloping surfaces whose main streams may indicate a fault or fracture zone (Figure 7).

C-Rectangular pattern when tributaries joining the mainstream at right angles, forming rectangular shapes. It is controlled by bedrock jointing, foliation and fracturing, indicative of slate, schist, gneiss and resistant sandstone. (Figure 7).

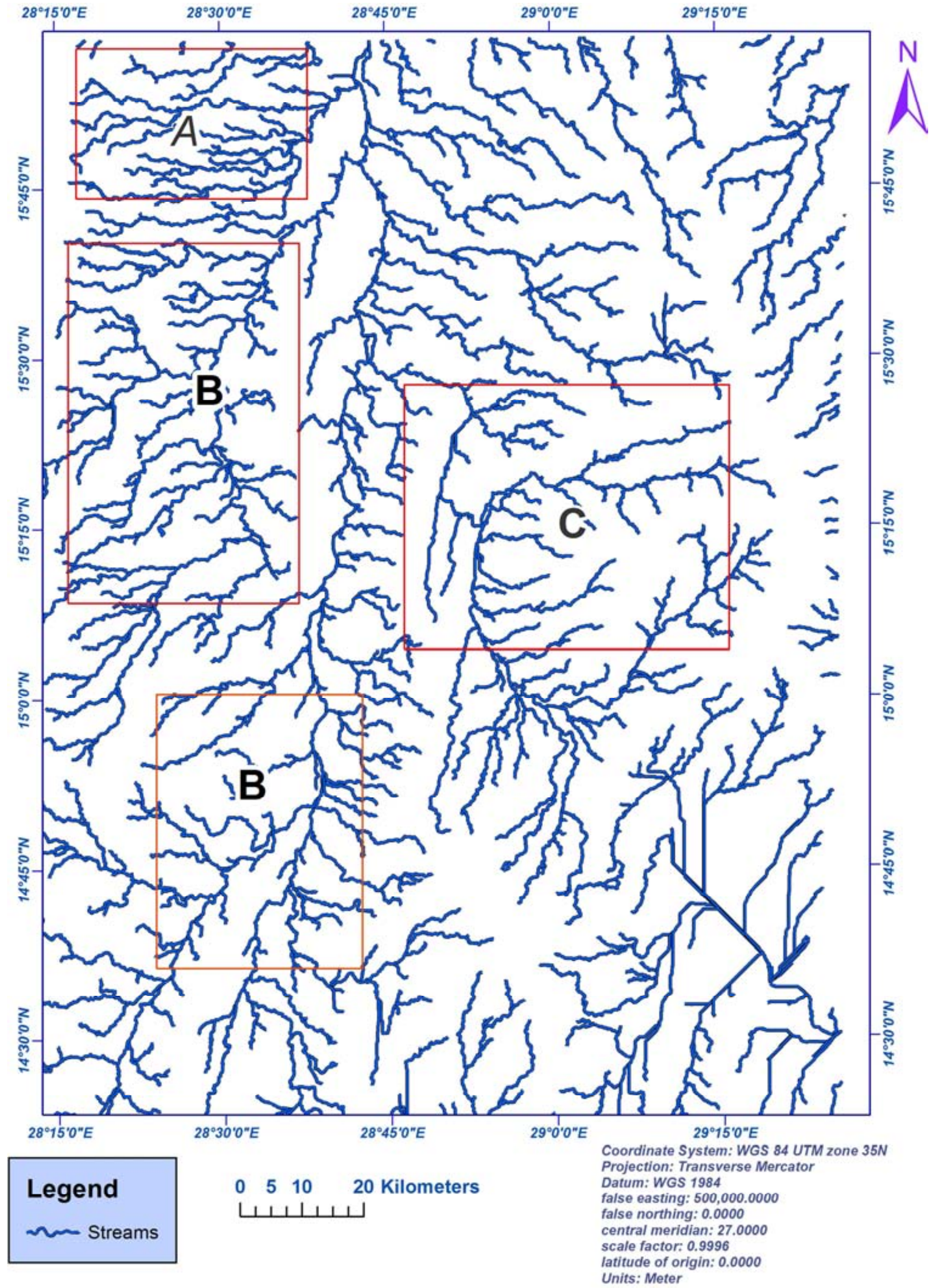



***Figure 7.*** *Types of drainage system A-Parallele B-Dendritique C-Rectangular Drainage.*

#### *6.6.2. Slope*

The slope amount map was derived from the DEM using spatial analyst tool (Figure 8). In relation to groundwater flat areas where the slope amount is low are capable of holding rainfall in the north east in the study area (green colour 28-29°), which in turn facilitates recharge whereas in elevated areas where the slope amount is high, there will be high run-off and low infiltration south west in the study area (Red colour 56-58°).

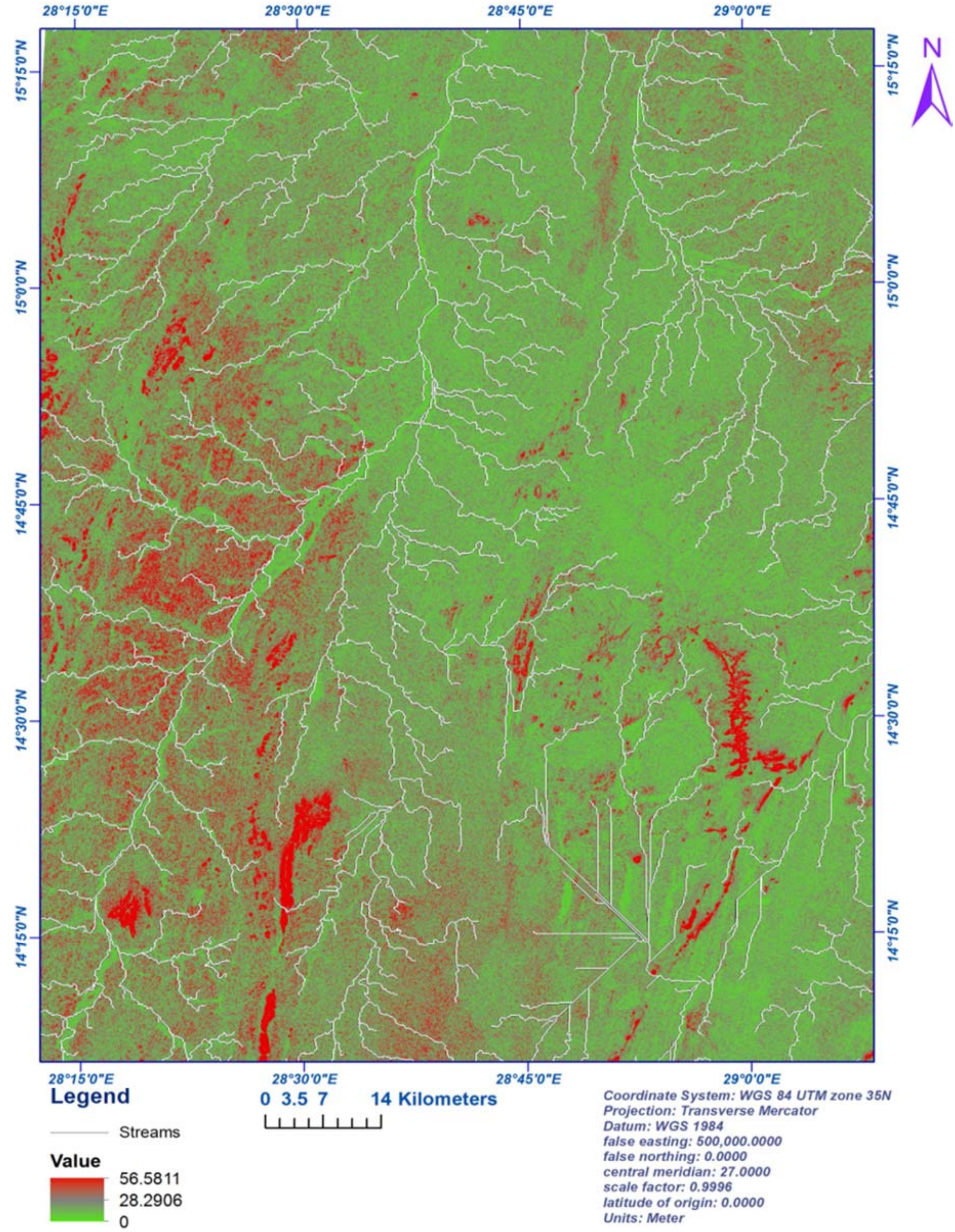



***Figure 8.*** *Slope map of the study area.*

### *6.6.3. Lineament and Drainage Densities*

In the study area, mainly 5 lineaments density categories have been identified and mapped as shown in (Figure 9). Very high density is found in the North East part (Umm sineita sub basin) of the study area. High density is found in the central west, eastern and nouthern part (along Wadi Elmilk) of the study area. Moderate and low drainage density concentrates in the sorthern and south western parts of the study area. With respect to groundwater occurrences the high drainage density is related to less infiltration of water to the ground, which in turn leads to higher run off and vice versa.

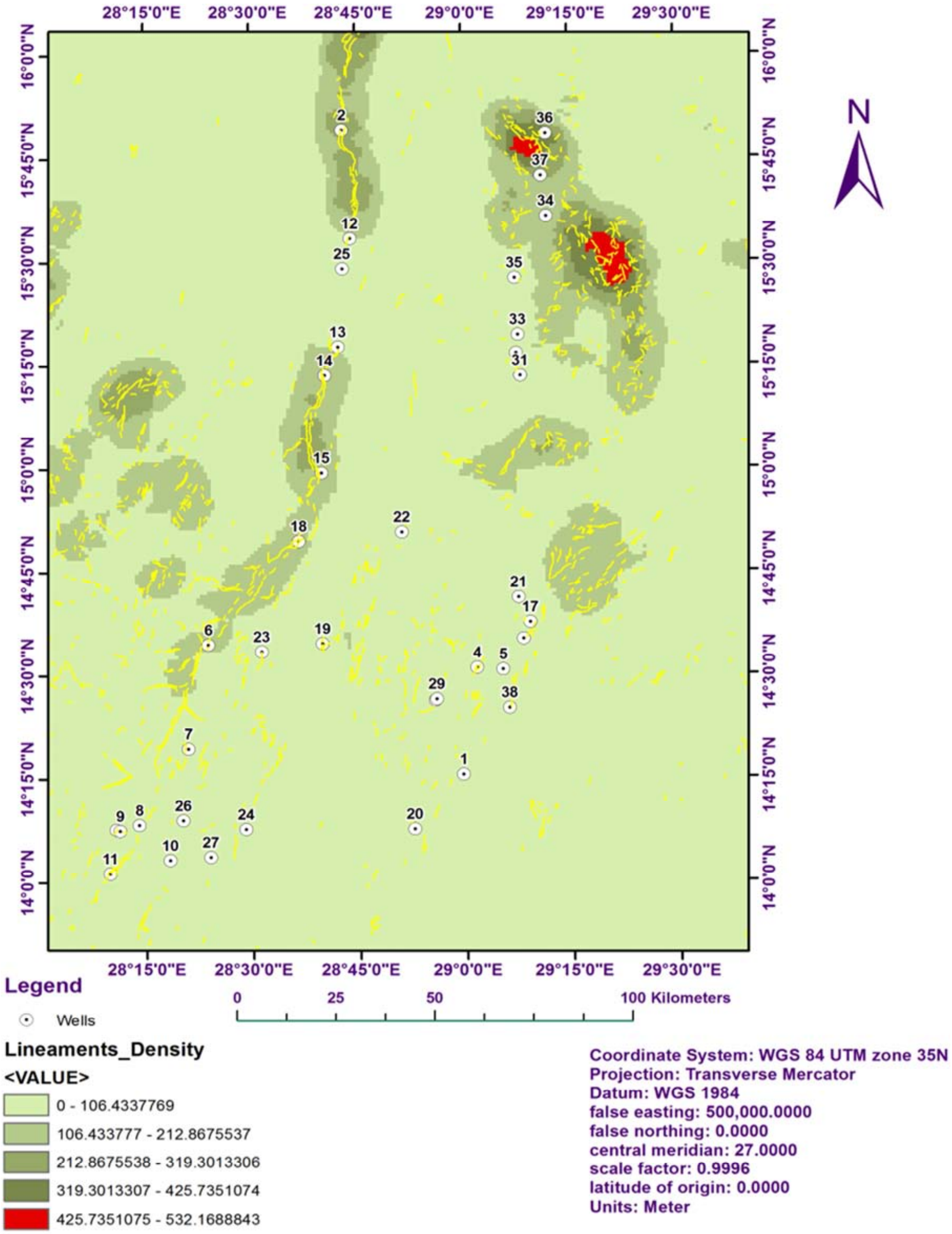



***Figure 9.*** *Lineaments density of the study area.*

#### *6.6.4. Classified and Intersection of Maps for Identifying Promising Sites*

The classified slope was derived using Spatial Analysis that has shown the elevation low in all of the study area but is mostly covered with sand dunes and it's broken occasionally by protruding Jubal and dykes. It was reclassified into 3 classes. Figure 10 show that J. Katoul and Abu asal in south east and other dykes in the south west and some sand dunes in the northren represent one class three (red color), sand dunes such as in North West and South east of Wadi Elmilk represent the low class tow (light green color) and the rest of the study area is covered by (dark green colour).

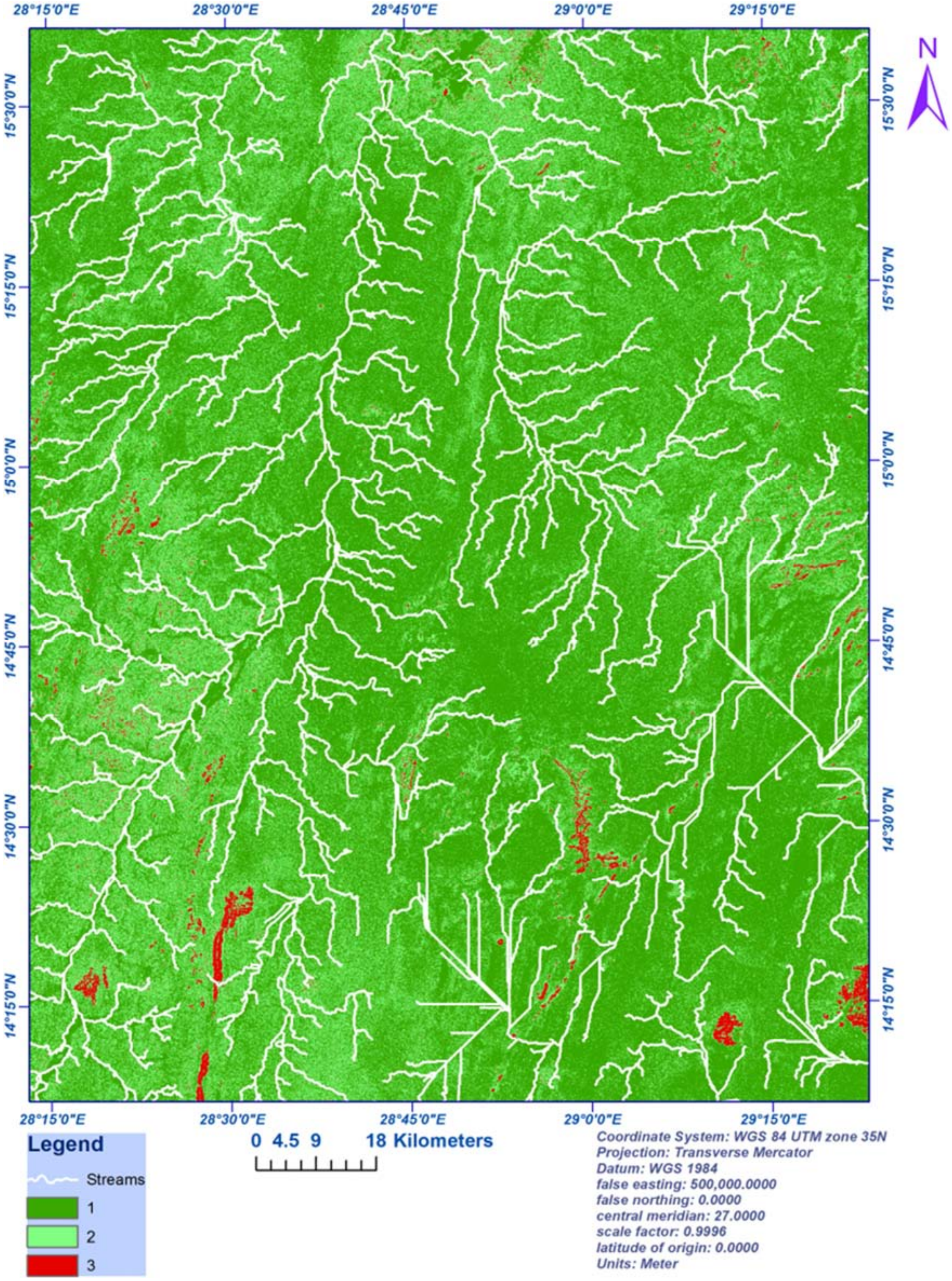
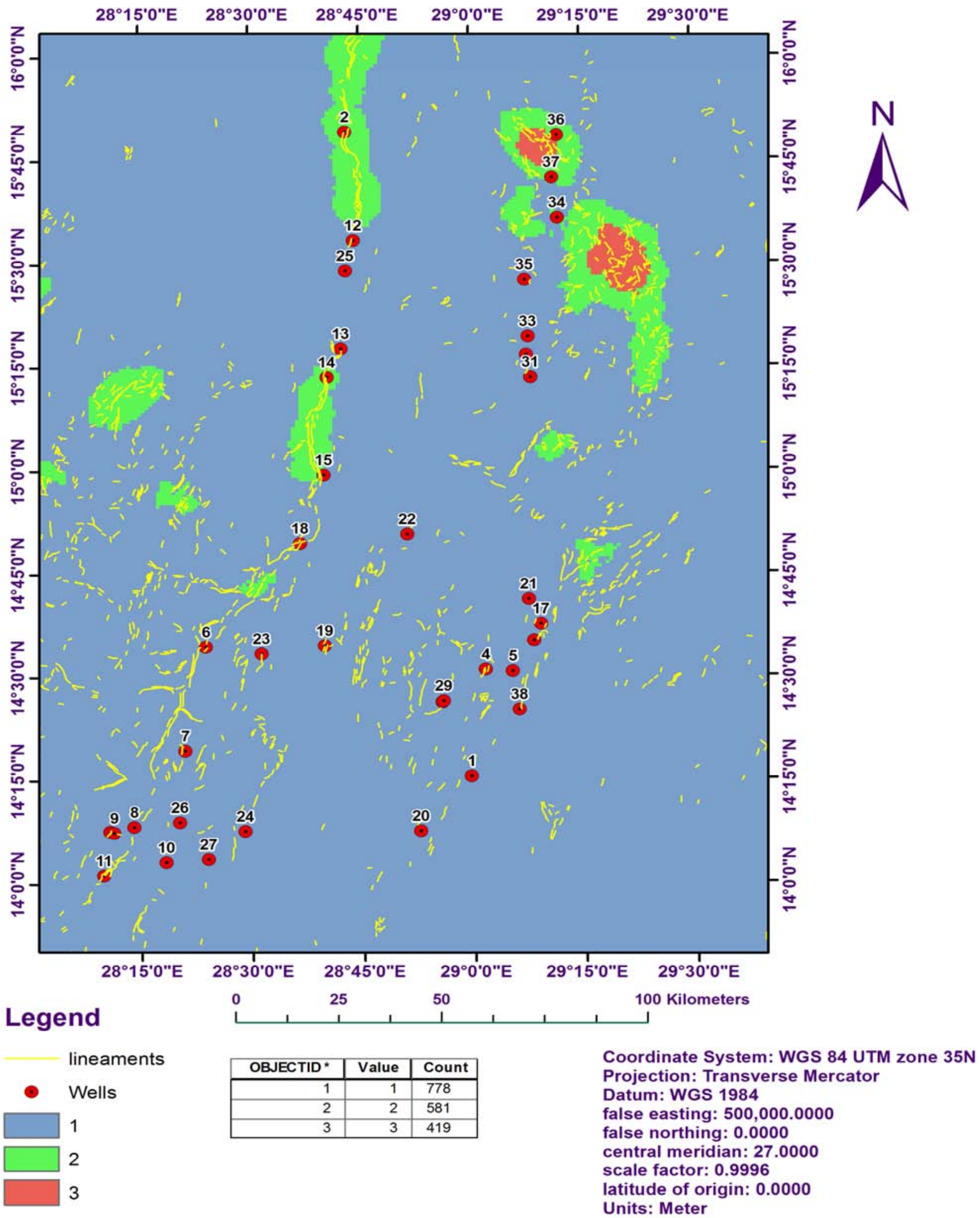



***Figure 10.*** *Reclassified amount of slope map.*

The classified lineaments density and account, figure 11, it was reclassified into 3 classes, the intersection of main fracture of the map that reveals the variation of groundwater potentiality in the upstream area of the Wadi Elmilk basin. The high intensity of lineaments in class3 (red colour) and class tow (green colour) indicates promising zones for the groundwater occurrence.




| OBJECTID * | Value | Count |
|---|---|---|
| 1 | 1 | 778 |
| 2 | 2 | 581 |
| 3 | 3 | 419 |

***Figure 11.*** *Reclassified lineaments density and account map.*

The classified drainage density and account in figure 12, it was reclassified into 3 classes, Very high and high drainage density is found in the central, west and nouthern part (along Wadi Elmilk) of the study area. Moderate and low drainage density concentrates in the northern and southrn parts of the study area. With respect to groundwater occurrences the very high and high drainage density and acount is related to less infiltration of water to the ground calss 3 and 2, which in turn leads to higher run off and vice versa.

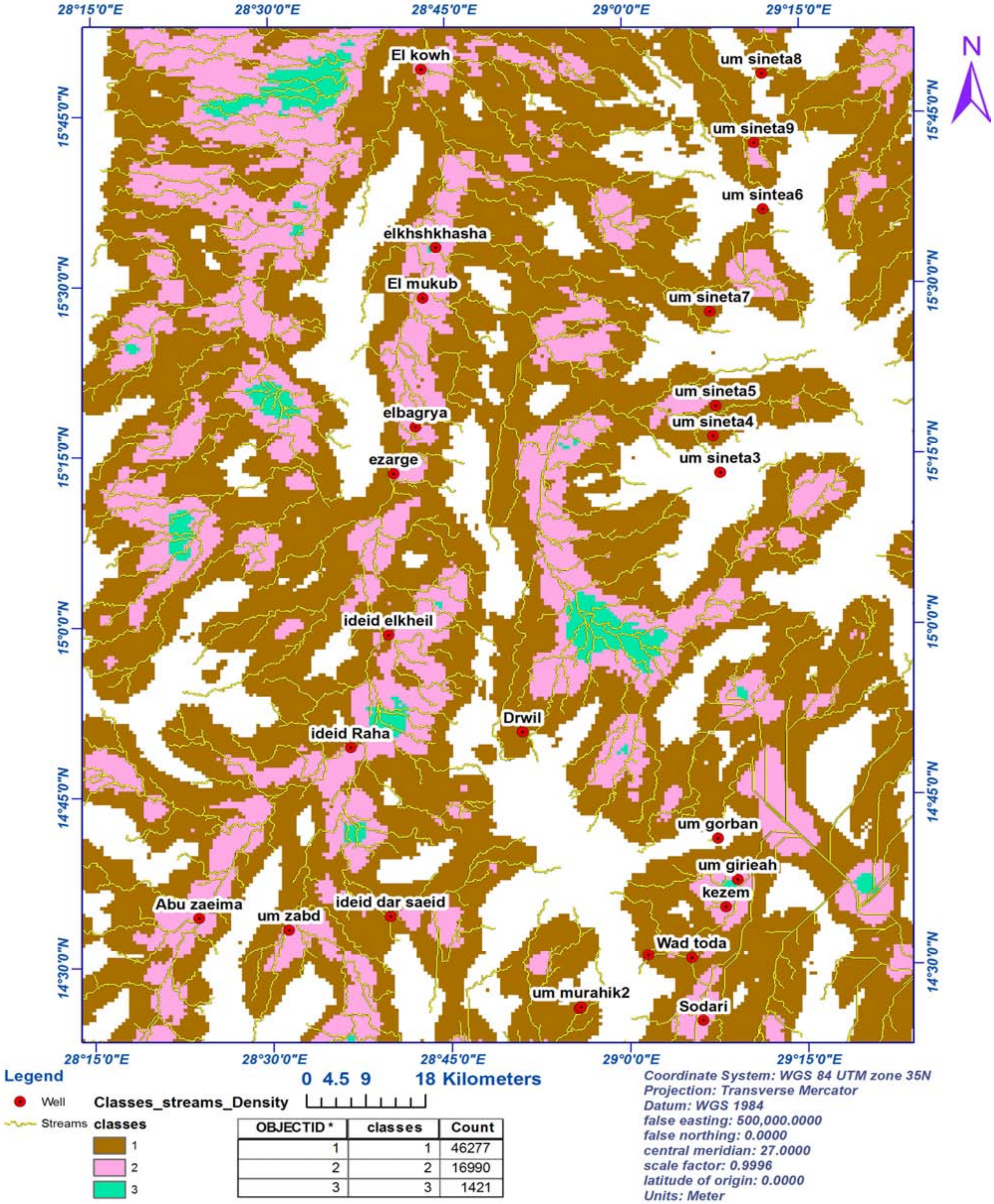



***Figure 12.** Reclassified drainage density and account map.*

Sum results of intersecting the intervals of lineament and drainage count and density with the lithology and altitude are presented in figure 13 Availability of groundwater can only be occurred in the study area in present of lineament with sufficient run-off and rainfall at some places such as Khor revealed higher fracture intersection rates, which are the most significant predictors of groundwater occurrence. The area can be classified into three high lineaments density zone (red colour) at the direction of Wadi Elmilk and other runoff (central and north direction), that indicates promising zone for the high infiltration and percolation of the surface water, as well as, the thickness of the alluvial deposits range between 2- 8 m.

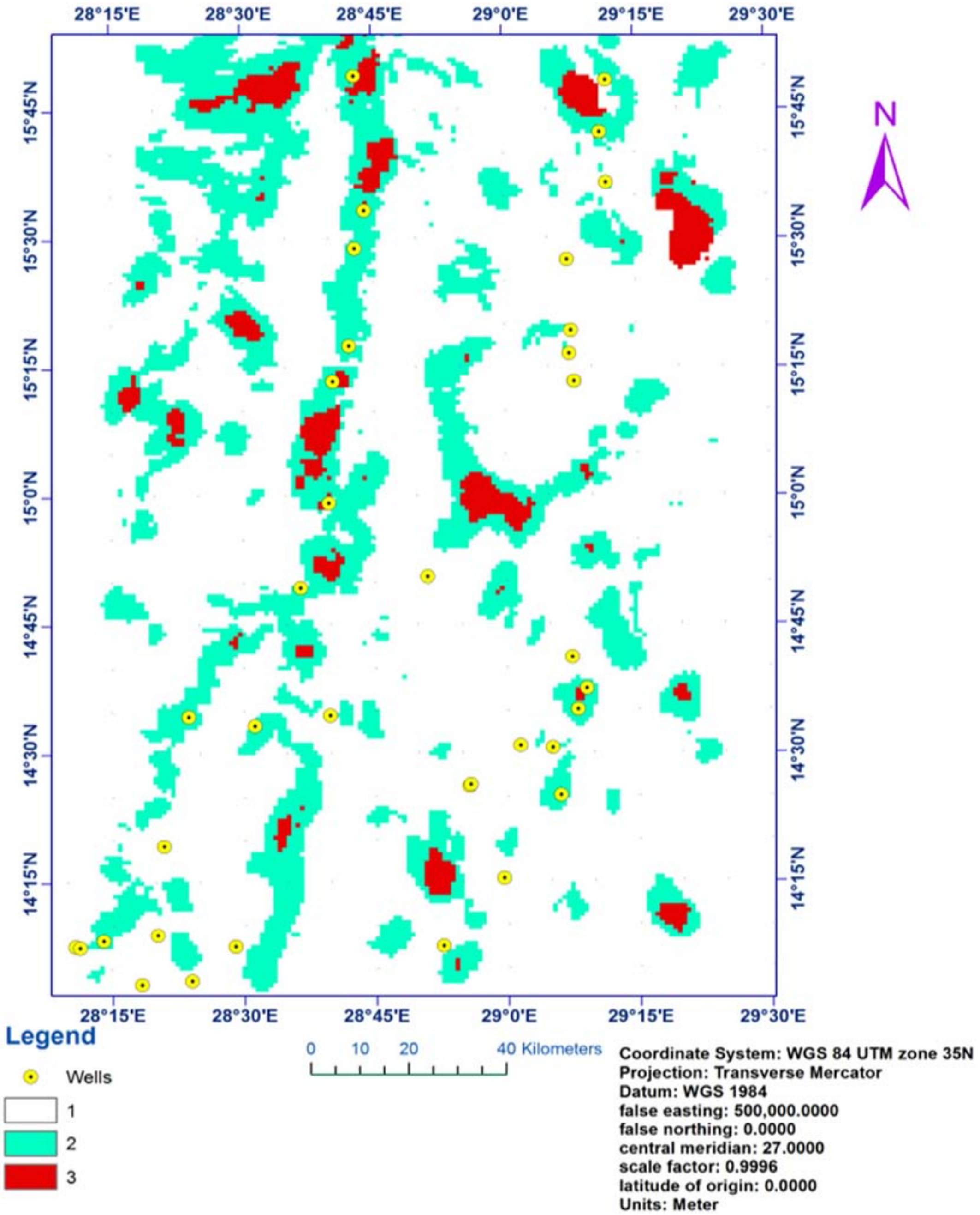



***Figure 13.*** *Reclassified sum liniment, drainage densities and account map.*

The rose diagram figure 14 constructed from the Lineament map generated from remote sensing images interpretation in figure 10, shows that the NE trend covers a range between 15° and 45° but most of the long and highfrequency lineaments are clustered around 30. The study area all the lineaments are clustering into two main directions: NE-SW in figure 14. This may lead to the conclusion that the two prominent lineament directions: NE from SW are the major structural trends in the central Sudan and is most likely related to the Central African Shear Zone.

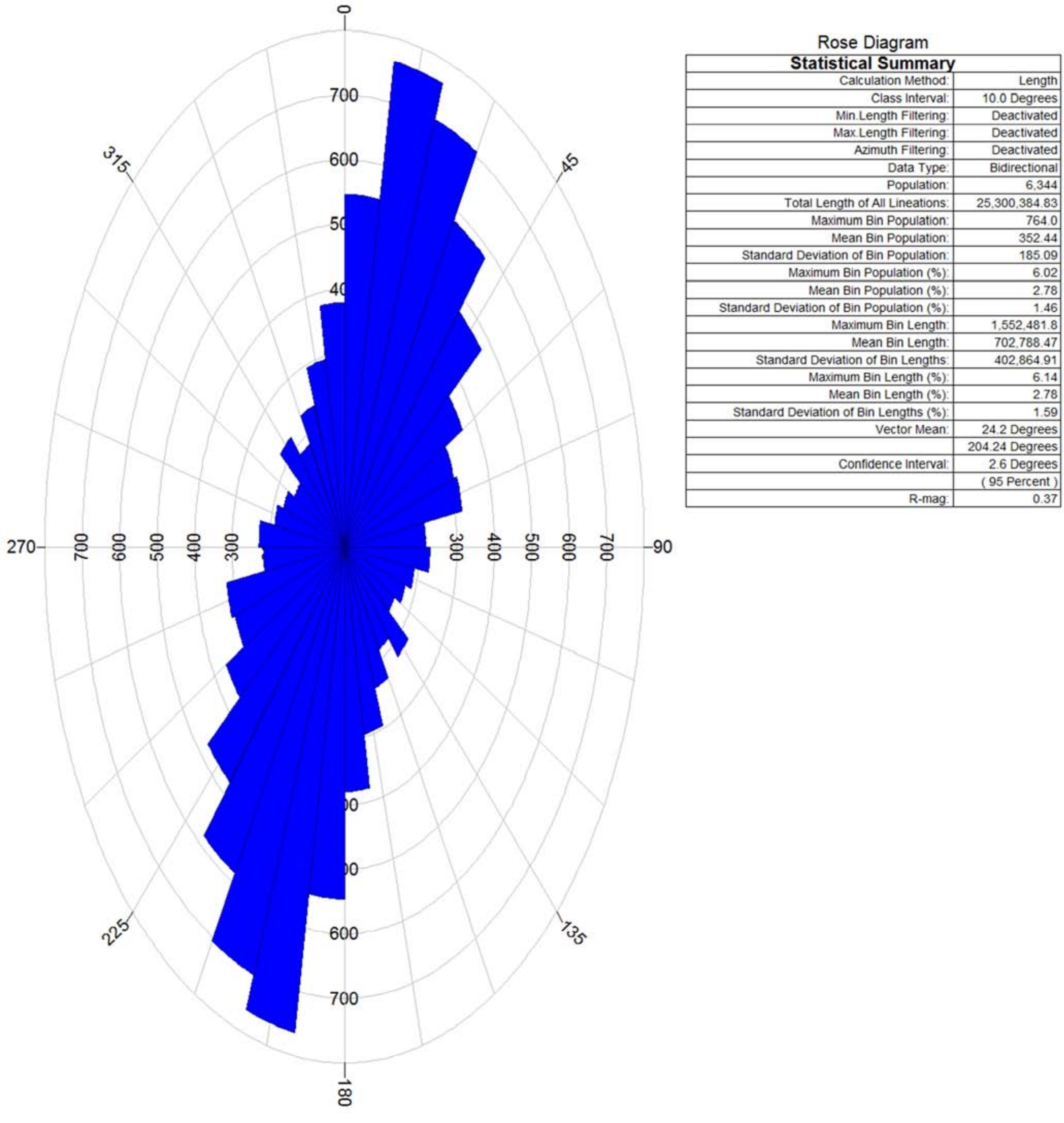



***Figure 14.*** *Rose diagram of the lineament frequency of the study area.*

# 7. Conclusions

These results showed that sites with possible high yield were related to moderate intervals of lineament and stream densities. The other important data that affected the spatial distribution of the promising sites were lithology and topography. The study showed that GIS tools were very useful in refining the intervals of lineament and stream densities and in identifying the most promising sites for along wadi Elmilk and other Wadies based on data of existing groundwater well. The conclusion that the two prominent lineament directions: NE from SW are the major structural trends in the central Sudan and is most likely related to the Central African Shear Zone.

All drainage lines flow from the south west to the north east direction; they are all covered with sand dunes. Structurally controlled drainage patterns are observed generally in the NW-SE direction. With respect to the groundwater occurrences the high drainage density is related to less infiltration of the water to the ground, which leads to higher run off and vice versa. Base on this fact, drainage density areas with low drainage density were assigned high weight. The reclassified map was produced based on these weights.

With respect to the slope the groundwater occurrences is related to the low slope angle gives a better chance for groundwater accumulation, based on this fact, areas with flatter topography were assigned high weight. The reclassified map was produced based on these weights.

Reclassified map of lineament was produced based on the fact that the present of lineaments increases the porosity and permeability which in turn allows mor accumulation of groundwater.

The most promising potential zone in the area is related to deep basement, thick water bearing zone, certain geologic formation (Nubian Sandstone), slopes and drainage density.

Very good and good categories of groundwater prospecting in the basement are in highly weathered zones and greatly fractured and jointed ones.

The study has demonstrated the capabilities of using remote sensing and Geographic Information System for demarcation of different groundwater potential zones. This could give more realistic groundwater potential maps which may be used for any groundwater development and management program.

## 8. Recommendations

1) More detailed studies should be conducted in order to check the information extracted from remote sensing and DEM.
2) More detailed analysis of the lineaments and drainage system of the study area is needed in order to classify the structural system.
3) More detailed studies in the future to improve detailed geological mapping using remotely sensed data and Radar.

## Acknowledgements

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