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RESEARCH ARTICLE

THE USE OF LANDSAT ETM+ IN HYDROGEOLOGICAL INVESTIGATION IN BASEMENT TERRAIN, HAMISSANA AREA, N-E SUDAN

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Abstract

The objective of this study is to perform a hydrogeological survey using remote sensing techniques in order to delineate target zones for groundwater exploration within terrains underlain by crystalline rocks. The study area is situated in north western flanks of the Red Sea hills in the Hamissana area, Red Sea State within the Arabian Nubian shield (ANS) which belongs to the Pan-African Era. The region is characterized by desert climate, where acute shortages of water is experienced. The study area is covered by the basement complex rocks (Precambrian age) which is overlain by alluvial deposits. The remotely sensing data of Enhanced Thematic Mapper (ETM+) were used in this study in addition to Geographic Information System (GIS) to illustrate the geological features in the study area, mainly the Lineaments. The structural analysis had been applied to classify the open potential fractures that commonly found in NW-SE and in NE-SW directions, while the closed shear fractures are oriented in N-S direction. Based on the study of lineaments, target zones of ground water were indicated by the overlap of high-intensity opened lineaments and the low-drainage intensity.

Key Words: Remote sensing, Groundwater, Red Sea hill, Hamissana, GIS, Structural analysis, Lineament.

1. Introduction

The main objective of this study is to use the remote sensing techniques in hydrogeological investigations in basement terrain. Remote sensing data acts as a very useful guide and efficient tool for regional and local groundwater exploration particularly as a fore- runner in a cost- effective manner (Singh al and Gupta 1999). The mapping of linear features on various types of maps or remotely sensed data is one of the keys to understand groundwater occurrence, especially in hard rock terrain. Lineaments mapped with remote sensing data have therefore been the focus for targeting well sites (Sander 2007).

The study area lies in the north-western flanks of the Red Sea hills in the Hamissana area, Red Sea State, (Fig.1). The area is bounded by latitudes (20. ° 00624-21°.0024°) N and longitudes (34. °4969°-35°.31254°) E, and it is characterized by the desert climate and undulating topographic surface with average annual rainfall range from 25 to 25 mm/year. The drainage pattern of the Red Sea Hills is structurally controlled by faults and folds that produce rectangular drainage patterns. In the study area, the general geology and surface topography brought about the observed water shortage that characterize that part of Sudan.

The Hamissana Shear Zone (HSZ) is a broad N – S deformational zone, making it one of the largest basement structures in NE Africa (Stern et al., 1989). The study area is dominated by meta-sedimentary, meta-volcanic and ophiolitic rocks marking an old suture between Gabeit and Gabgaba terrains (Almond et al., 1984) These sequences are intruded by the syn to late- orogenic and post-organic igneous intrusions.

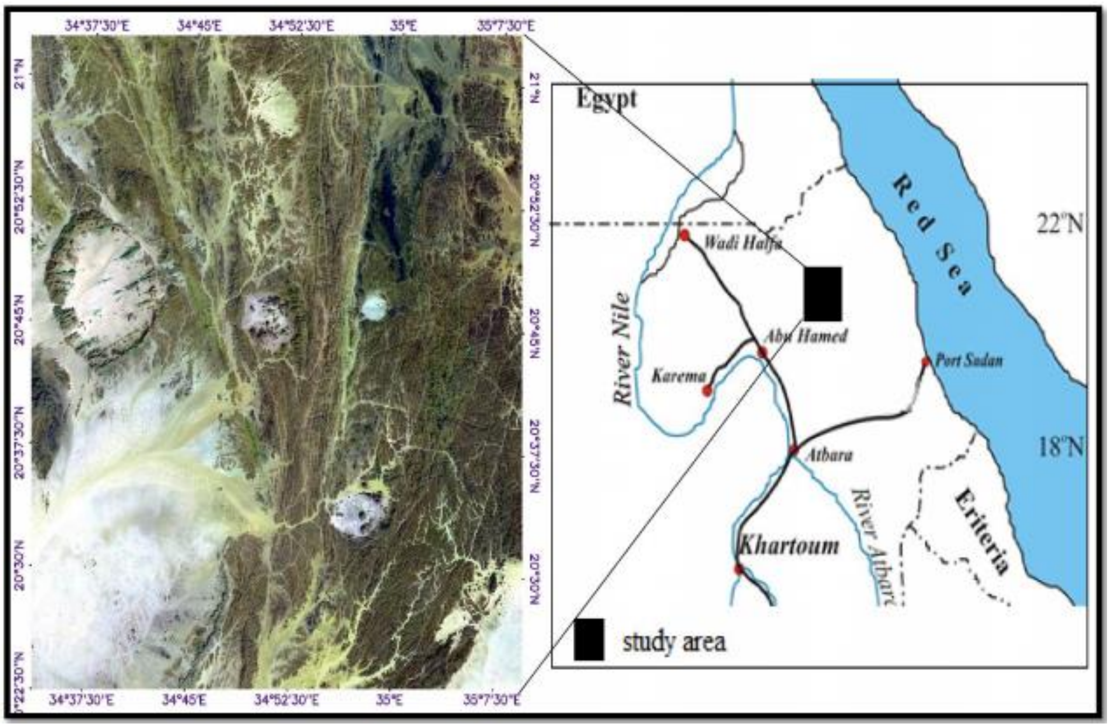


Fig. 1: Location map of the study area

2. Methodology

2.1 Remote sensing

Remote Sensing is defined as science or art, used to get information about an object, area, or phenomenon without direct contact, using sun light energy (passive sensors) as in the Landsat image and air-photo, or by omitting of energy such as in radar (active sensors) (Sabins,1996). The basic principle involved in remote sensing is that each object, depending upon its physical characteristics, reflects, emits and absorbs varying intensities of radiation at different wavelength range (Lillesand&Kierfer, 2000).

Enhanced Thematic Mapper ETM+ Land Sat satellite data of p172 r45, p172 r46, p173r45, p173 r45 imagery were used in this study. The handling of the satellite data include the pre-processing of satellite images and enhancement of satellite data using different processing manipulations. Digital image processing techniques were applied to satellite images, which facilitated the delineation of the lineaments manifestation in the study area. The processing phase of the Image enhancement includes colour composite and image filtering .The rule of color composites is to set the most informative band for a particular purpose in the red, the next in green and the least informative band in blue filters (Drury, 1993). Digital filter technique (directional filter) is applied in this study for edges and lineaments enhancement where a new structural lineament map was prepared.

2.2 Structural Analysis

The structural analysis is done based on the tectonic and geological history of the area in addition to the interpretation of the remotely sensed data. The structural analysis used in this study is mainly directed to the fractures analysis by using the Stress And Strain Ellipsoids to classify the main fracture types (Fig.5), which are reflected in the form of faults and tectonic fractures. These fractures could be favorable zones for groundwater occurrence and movement. The Hamissana shear zone is extending in N- S trend. Accordingly, the Stress- Strain analysis was applied to differentiate the potential open fractures (Extensional, Tensional & Release fractures) from the closed shear fractures in the study area.

3. Results and Discussions

The occurrence of groundwater is controlled by the surface features (indicators) which are grouped in two categories, direct indicators and indirect indicators. The first indicators are directly related to the groundwater regime such as recharge and discharge zones, soil moisture and vegetation. The second indicators are this geological and morphological feature that controls the occurrence and distribution of groundwater, such as the rock types, geological structures and landforms. (Singhal and Gupta, 1999). The enhanced image was used mainly to determine the indirect indicators. These indicators include rock types and geological structures.

Different (RGB) combinations were used in this study to discriminate the rock types in the study area. It was found that the false color composite Landsat ETM images (e.g. bands 7; 4; 2 and 7; 5; 4) (Fig.2) are most-suitable for identifying major geological units. Directional filters are proved to be useful in the illustrating lineaments that trend in a specific direction, such as northeast, northwest and north (Fig.3).

(a) (b)

Fig. 2: Color componsite of bands: (a) 7, 4, and 2 in RGB, respectively and (b) 7, 5, and 4 in RGB, respectively.

Lineament map displayed in Figure (4,a) were produced through the visual interpretation of spatially enhanced TM image of the area under consideration. The lineament map shows that the area under consideration is highly fractured with lineament concentration in the northern and southeastern parts whereas the southwestern parts of the area shows poor or no lineaments. For clear understanding of the lineament distribution in the area, lineament density contour maps was produced (Fig. 4,b) as suggested by Sree Devi et al., (2001). The lineament map was superimposed on a grid map of 1cm2 and the total length of lineaments passing in each grid was measured and plotted in the respective grid centers. Then the values were interconnected by iso-lines as a result the lineament density map was produced.

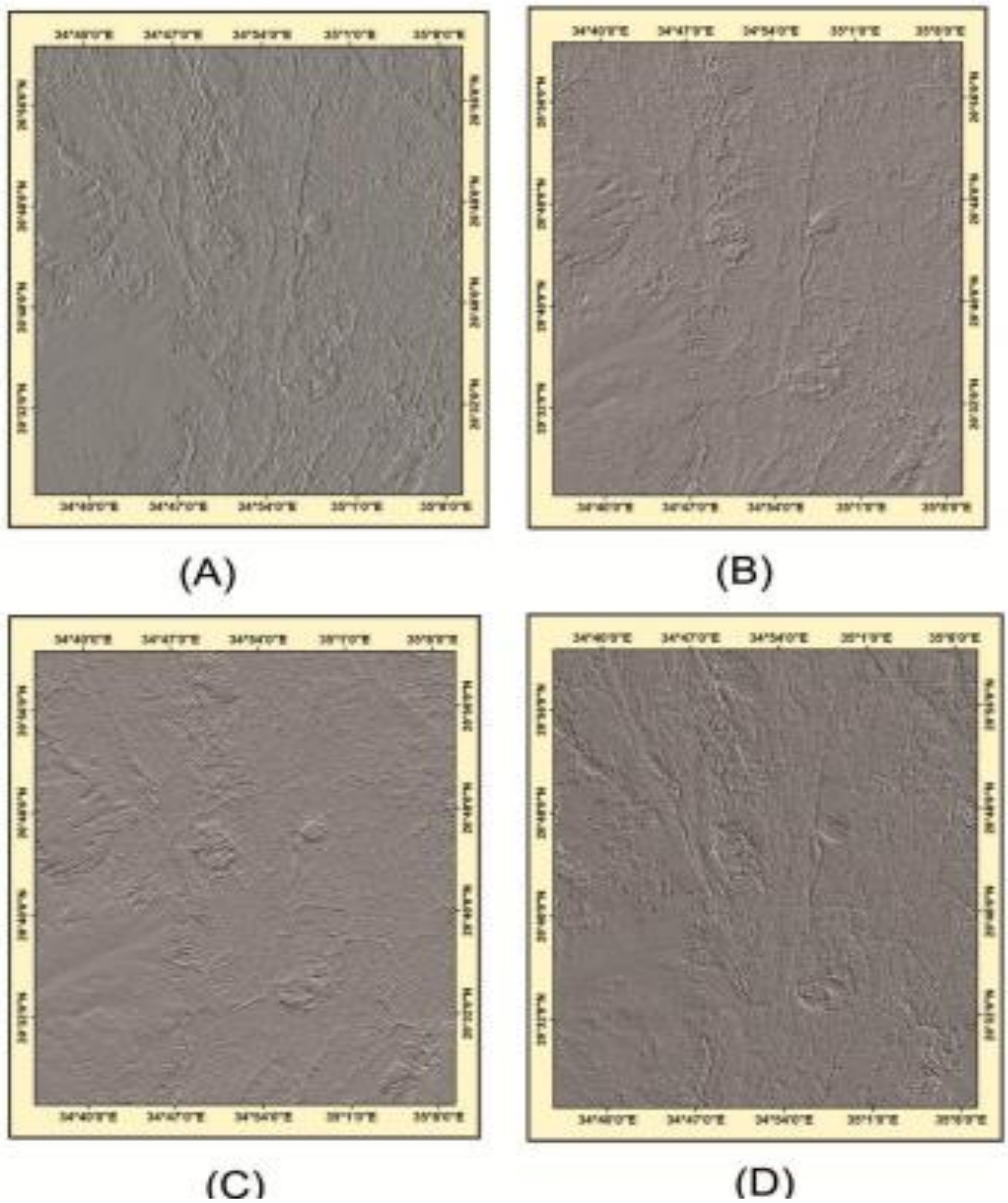
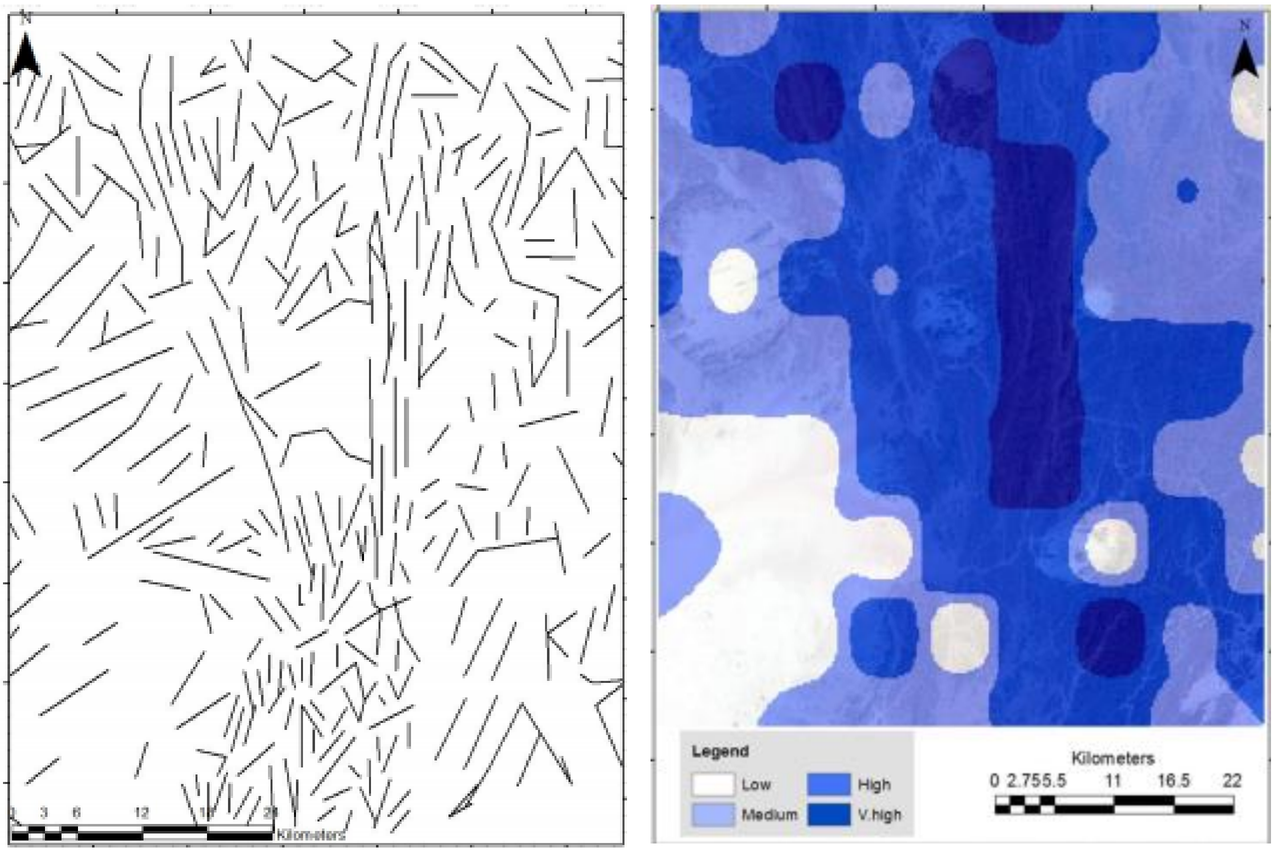


Fig. 3: Image filtering (A) 0 directions (B) 45 directions (C) 90 directions (D) 315**.**



(a) (b)

Fig. 4: (a) Lineament map of the study area. (b) Lineament density maps of the study area calculated directly from lineaments map superimposed on the Landsat image of 7, 4 and 2 in RGB respectively.

Unfortunately, the maps are constructed based on lineaments map without any classification or structural considerations. So, high number of lineaments in an area does not always ensure the existence of fractured rock aquifers. This may give unreliable results, since some of the fractures do not contain water i.e. shear fractures. Therefore, the lineaments analysis is much needed.

The structural analysis is done based on the tectonic and geological history of the area in addition to the interpretation of the remotely sensed data and the field confirmation. The Hamissana shear zones is extending in N- S trend. Accordingly, the Stress- Strain analysis was applied to differentiate the potential open fractures (Extensional, Tensional & Release fractures) from the closed shear fractures in the study area. The results shows that the extensional fractures trending NW-SE, while the trend of the release fractures is in the NE- SW direction, (Fig. 6, a).

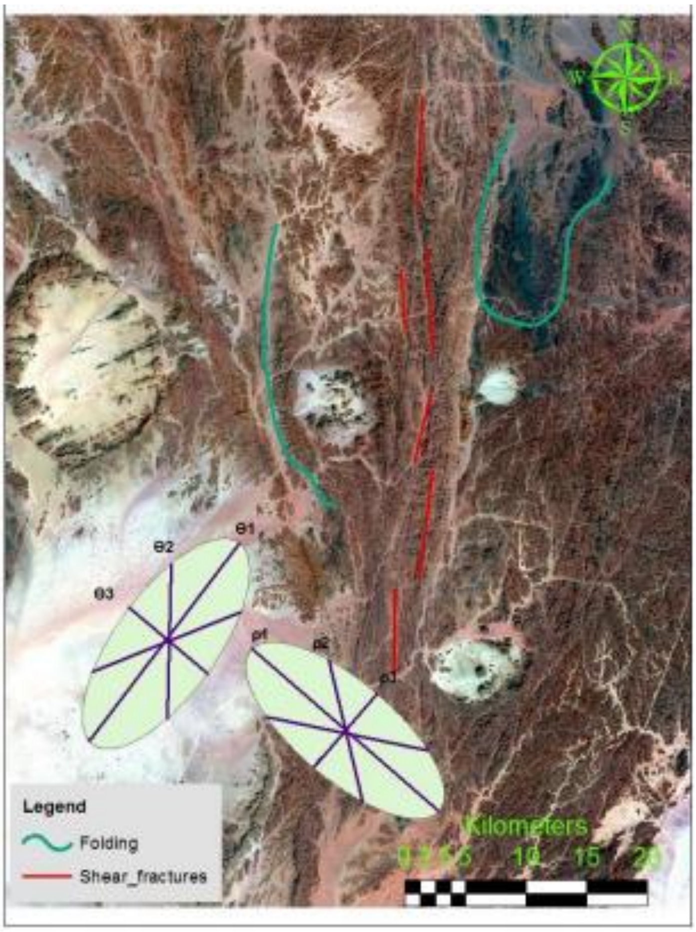
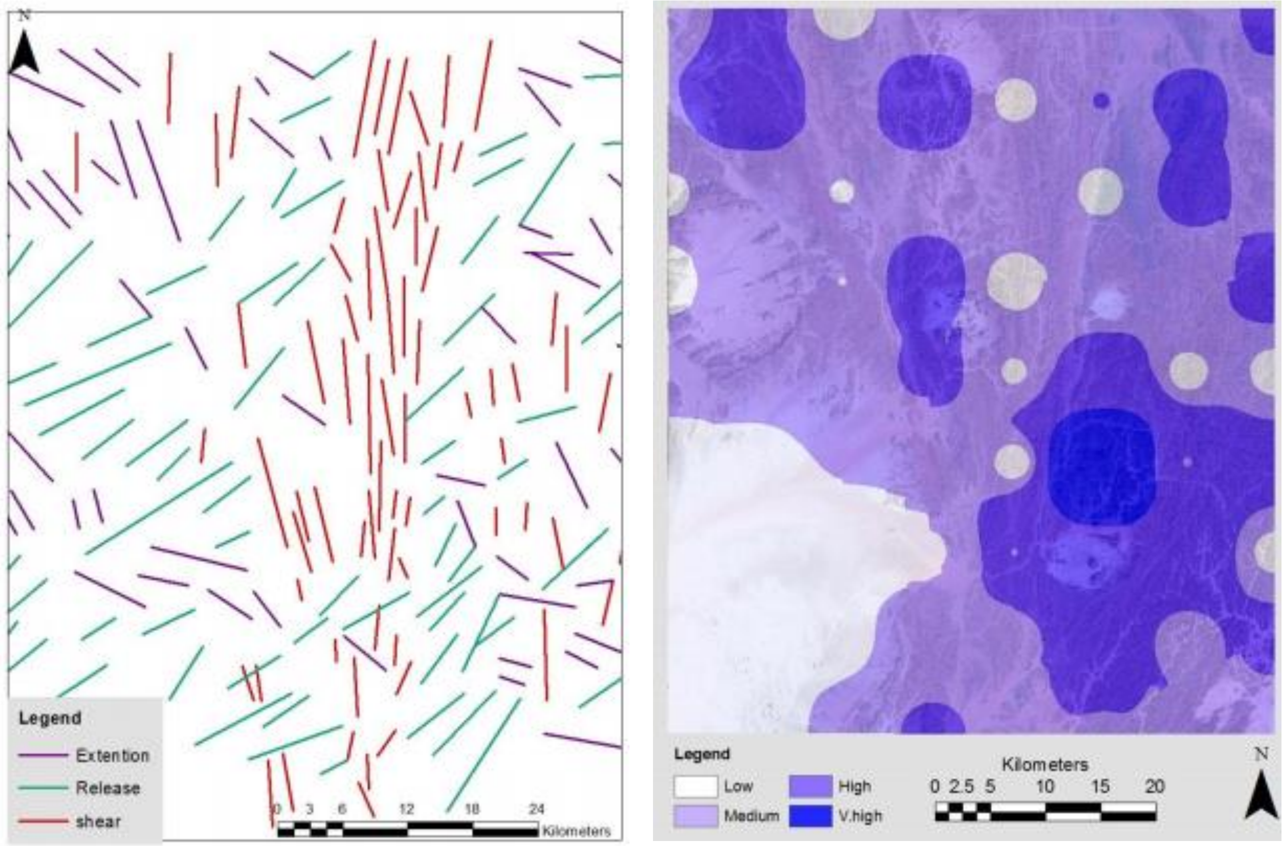


Fig. 5: Stress-strain ellipsoid of the study area.
(**ρ1** = Greatest stress axis - **ρ2** = Medium stress axis - **ρ3** = smallest stress axis)
(**Ɵ1**= Greatest strain axis &**Ɵ2**= Medium strain axis &**Ɵ3** = smallest strain axis)

Putting the structural considerations in mind, the 180º±10º trend was calculated to constitute the shear trends in the study area. Therefore, all the fractures that have either of these trends were filtered out from the lineament map, thereby a filtered version of the lineament density map was produced, Fig. (6, b).



(a) (b)

Fig. 6: (a) Classified lineaments map of the study area. **(b**) Lineament density maps of the study area calculated after filtering the lineament map from shear fractures superimposed on the Landsat image of 7, 4 and 2 in RGB respectively.

From the two lineaments, density maps (the unfiltered and filtered versions of lineament maps), many differences in shape and spatial distribution of the lineament density contours was observed. The high density area in the middle region had been changed in shape and decreased in spatial distribution after the filtering process took place and this is an indicator to that the lineaments of the center and several separated area are almost shear fractures. So, filtering out shear fractures produces more accurate lineament maps for groundwater accumulation, since closed fractures do not contain water. By this stage, all the determined areas are the target zones with high probability of groundwater occurrence and can be used as a guide for groundwater investigation in the study area. From the above results and discussions in this paper, it reveal that the southeast part study area represents the highest target zone and the most favorable for groundwater accumulation.

4. Conclusions

- The remote sensing and GIS techniques were applied to enhance the geological, geomorphological and hydrogeological features controlling the groundwater occurrence.

- The structural analysis proved to be an effective tool to classify the fractures in study area as to recognize the potential fractures (open fractures).

- Groundwater exploration in the area studied is recommended in the favorable sites suggested by the filtered density map.

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