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Landsat ETM+7 Digital Image Processing Techniques for Lithological and Structural Lineament Enhancement: Case Study Around Abidiya Area, Sudan

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Abstract: Remote sensing techniques were applied to delineate lithological and structural features of the area around Abidiya area in north central Sudan. Landsat Enhanced Thematic Mapper Plus (ETM$^+$7) Satellite data of five multispectral bands (1, 2, 3, 4, 5, & 7) were utilized in the course of digital image processing techniques. The techniques consist of spectral enhancement (e.g. linear contrast stretching and image ratio) and spatial enhancement such as image filtering and Intensity-Hue-Saturation transformation (IHS). The spectral enhancement techniques were used to extract the initial geological information, which showed a clear discrimination of felsic and granitic rocks from mafic and ultramafic lithologies of ophiolitic origin. Intensity, Hue, Saturation (HIS) transformation proved to be superior in enhancing geological information extraction. The high pass and directional filtering techniques allows the delineation of the lineaments in the region.The patterns recognized in the digitally processed satellite images assist in extract the initial lithological information as well as delineate the regional structural lineaments in the region. Further these patterns used as a base for generated geological and structural maps through visual interpretation and ground truthing.

Keyword: Remote sensing, spectral enhancement, band ratio, image transformation, image filtering.

1. INTRODUCTION

The technological advancements in the field of remote sensing have been a boon for such surveys. It has been used in geology for lithological discrimination of different rock types and delineation of geological and structural features [1]. Digital image processing is defined as the manipulation of remotely sensed data to improve the appearance of the image and creation of new modified images that contain more information to ease the visual interpretations of certain features. Visual and automated remote sensing studies have been applied successfully in geological studies in Sudan involving optical and radar data [2, 3].

In this study remote sensing investigations have been applied to study the area around Abidiya city in north central Sudan covering the area east and west banks of the River Nile (Fig. **1**). It is about 8100 Km^2, which stretches from Latitudes 17º 50`N to 18º 30`N and from longitudes 33º 40` E to 34º 35`E. The area is lying at geologically and tectonically interest area between the N-S trending Keraf Shear Zone and the NE trending Nakasib Suture Zone (Fig. **1** and **2**). The NE trending Nakasib Suture in northeast Sudan represents a major prominent Structural lineament of the Nubian Shield [4]. North trending Keraf Suture in north central Sudan [5, 6] represents more or less the boundary between East Saharan Metacraton (Archean, Paleo-, Meso-, and Late Proterozoic rocks) to the west and the Nubian Shield to the east [7]. The SW lineament traces of Nakasib Suture west of longitude 35° and its interference with Keraf Shear Zone is not fully defined due to the sand and gravelly sand covers and complexity of Structure within the area. Therefore, this study highlight some digital image processing techniques using Landsat ETM$^+$ data to show their role in enhancing lithological units and structural features (e.g. fault and lineaments), which leading to more accurate and improvement of geological mapping.

2. MATERIALS AND METHODS

Landsat Enhanced Thematic Mapper Plus (ETM$^+$7) imageries among other Satellites provide a number of bands in the visible, SWIR and thermal infrared regions, centered on particular spectral features due to different kinds of surface material [9]. They are available and free of charge via the USGS Global visualization Viewer (http://glovis.usgs.gov). The selection of the imageries was based on the acquisition date, availability and spatial resolution as well as the user need. A total of four ETM scenes have been utilized in this study (p173r47, p173r48 (23/1/2000), p172r47 and p172r48 (29/11/1999)) Table **1**. The selected bands include band 1 through band 5 and band 7 (Visible & Reflected Infrared "VNIR") that characterized with 30 m spatial resolution. In addition to band 8 as the Panchromatic band (15 m). The thermal Infrared band 6 has been excluded for its low spatial resolution (60 m).

ENVI 4.5 and ERDAS IMAGINE 8.6 software packages are both used in digital processing to enhance the quality of the satellite raw digital data and produce image suitable for

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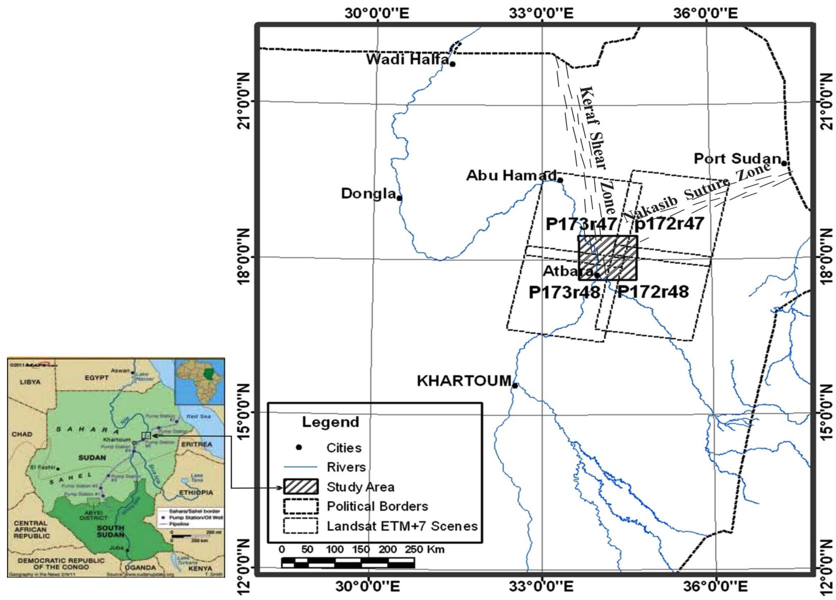

Fig. (1). Location map of the study area and the Satellite Landsat ETM+7 scenes.

Table 1. Landsat ETM+7 Scenes, Path, Row & their Acquisition Date

	Scene (Path, Row)	Acquisition Date
1	ETM+7 (p172, r47)	29\11\1999
2	ETM+7 (p172, r48)	29\11\1999
3	ETM+7 (p173, r47)	23\01\2000
4	ETM+7 (p173, r48)	23\01\2000

visual geological interpretation.Geo-referenced topographical maps (NE – 36 G & K- named Atbara and Berber sheets, respectively) were overlaid on the subset Landsat ETM imageries to create a field map (scale 1:100,000) using Arc GIS 9.2 software. The map facilitated image classification and post-classification processing for geological and structural information extraction.

3. DIGITAL IMAGE PROCESSING

The major role of digital image processing is to increase the extracted geological information through the enhancement of the qualities of tones and hues, image textures, fracture patterns, lineaments and their trends [1]. Based on the objectives and techniques, digital image processing can be categorized into: (i) pre-processing techniques including geometric and radiometric corrections of the satellite raw data;mosaiking and subsetting techniques for the targeted area. (ii) Image enhancement techniques involve procedures for creation of new modified images that contain more information to ease the visual interpretations of certain features. Moreover, digital image processing ended by the information extraction procedures including image classification techniques.

The initial step toward digital image proccessing is to calculate the statistical parameters of the raw satellite data (Table **2**). These parameters are used in different DIP techniques such as radiometric correction, band combination selections and image transformations [9].

Table 2. Calculated Basic Statistics of Landsat ETM7 Data

Scene	Band	Min	Max	Mean	St.Dev Deviation
P172r47	1	46	251	67.1	52.26
	2	28	255	69.2	55.39
	3	18	255	91.3	74.69
	4	11	255	70.5	57.42
	5	1	255	93.9	75.25
	7	1	255	83.6	66.88
P172r48	1	52	225	68	5203
	2	32	215	713	5521
	3	20	255	96.3	75.67
	4	2	242	75.5	59.30
	5	1	255	93	74.22
	7	1	255	81	64.96
P173r47	1	53	177	72.93	56.56
	2	30	222	80.25	63.26
	3	20	255	109.60	87.32
	4	1	255	85.46	67.71
	5	1	255	108.71	86.01
	7	1	255	99.12	78.62
P173r48	1	51	211	64.20	48.55
	2	32	233	72.72	55.89
	3	18	255	105.81	83.18
	4	1	255	85.72	67.25
	5	1	255	111.45	87.45
	7	1	255	97.90	77.41

3.1. Pre-processing Techniques

Preliminary examination of utilizing raw satellite data is to verify that they are free of geometric and radiometric errors [9, 10]. Therefore, field survey was executed in 5 days for ground truthing and collect forty Ground Control Points (GCPs) using a

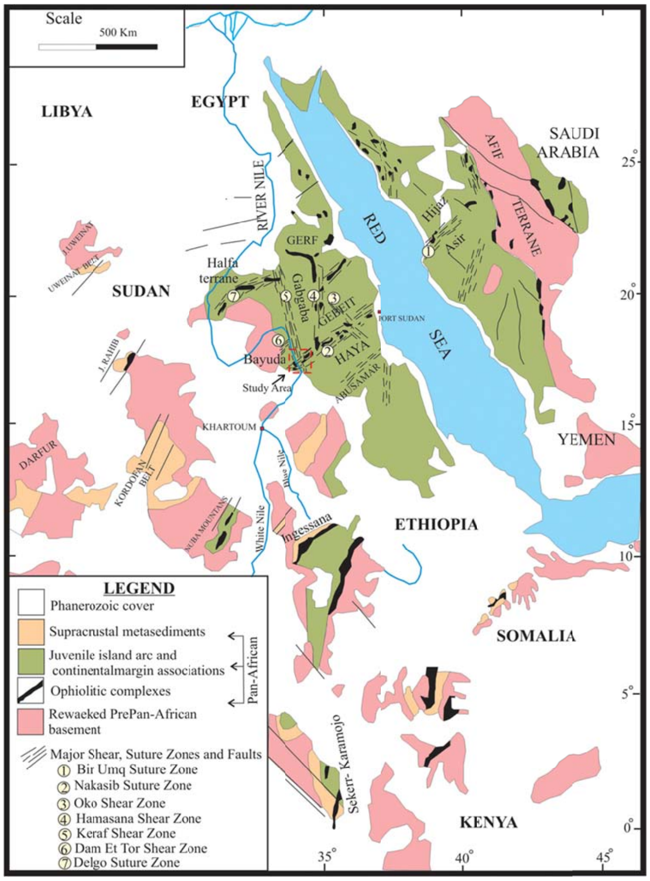

Fig. (2). Tectonic map of the Precambrian structures, major shear and suture zones of the Arabian- Nubian shield (ANS). (Modified after reference [8]).

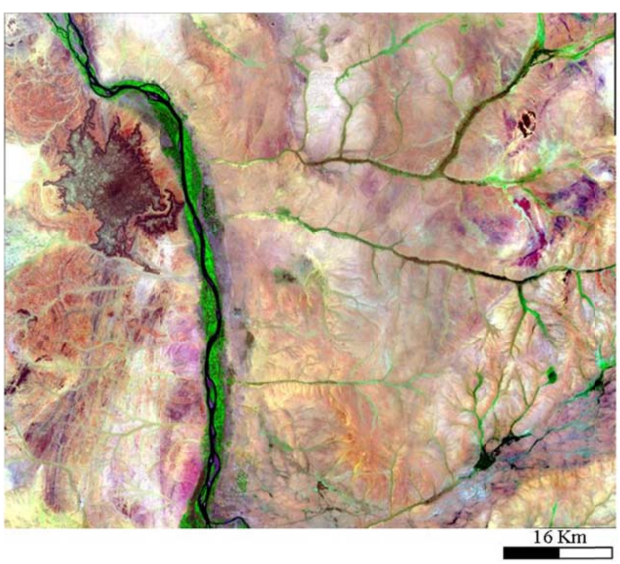

Fig. (3). A false colour composite image of bands 7, 4 & 1 in the RGB using linear contrast enhancement.

Global Positioning System (GPS) which used to confirm the spatial accuracy of the satellite imageries. To reduce the atmospheric effects such as scattering and absorption, which cause haze and produce low contrast image [11] radiometric corrections have been applied to the raw satellite data using the relative method of histogram minimum subtraction method

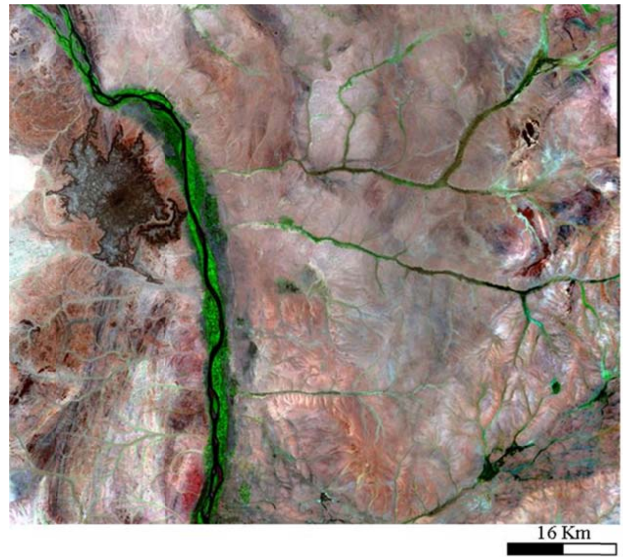

Fig. (4). A false colour composite image of bands 5, 4 and 3 in the RGB using linear contrast enhancement.

described by [12]. The calculated minimum digital number (DN) value in each band (Table **2**) is subtracted from the whole DNs in the scene of that band. The corrected imageries were subsets and mosaicked into one large image to preview a regional synoptic view using ENVI 4.5 and ERDAS Imagine® 8.6 software.

Thereafter, field geological survey data associated with their image characteristics and collecting sufficient data were used for validating the geological interpretation map generated from the satellite imageries.

3.2. Image Enhancement Techniques

Digital image processing (image enhancement) should be carried out after image correction to avoid the enhancement of the different image distortions and noises. Optimal geologic information depiction in a color composite image relies upon the selection of three channels that are individually informative and collectively minimally redundant [13]. In this study bands 7 and 5 are found to be more informative than bands 4, 3, 2 and 1 respectively. The rule for band combination is to render the most informative band for a particular purpose in red, the next in green and the least informative in blue [9]. The best lithological contrast appear to be displayed by the band-triplets 7, 4, 1 and 5, 4, 3 in R, G, B respectively. The image processing applied in this study comprises different techniques of spectral and spatial enhancement.

3.2.1. Spectral Enhancement

The recorded DNs in the satellite data are usually low and do not fully utilize the grey scale range (0 - 255 grey tones). Therefore, Spectral enhancement techniques deal with enhancing the spectral characteristics of the digital images [14]. In order to get best contrast level within the image, contrast stretching techniques areused to fully accommodate the grey scale range; so that features of interest are better shown in the image [1]. Linear contrast stretching has been applied for color composite images of bands 7, 4 & 1 and 5, 4 and 3 (Fig. **3** and **4**). The produced

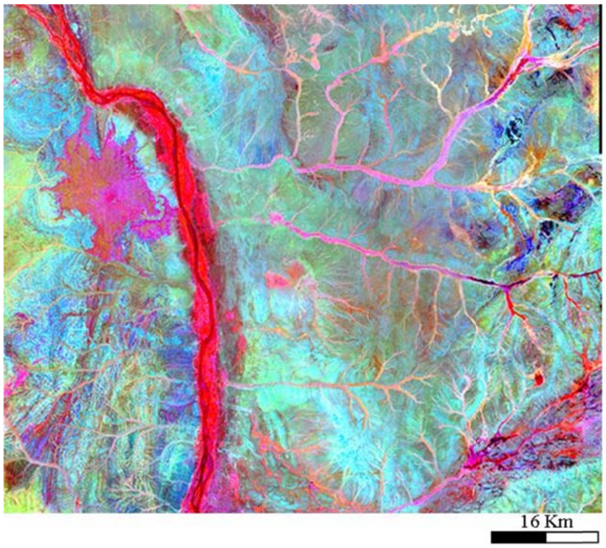

Fig. (5). Sultan's colour composite ratio image of bands 5/7, 5/1 and (5/4 * 3/4) in RGB, respectively.

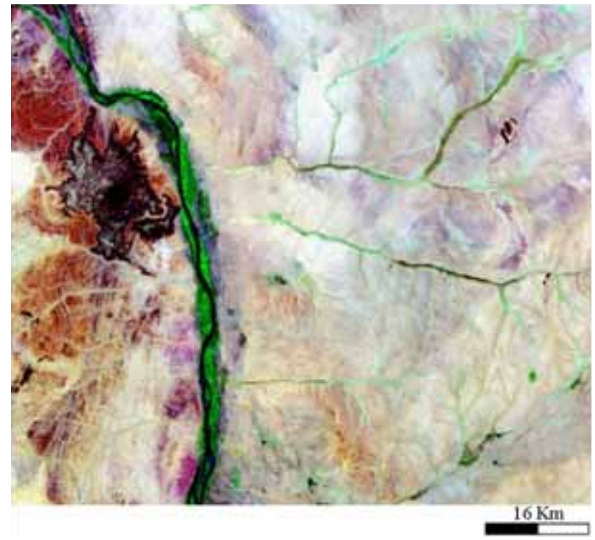

Fig. (6). IHS Saturation-stretched image of bands 7, 4 and 1 with the panchromatic band 8 in RGB colour composite.

false color composite image (bands 5, 4 and 3) has much better contrast and spectral resolution.

Major differences in topography and lithology between the terrains east and west of the Nile reduce the possibility to set the contrast enhancement to a satisfying level. Therefore, band ratioing is used to extract and emphasize differences in spectral reflectance of materials and subdues the topographic and shadow effects [11]. Ratio images are prepared by dividing the DN value in one band or more by the corresponding DN value in another band or more for each pixel where the resulting DN values represent the ratio image. Ratio images can be displayed as grey scale or colour composite image.The iron oxides and hydroxyl-bearing minerals are recognized using band ratios 3/1 and 5/7, respectively [9, 11].

In this context a color composite band ratio image of 5/7, 5/1 and (5/4 * 3/4) in RGB respectively, has been used as a powerful combination in lithological discrimination [15] (Fig. **5**).

3.2.2. Spatial Enhancement

Image sharpening is one of digital image processing methods for spatial as well as spectral enhancement. Image sharpening is performed by image fusion usually through Intensity- Hue- Saturation (IHS) transformation. The steps of IHS transformation starts with the decomposition of an RGB color composite into IHS color space; the intensity (I) is replaced by a linearly stretched high–resolution band and the saturation (S) component is linearly stretched,then the new IHS components are retransformed back to RGB color space [1].

In this study a 7, 4, 1 RGB color composite is transformed to IHS space and the intensity component is then replaced by the panchromatic band (band 8) that has a higher spatial resolution. The saturation image was then linearly stretched, while the Hue component was kept unchanged in order to ease interpretation by preserving the spatial information for qualitative studies. The resultant IHS image was then converted back to RGB color space. An RGB color composite was then prepared and a linear contrast stretch was applied (Fig. **6**).

Change in DNs per unit distance for any specific part of an image is called spatial frequency. Spatial frequencies are of two types: low frequency variations imply regional changes in the image, while high frequency variations correspond to detailed local changes [9].

Methods for selectively emphasizing or suppressing image information at different spatial scales are known as image filtering [16]. Directional filter is one of the spatial convolution filtering that detect lineaments in a specific direction, which expanding the width of the linear features and increasing the DNs across the feature as narrow lines against a background of contrasting brightness. This method is implemented through matrix operation using a convolution masks (filter kernel: 3X3, 5X5, 7X7…etc) by multiplying the kernel coefficient by the underlying input pixel values and the resulting total value is ascribed to the central pixel in the output image [11].

High-pass filter used to enhance lithological boundaries and the lineaments which are undistinguishable in the original image. The linear and edge in the original image become more obvious and sharper in the filtered image. Lineaments arenatural and man-made geomorphic features that have a surface expression, which could be fault, fracture, dykes, geological sharp boundaries or artificial road and canals. Therefore, the directional filters give good information about the lineaments in a specific direction that expanding the width of the linear features and increasing the DNs across the feature as narrow lines against a background of contrasting brightness. In this study north-south and northeast-southwest directional filter techniques have been applied for the study area and the adjacent area to the east of longitude 34º 30̀ (Fig. **7a** and **b**) using color composite image of band 7, 4 & 1 to delineate the regional structure lineaments. Linear structures in the original image became more obvious and sharper in the filtered image, and a new regional structural lineament map was constructed (Fig. **8**).

4. RESULTS AND DISCUSSION

Based on the above mentioned digital image processing techniques the images became more interpretable. When

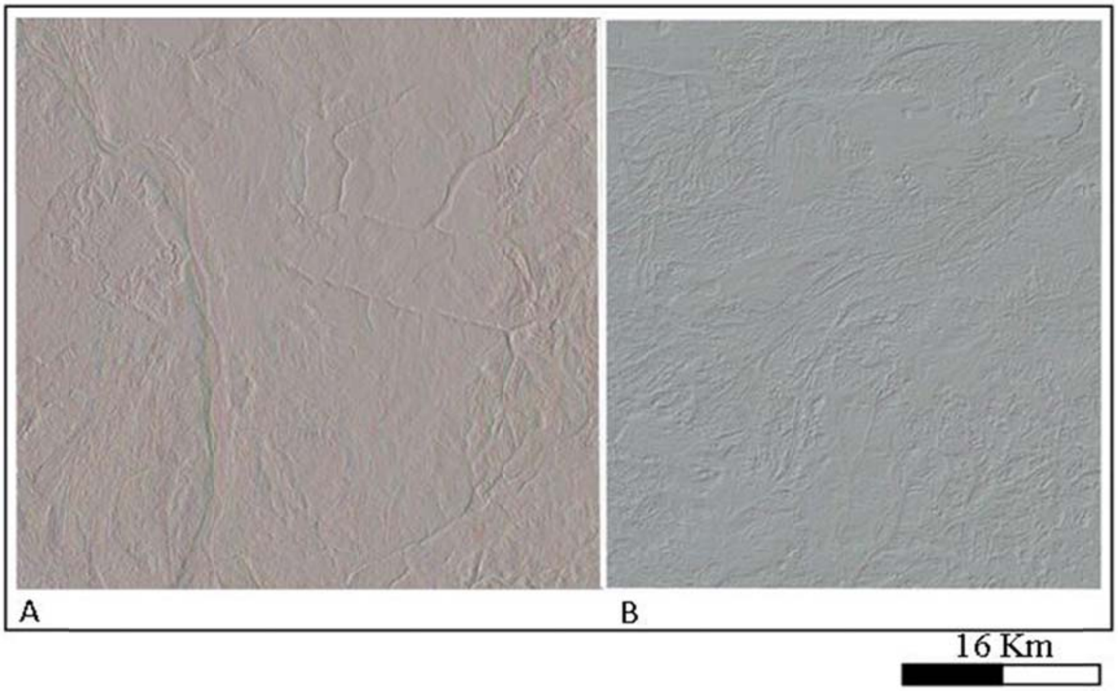

Fig. (7). Directional filtering of bands 7, 4 and 1 color composite image. **A**) N-S directional filter of study area. **B**) NE-SW directional filter (the area east of longitude 34º 30̀).

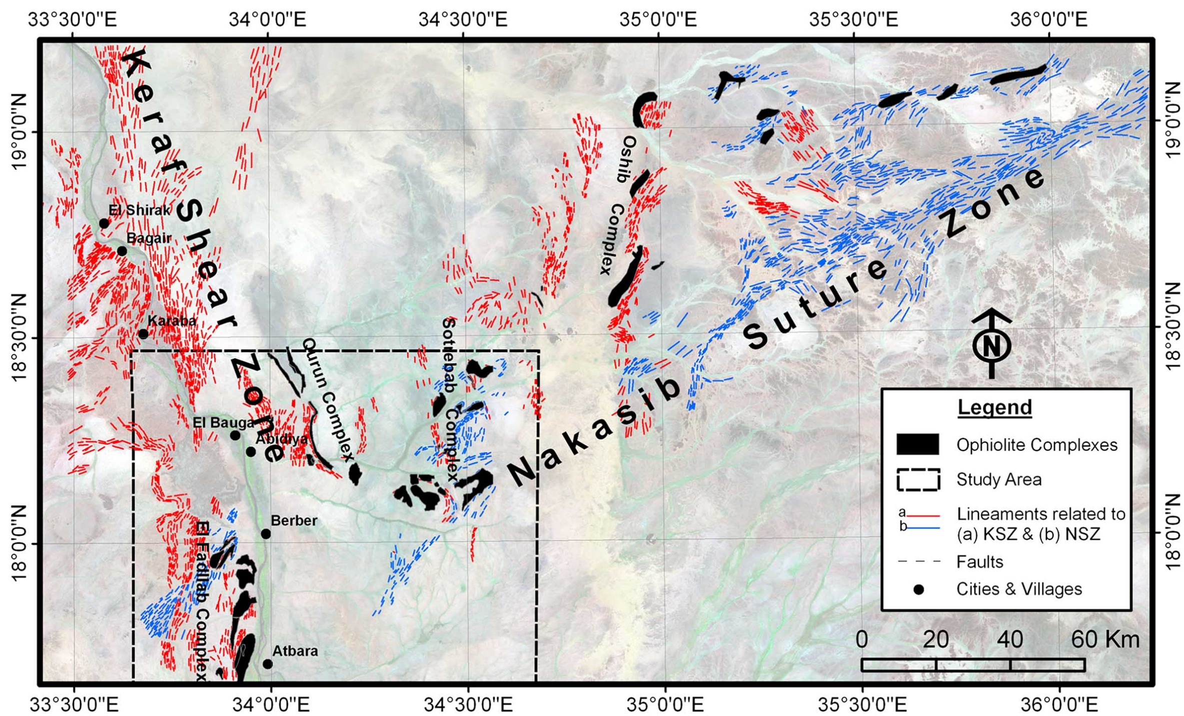

Fig. (8). Tectonic lineament map interpreted from Landsat ETM+7.

image data is available and radiometrically quantified into discrete brightness levels, several approaches are possible to extract information. Information provided by remote sensing have been verified and confirmed by ground trothing and lead to refine the scale of the output geological map (Fig. **9**) based on the following results:

1. The contrast enhancement applied to color composite images of bands 7, 4, 1 and 5; 4; 3 (Fig. **3** and **4**) are suitable for identifying and distinguishing major geological units and topographical features such as wades, which became more distinguishable in the new image. The syn-orogenic granites and mafic - ultramafic ophiolitic rocks mainly exposed east of the River Nile are deeply eroded and crop out as low-surface exposures. They can be differentiated by their tones, since the felsic and intermediate granitic rocks are lighter in color due to their mineral composition as well as their sandy weathering products. The metavolcano-sedimentary rocks

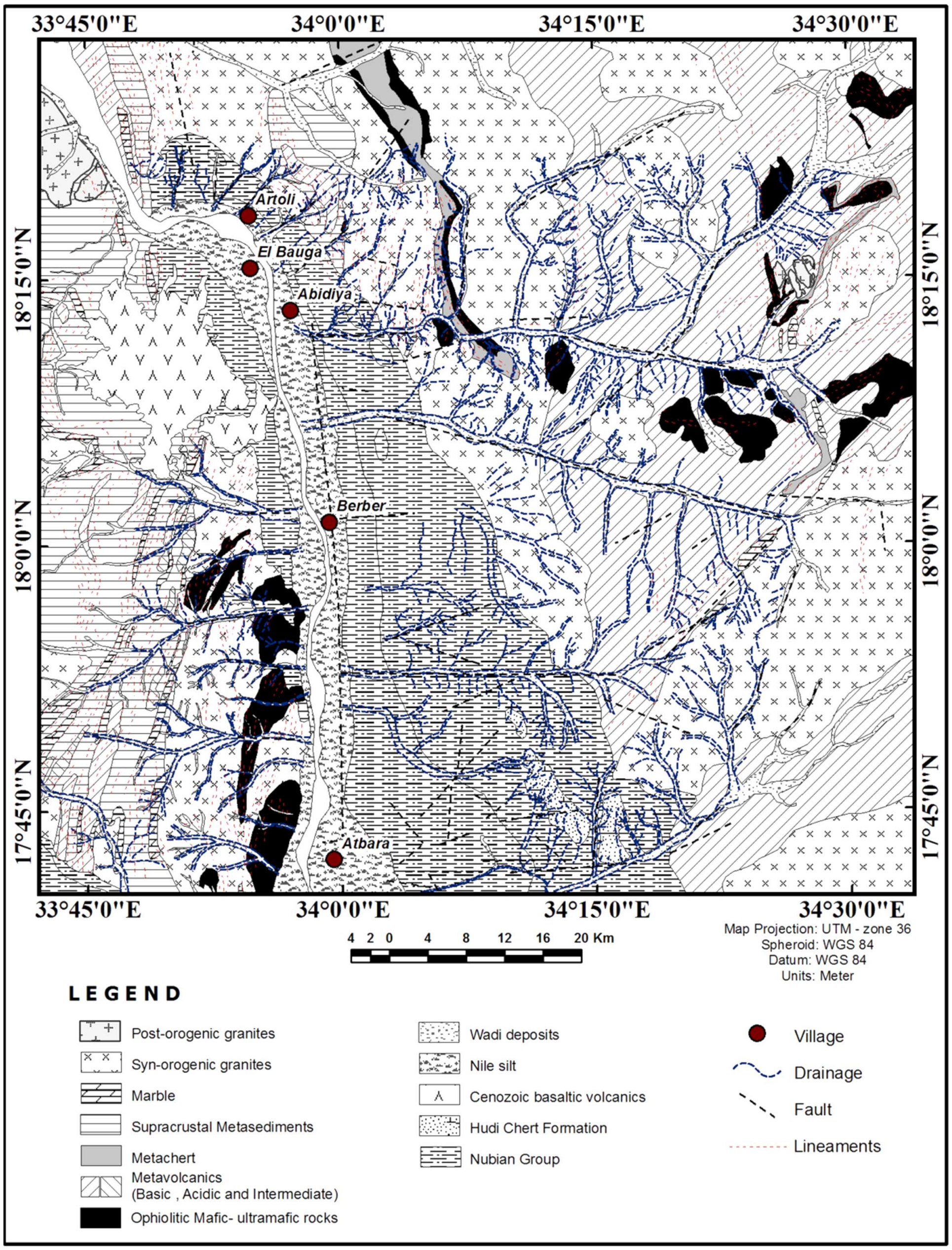

Fig. (9). Geological interpretation map of the study area.

have medium relief and distinguishable foliation trend; however, it is clearly that the basic metavolcanics display dark brown hues (Fig. **3**) and dark reddish colour (Fig. **4**). The intercalated carbonate layers show discernible low relief with dark cyan -blue tints in 5, 4 & 3 and 7, 4 & 1 image. Post-orogenic granites are revealed by their oval shapes in high distinctive relief with dark reddish brown color in different used colour composite images. The alkaline Cenozoic basaltic lavas are notable by their high absorption and deep black color. They show outstanding geomorphological prints of their volcanic cone shape and bold rims lava flows. The Nile silts and alluvial deposits are characterized by high absorption caused by clay contents and usually masked by green vegetation cover.

2. Band ratios and multiplication techniques maximize rock discrimination because they are sensitive to specific chemical and mineralogical components of the rock. Therefore, Sultan's colour composite ratio image of band 5/7, 5/1, and 5/4*3/4 set into R, G, B respectively, is found suitable image for distinguishing lithological units. This technique, display felsic and granitic rocks in green-blue hues, mafic and ultramafic rocks appear reddish hues (Fig. **5**). The red color of the ophiolitic mafic- ultramafic rocks ascribed to the band 7 high absorption feature of ferromagnesium and hydroxyl bearing minerals.

3. The Intensity-Hue-Saturation (IHS) transformation as shown in Fig. (**6**) proved to improve the spatial resolution as well as the spectral characteristics, where details of lithological units are more obvious and distinguishable.

4. Directional filtering enabled the delineation of structural features such as lineaments, faults and fractures. The N-S and NE-SW lineaments predominate and represent the Keraf shear zone (KSZ) and Nakasib suture zone respectively (Fig. **7a** and **b**). Filtered image indicated that the drainage patterns are structurally controlled, where the original image showed that these wades are fully covered by sand and grasses (Fig. **3**, **4**). Regional lineament delineation, supported by the filtered satellite data, revealed the extension of the KSZ related lineaments to the vicinity of Atbara city. It is obviously that the Nakasib suture can be traced in the filtered image further west of longitude 35° E up to the west of the River Nile (Fig. **8**).

5. CONCLUSIONS

The major problem faced in conventional geological mapping is the accurate delineation of geological boundaries and tracing the regional tectonic structures. This study demonstrated the potential of digital image processing technologies for geological discrimination and structural enhancement. Landsat ETM^+7 satellite data were used, to study the area between NE trending Nakasib Suture Zone of the Nubian Shield and north trending Keraf Shear Zone, around Abidiya area, north Sudan. Several digital image processing techniques were applied to improve visual image interpretation for geological purposes, such as Lithological identification and lineament delineation. Spectral and spatial enhancements are the main digital image processing techniques. Contrast stretched color composite images 7, 4, 1 & 5, 4, 3, set in R, G, B respectively were used to extract the initial geological information. The band ratio color composite image 5/7, 5/1, and 5/4*3/4 set into R, G, B respectively, showed clear discrimination of felsic and granitic rocks from mafic and ultramafic lithology of ophiolitic origin. Intensity, Hue, Saturation (HIS) transformation method is used to enhance the spectral characteristics as well as the spatial resolution of the color composite 7, 4, 1 and proved to be better in enhancing geological information extraction. Structural lineaments, faults and fractures were carefully delineated with the help of directional filtering. One of the fruitful results of this study is a refined geological map for the study area. Moreover, this investigation revealed the continuation and intersection of the Nakasib Suture–related lineaments with the Keraf Shear Zone west the River Nile.

This study has clearly concluded that the remote sensing technologies display better tool for enhancing and improving geological mapping. Landsat ETM^+7 remotely sensed data proved to be a potentially rich source of inherited geological information.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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