



Identifying Alluvial fans features using multispectral image processing techniques in selected area, northern Iraq

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Article info

Original:
11 January 2016
Revised:14 June 2016
Accepted:31 July 2016
Published online:
20 December 2016

Key Words:

Alluvial fans, image transformation, image enhancement, DEM, tectonic

Abstract

Landsat 7 Enhanced Thematic Mapper Plus image data was used to identify and map alluvial fans features in Shaikh Ibrahim anticline northern Iraq. In the present study, an active flowchart was design to extract and determine alluvial fans using digital image processing operations and digital elevation analysis. Two image processing methods including (image transformation and image enhancement) were used. Image transformation including principal component analysis (PCA) and ratio images (RI) analysis, while image enhancement operation including false color composite images (FCC). In image transformation processing, Based on the detailed analysis of eigenvectors and eigenvalues derived from different combinations of (PCA), five (PC) images of bands (13457) have been extracted and –PC4 has relatively strong positive loading for band 5 (0.632166) and high negative loading for band 7 (-0.369417) consequently, PC4 was given effective delineation about the major alluvial fans at the southwestern footslope from Shaikh Ibrahim anticline. In ratio image analysis, A combination of (RI) based on the spectral characteristics of alluvial fans materials were selected. Image enhancement includes A false color image of the subscene was produced by assigning band (741). This color composite was found to be useful in emphasizing to the all materials of alluvial fans. Digital elevation models (DEM) were used for describing topographic features related to the alluvial fans.

Introduction

The present study represents an endeavor of applying remote sensing and digital image processing alluvial fans studies. Since the inception of the Landsat program in the early 1970s, remote sensing in particular has become an increasingly important tool for improving conventional methods of data collection and map production in geosciences (Badaway, 2008). The potential of using remote sensing accompanied by digital image processing in geology and geomorphology has been long term discussed in the principal literatures such as (Lillesand and Kieffer 1994; Sabin, 1997). In mountain areas, digital elevation models (DEM) are fundamental for the geological and geomorphological analysis of satellite imagery. Digital elevation models are providing topographic information which is can be used to describe more completely the distribution of terrain components contributing to spectral response (Franklin, 1991). In the present study, an active method was used to extract and determine the alluvial fans using digital image processing operations and digital elevation analysis. The advantage of this study is its capability for applying in the areas which their alluvial fans characterized has relatively small size and the fan –shape invisible. The purpose of this study also is to improve the relationship of the extracted alluvial fans with the tectonic setting

of Shaikh Ibrahim anticline. The relevance of the detected alluvial fans to the tectonic setting that will be examined could provide new insights into the role of tectonic control on the alluvial fans genesis.

Previous studies

Previous studies related to the alluvial fans in Shaikh Ibrahim anticline are not reported and the current study is the first in exploring and delineating these features at this anticline. Therefore, just the studies which are related to the alluvial fans in the northern Iraq will be described in detail below. It has been noticed that the most of these previous studies related to Sinjar anticline northern Iraq. In this context, the interesting alluvial fans of the Sinjar anticline have attracted the attentions of many researchers in Iraq.

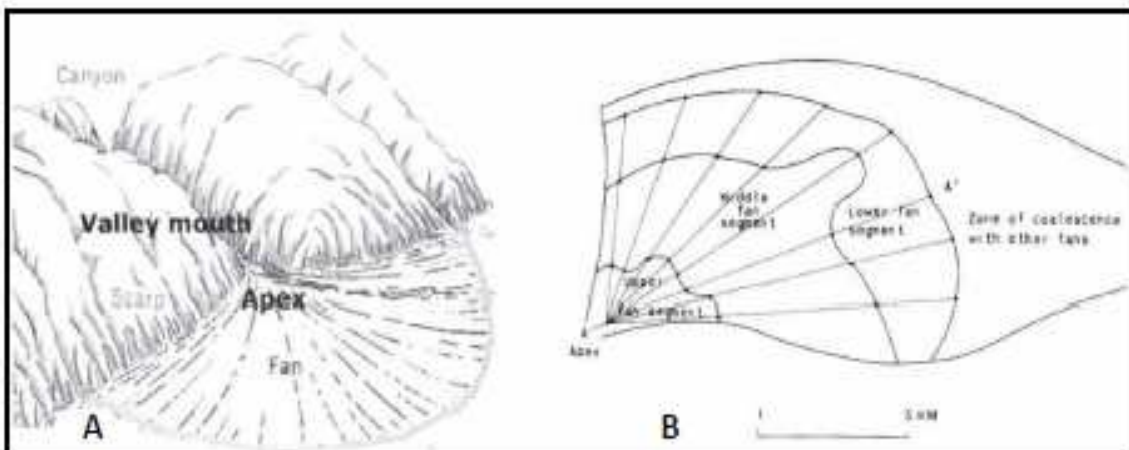
1. Ma'ala (1977) executed regional geological mapping of Sinjar anticline and surrounding areas. He delineated two stages of alluvial fans that were developed during Pleistocene – Holocene.
2. Al-Daghastani (1989), creates geomorphological map of Sinjar anticline from interpretation of black and white aerial photographs, scale 1:50,000, and he recognized one stage of alluvial fans surrounded by accumulation glaciais.
3. Sissakian (2011), also studied on alluvial fans in Sinjar anticline and he described four stages of alluvial fans in the northern limb.
4. Al- Sa'igh (2012), performed morphotectonic study of selected alluvial fans in the low folded zone using remote sensing techniques. This study identifies new alluvial fans in Sinjar, Bashiqa, Maqlub and Alqush anticlines.

Geomorphologic Knowledge of Alluvial Fans

Alluvial fans are a conspicuous conical landforms commonly developed where a channel emerges from a mountainous catchment to an adjoining valley plain at the break of slope. Alluvial fans are formed due to where steep high power channels enter to another zone of reduced stream power as a result of decrease of gradient due to drop in local base level (fig. 1). Hence, the Alluvial fans develop at the base of streams where feeder channels release their solid load (Blair and McPherson, 2009). According to (Mllaresls and Argialas, 2000), the Alluvial fans exhibit a characteristic semi-circular, semi-conical shape, (Bissenbach, 1954) states that the main morphological parts of alluvial fans are:

1. The fan-head, the area of the fan closest to the apex (the highest point of an alluvial fan where the stream emerges from the mountain valley).
2. The fan-toe (or fan-base), the outermost or lowest zone of the fan
3. The mid-fan, the area between the fan head and the fan-toe.

Alluvial fans commonly occur in regions of active deformation and therefore often used as a proxy for tectonic activity. Whereas on a quaternary timescale, alluvial fans evolution is strongly controlled by climate changes and in some cases by base-level changes (wells et al., 1987; Al-Sa'igh, 2012). Alluvial fans common in arid and semi-arid areas which are characterized by decreasing in the amount of rain water precipitation. Consequently, the vegetation and weathering would be limited and sediment transport would be restricted to dry mechanisms such as the rock fall and rockslide.



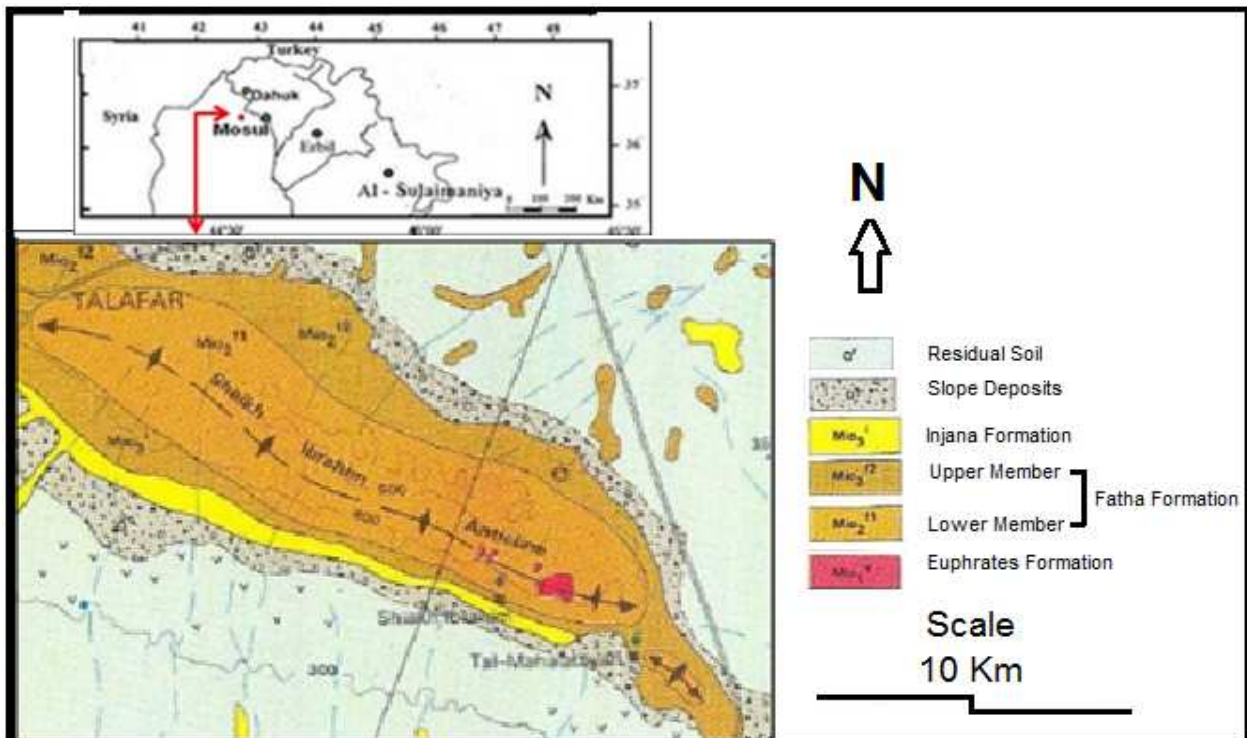
Figuer-1: Morphology of alluvial fans. (a) Fan developed in front of a valley mouth at the adjacent valley floor. (b) Development of an alluvial fan with segmented radial profile. Bull (1977).

Location and geologic setting of the study area

The area under study is located in the western part of Mosul city, specifically on the footslope zone of Shaikh Ibrahim anticline with geographic position between (Lat. 36°20'30"N and 36°12'30 "N) and (Long. 42°60'0"E and 42°35'30"E), and it covers about (300) km2. Generally, foot slope zone of this area represents a zone of Quaternary deposits or pediment surface surrounds the major exposed folds (i. e. Shaikh Ibrahim and Almohalabiya anticlines). Shaikh Ibrahim anticline is the major anticline in the study area. Geologically, this anticline lies mainly in the low folded zone in Iraq and is asymmetrical, cylindrical and double plunging anticline. The fold axis of this structure trends towards North West – south east as well as, the vergence towards the southwestern part (i. e. steeper southwestern limb). According to Iraqi state company of geological survey (Geosurv, 1995), stratigraphic units being exposed on the surface of this anticline consist of two main geological formations (fig. 2). Fath'a is the first formation (Middle Miocene) which is exposed widely and divided into two members: Lower member consisting of green marl, limestone and gypsum, when the upper member consisting of green marl, claystone, green marl, limestone and gypsum. Injana is the second formation (Upper Miocene) consists of red and reddish brown clastic rocks (sandstone, siltstone and claystone). Also the stratigraphic units in the Shaikh Ibrahim anticline consist of limited extension lithological units of Euphrates-Jeribe formations (Lower-Middle Miocene) which forms continuous strike ridges and are partly exposed in the core of the anticline. The study area has a semi-arid climate.

Techniques and data used

The data utilized in this research is a subset of single spectral bands of Landsat-7 ETM+ data set (Row 35/Path 170- dated 13 Jun 2001). These images also are geo-referenced to the UTM coordinate system, Zone 38 North based on some available topographic maps with acceptable root mean square error. Using (ENVI 4.6) software a number of processes have been done to the used bands in order to get the high efficiency of extracted alluvial fans. Geographical Information Systems (GIS) software (ArcGIS 9.3) is utilized to prepare final maps of the alluvial fans.

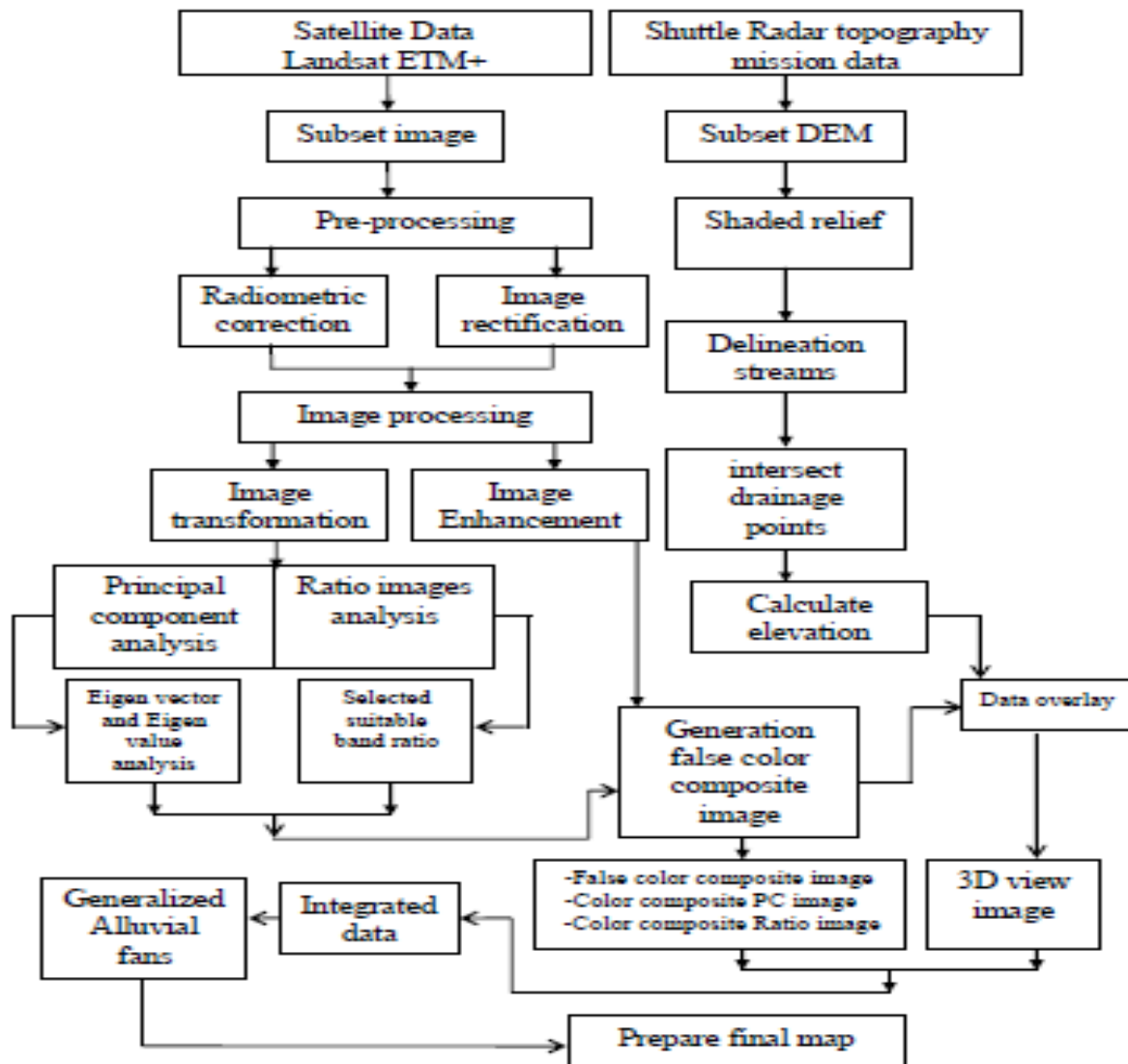


Figuer-2: Geological map of Shaikh Ibrahim anticline, after (Geosurv, 1995)

Methodology

Different methods of image processing are applied to fulfill the acceptable extraction of the alluvial fans as well as to define the main characteristic features of these fans in the study area. The flow chart designed below was utilized as a methodology to extract the alluvial fans in the study area (fig. 3). Methodology could be summarized as follows:

1. Pre-processing operation includes FLAASH corrections (to remove atmospheric noise) and image rectification to correct the image geometrically.
2. Image transformation using principal components analysis and band ratio of Landsat ETM+ data. And then use the Eigenvalue and Eigenvector in principal component analysis and use the best rationing combination images in ratio images for detecting the alluvial fans.
3. Image enhancement using false color composite image to extract and display alluvial fans in suitable color.
4. Extract the hill shaded relief from the digital elevation models to display Terrain features viewed at specific angle.
5. Delineate the streams with their main secondary channels to detect the catchment area of alluvial fans
6. Extract the intersect drainage points in order to determine alluvial fan head.
7. Determine elevation zone to study the relationship between the elevation and alluvial fans.
8. Product 3D view image to display the fan and clarify the extensions of these features in 3D
9. Integrated all previous data to conclude the role of tectonic setting in the control of these features.



Figuer-3: The flowchart of this study

Data Preprocessing

1. Preprocessing

Before applying image processing methods to extract the alluvial fan, it was necessary to apply certain preprocessing so that to have the same reference system for all data and to handle certain acquisition errors. The Landsat ETM+ imagery was projected to UTM projection (WGS, Zone 38 N), path and row of the image were 170 and 35 respectively, dated 13 June 2001. A subset throughout the whole scene covering only the study area was extracted. The Landsat ETM+ data were corrected for haze and atmosphere interference by using ENVI'S FLAASH method, or Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercube.

2. Image transformation

Satellite images are often composed of many bands. In such cases it is possible to combine them to obtain one or more new bands more directly related to the parameters of interest and less dependent upon other characteristics. In other cases, the combination of bands aims at compressing the information in with a minimum loss (Mather, 1987). In this study, two types of image transformation methods were used. The first: principal components analysis (PCA) and the second: ratio images (RI).

A. Principal Component Analysis

Principal Component Analysis (PCA) is a technique used in various lithological and geological mapping studies. The Principal Component Analysis (PCA) is a useful statistical technique used to produce uncorrelated bands, as well as to isolate noise components, and reduce data quality without the loss of its spectral information. Transformation of the raw remote sensor data using principal component analysis can result in new images which are may be more readily interpretable than the original images. Principal Component bands produce more colorful composite images than spectral color composite images, because data are uncorrelated (Jensen, 2005). Alluvial fans in the study area are consisting of eroded rock fragment, clay and calcareous and/or sandy materials. These alluvial fans materials are show diagnostic spectral characteristics on several ETM+ bands, including the visible spectrum (bands 1 and 3) and the near and middle infrared (bands 4, 5, and 7). Clay minerals and calcareous exhibit diagnostic absorption spectral features centered at 2.20 and 2.35 μm (band 7), respectively, and high reflectance at 1.65 μm (band 5) (Hunt, 1977 and Goetz and Rowan, 1983 in Yang et al., 2000).

The principal component images which are extracted from Shaikh Ibrahim anticline Landsat ETM+ bands are showed in (Fig. 4), using the five reflected ETM+ bands as input bands. The bands of (13457) were given effective delineation about the major alluvial fans at the southern foot slope from Shaikh Ibrahim anticline and their eigenvectors and eigenvalues are listed in (Table 1). Based on the sign and magnitude of the eigenvectors, this technique (PCA) indicates whether the materials are represented by bright or dark pixels. PC1, with an eigenvalue magnitude of 80.25% of the total variance, gave a view much like a black and white panchromatic aerial photo and gives information mainly on albedo and topography. Clay and carbonate minerals have opposite spectral characteristics on spectral Landsat bands (5 and 7) , so the PC image that best discriminates them is that with a moderate or high eigenvector loading, irrespective of sign, for (band 7) and a moderate or high eigenvector loading of opposite sign for (band 5). As shown in (Table 1), 13457-PC4 has relatively strong positive loading for band 5 (0.632166) and high negative loading for band 7 (-0.369417). Consequently, clay and carbonate minerals are manifested as dark pixels. Principal component color composites consisting of red (PC4), green (PC3) and blue (PC2) were most informative. The PC4–PC3–PC2 color composite (Fig.4) clearly delineates the major alluvial fans.

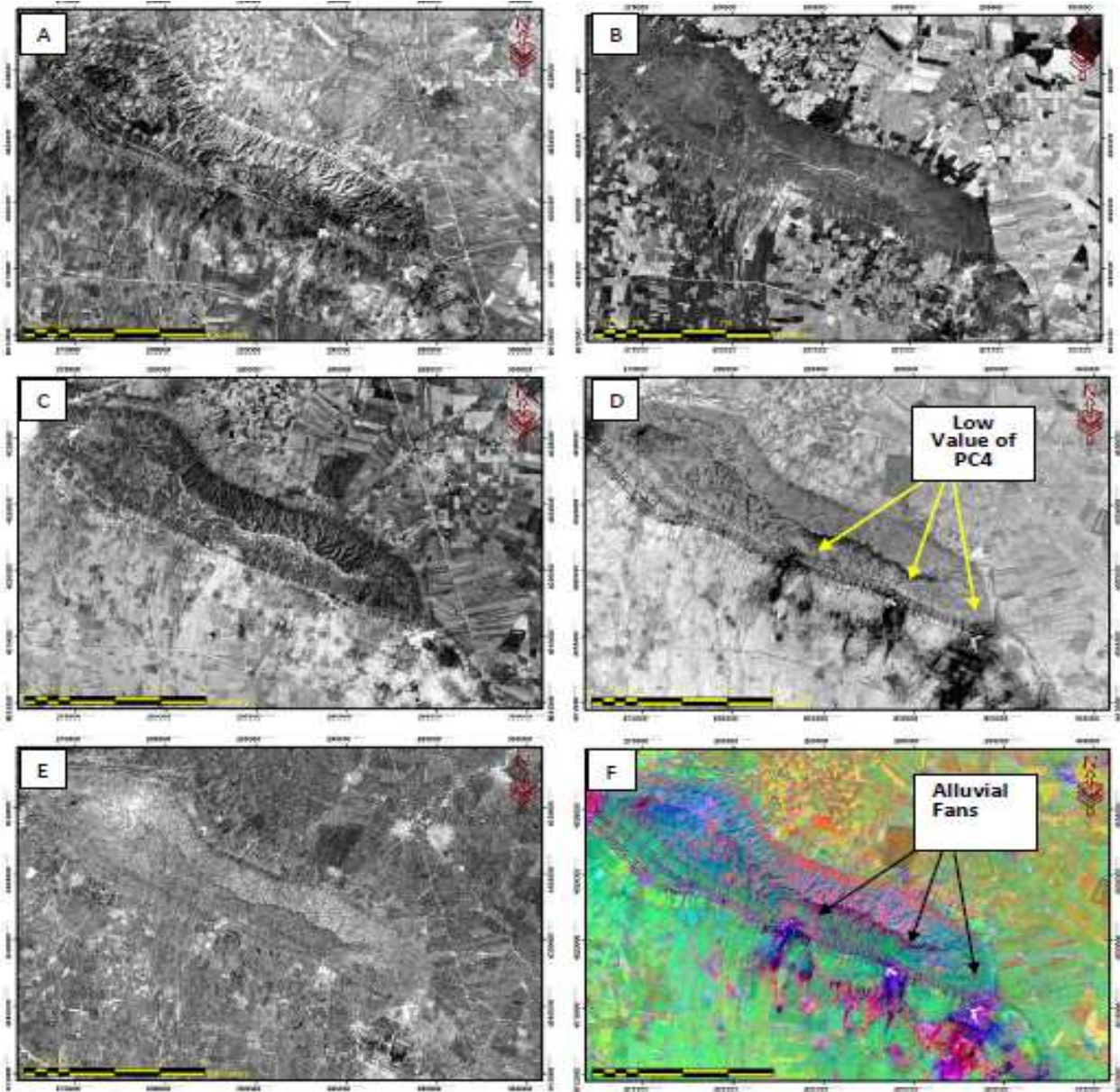


Figure-4: Principal component analysis. A: PC1, B: PC2, C: PC3, D: PC4, E: PC5 and F: FCC principal component image (PC4 Red, PC3 Green, PC2 Blue).

Table 1: Eigenvector and eigenvalue of PC images

Eigenvector	Band 1	Band 3	Band 4	Band 5	Band 7
Pc1	-0.442612	-0.477889	-0.436373	-0.465835	-0.410236
Pc2	-0.223281	0.225694	0.626425	0.020481	-0.711604
Pc3	-0.775203	-0.140583	0.093997	0.531447	0.296690
Pc4	0.380029	-0.555431	-0.104746	0.632166	-0.369417
Pc5	0.094228	-0.626432	0.630368	-0.317029	0.317542

Basic Stats	Min	Max	Mean	Stdev	Num	Eigenvalue
Pc1	194	5285	1432.628820	209.068228	1	4.012683
Pc2	488	6045	3051.530858	340.240701	2	0.554017
Pc3	1308	7400	4018.164054	366.500407	3	0.281981
Pc4	1168	7173	4478.044309	351.673966	4	0.114185
Pc5	775	8605	3790.497464	409.035781	5	0.037134

B. Ratio image

Ratio images (RI) is a well-developed technique, which utilizes spectral properties of certain minerals that influence the radiant of various rock types, therefore the major target of applying ratio images is to enhance the spectral differences between the image bands and reduce the effects of topography (R.S.I. 2003). Landsat ETM+ band-ratio images can be effective in utilizing the full potential of the spectral information, as well as, the band-ratio images generated from orbital multi-spectral optical remote sensing data can distinguish different rock types in many cases better than when only bands are used in the RGB color combination images (Abrams, 1984; Abdelsalam et al., 2000). Band rationing convey the spectral or colour characteristics of the image features regardless of variations in scene illuminations. It is often useful for discriminating spectral variations in a scene that are masked by the brightness variations (Lillesand and Kiefer, 1994). The operation is performed by division of pixel digital number (DN) of two bands and then producing an image that provides relative band intensities. According to Landsat-7 satellite bands (excluding panchromatic and thermal infrared bands), thirty possible combination could be produced. In order to determine band-ratios to be used for RGB color combination images is by examining spectral curves of dominant lithological units that are potentially present in the region covered with the orbital multi-spectral optical remote sensing data (Abdelsalam et al., 2000a).

According to the purpose of this study and after emphasis to the spectral curve of the alluvial fans materials and also after tested all of possible combination thirty ratio bands, Band ratios of specific Landsat ETM+ bands can detect alluvial fans features and band ratios of (5/7, 3/1, 4/5) have often been adopted for the materials of all alluvial fans in the study area (fig. 5). The band ratio of (5/7) has been effectively used in arid and semi-arid regions for mapping clay concentrations because clay minerals have high reflectance in (band 5) and low absorption feature in (band 7) (Sabins, 1997; Abdelsalam et al., 2000). The band ratio of (3/1 and 4/5) are two of the most common powerful combinations for lithological mapping in geological studies (Abrams, 1984). Three different band ratios with assigned particular color of RGB composite have been selected to identify the border of alluvial fans using band rationing technique. As shown in (Fig.5), colored composite ratio images using ETM+ Landsat bands: (4/5-R), (3/1-G), (5/7-B) have been used as a best selected ratio bands in this study. The Pink and dark blue or indigo colors determine and delineate the border of alluvial fans into the southern footslope of Shaikh Ibrahim anticline, as well as detect the structural framework of this anticline.

3. Image enhancement

This processing included color composite images of ETM+ data. Generally, digital images are typically displayed as additive color composites using the three primary colors, red, green and blue (RGB). Different spectral bands of ETM+ data have been selected and combined in RGB color system to make color composite images for the studied areas. These combinations were tried to select the best color composite ETM image to be useful in extracting meaningful information about the alluvial fans features. A false color image of the sub scene was produced by assigning band (741). This color combination was found to be useful in emphasizing to the all materials of alluvial fans. As shown in (Fig. 6), the alluvial fans appears dark violet to blue color because of relative absorption in band 7 and 4 bands.

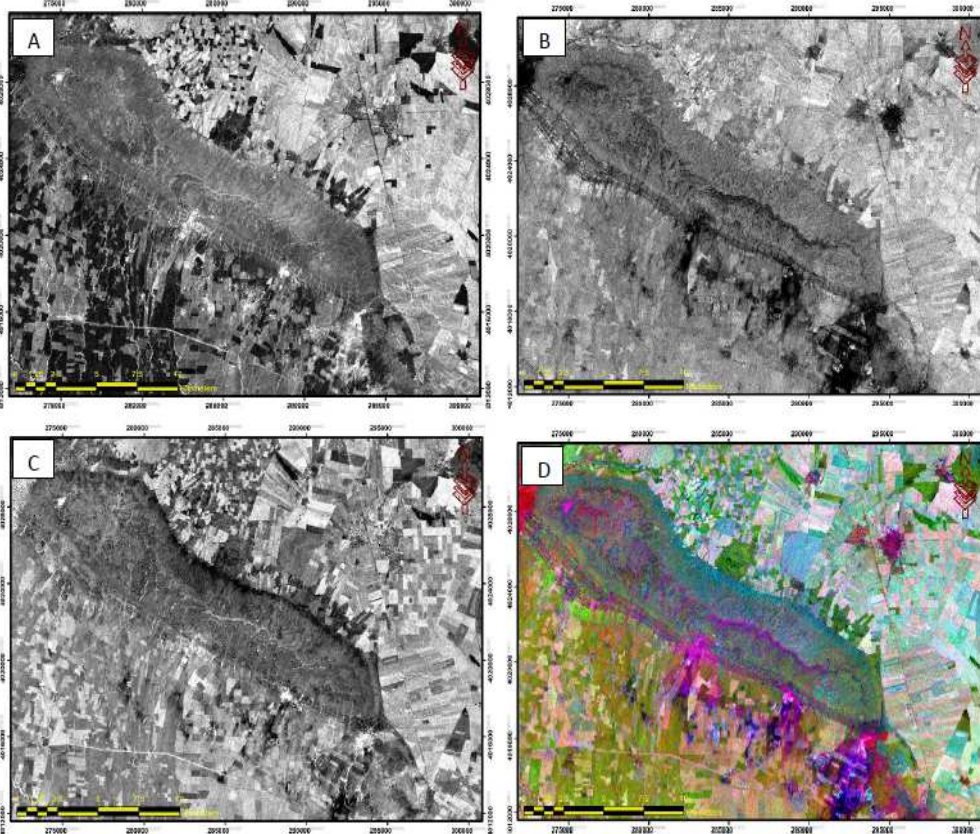


Figure-5: Ratio images analysis. A: (4/5), B: (3/1), C: (5/7) and D: FCC Ratio images (4/5 Red), (3/1 Green), (5/7 Blue)

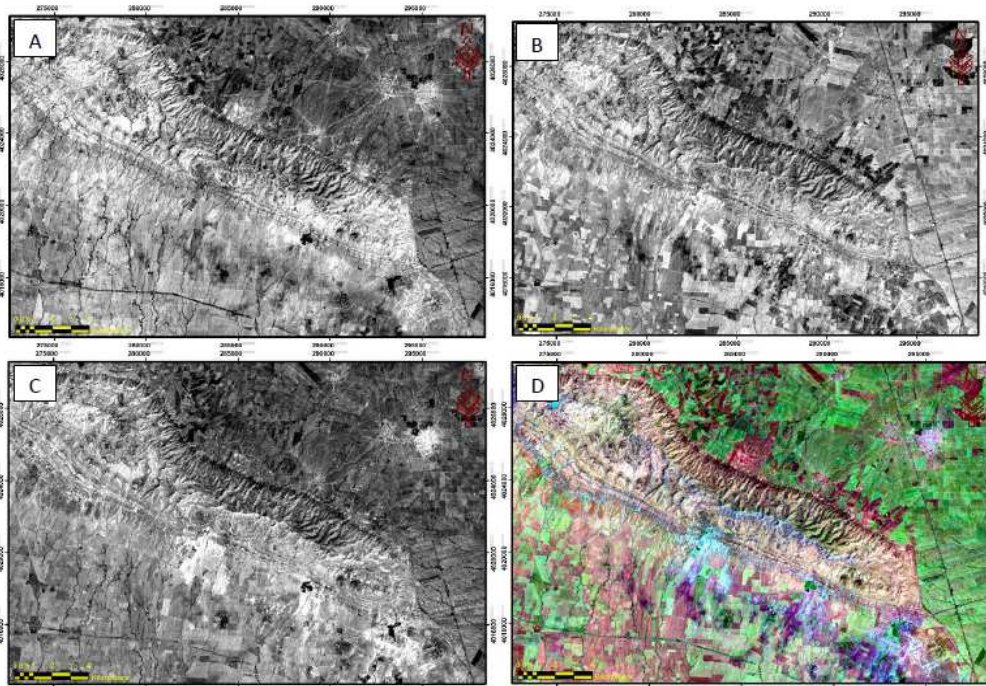


Figure-6: color composites image. A. band 7, B. band 4, C. band 1 and D. FCC 741

Alluvial fans recognition from DEMs

The main objective from using the digital elevation models in this study was the investigation and implementation of sequential models for the clarification and determination of alluvial fans based on their topographic features from digital elevation models. Data used included the 30-degree Digital Elevation Model with 30m grid size (Fig.7) some of models are performed at different levels as the following:

1. Shaded relief Hill

Shading is a technique for generating shaded topographic images of the Earth's surface elevations it simulates the reflection of artificial light arriving from a point source of illumination from a given altitude (inclination) and azimuth (declination). Terrain features viewed at all angles receive graduated shades of gray as a function of the cosine of the angle between the illumination vector and a vector perpendicular to the terrain surface (Masoud and Koike, 2006). Shaded relief maps of the study area by have been produced by selection azimuths (45°) in order to cover the direction of the alluvial fan in south western parts of Shaikh-Ibrahim anticline (fig.7). A shaded relief map was used also to extract the drainage network within study area.

2. Delineation streams

With the availability of digital elevation models (DEM) and GIS tools, drainage can be extracted by using automated procedures. Arc Hydro tools were used to process a DEM to delineate stream network (fig. 7).

3. Extract intersect drainage points

This model Create a drainage point at the most downstream point in the catchment as well as allows generating intersect drainage points in order to detect the flow points in the head of a alluvial fan. As shown in (fig. 7) the most of intersect drainage points are align in a straight or slightly curving relationship in the Alluvial fan Apex zone at the south western part of Shaikh-Ibrahim anticline.

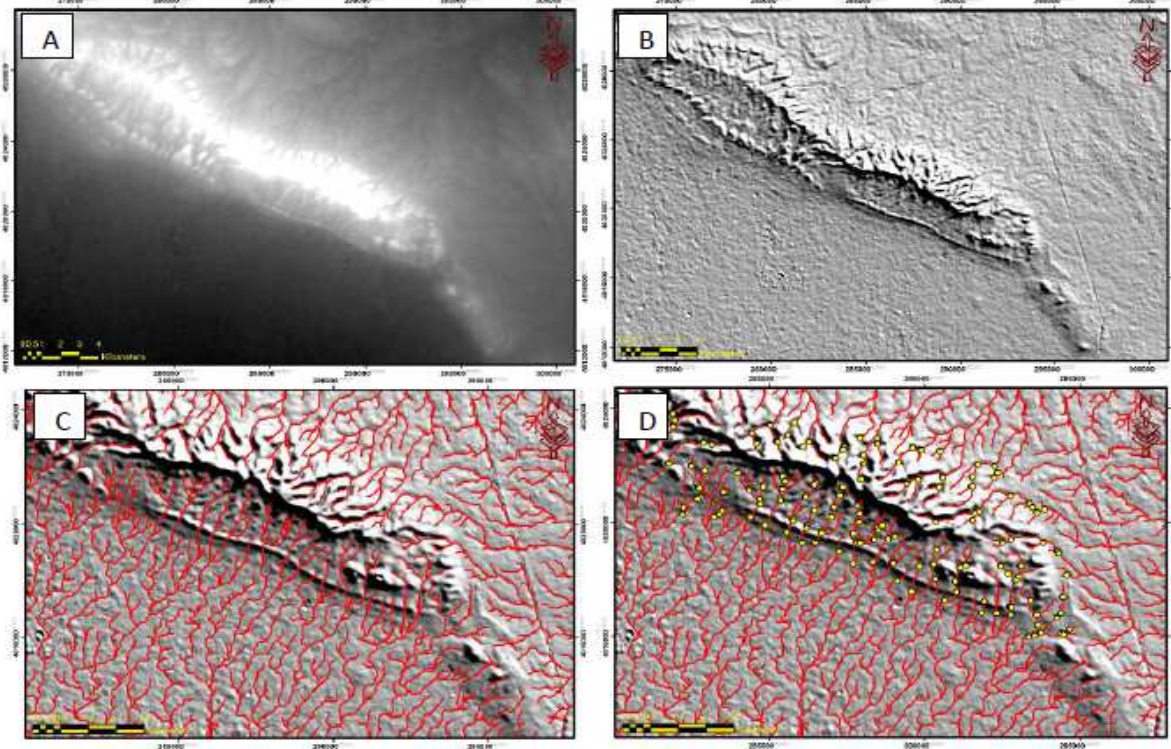


Figure-7: Digital elevation models analysis. A: Raw DEM, B: Shaded relief Hill shading, C: Auto delineation stream, D: Extract intersect drainage points.

4. Detect the elevation of the alluvial fans plain

Digital elevation model of the alluvial fans plain was delineate and classified in order to detect the elevation of all parts of these features. More specifically, A 1:80,000 subsample of digital elevation model for the study area was taken. This subsample reclassified from the original data of DEM. The elevation was extracted by polygon using density slice processing in ENVI software. Nine zones of elevation were extracted and their elevation value ranged from (371m) to (303m), (fig.8). These zones were selected depending on the intersect drainage points locations of the alluvial fan apex.

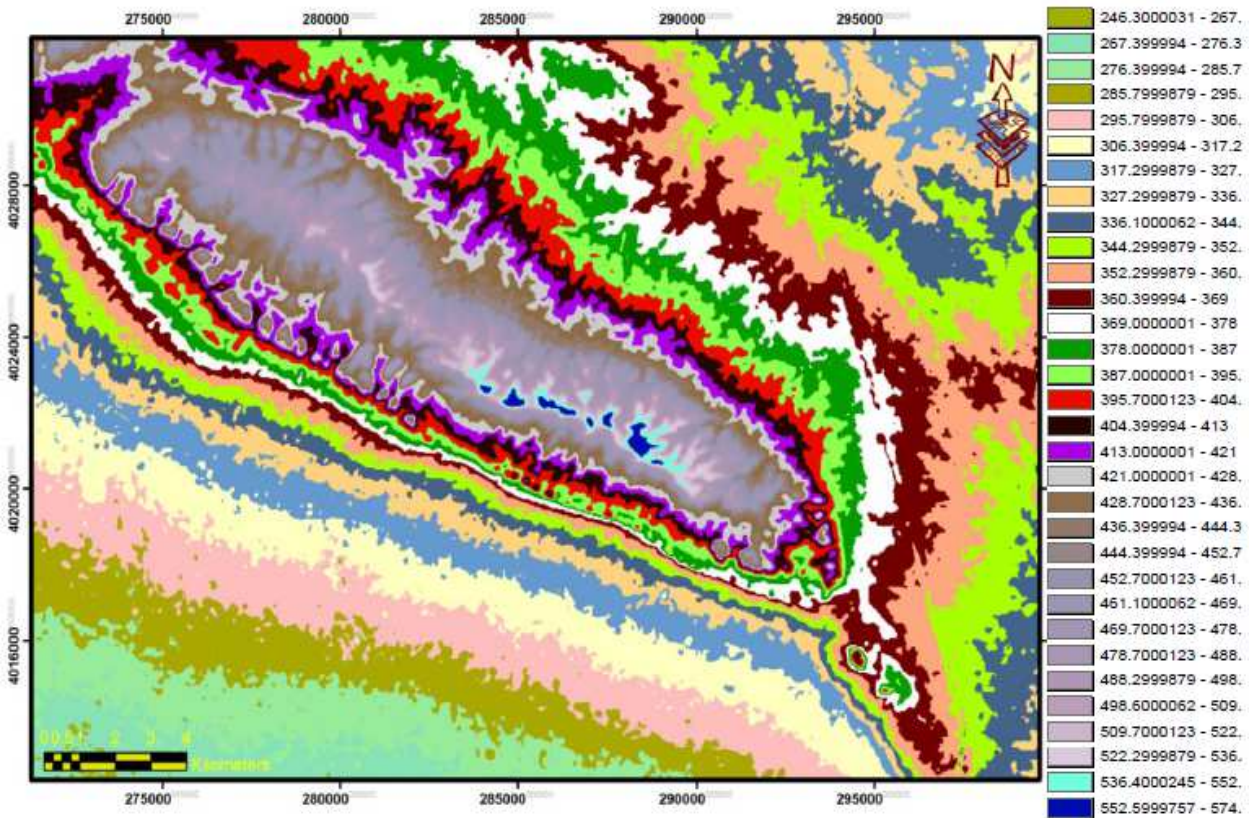


Figure-8: Elevation classification in Shaikh Ibrahim anticline

Tectonic and structural control of extracted alluvial fans

Alluvial fans along southwestern part of Shaikh Ibrahim anticline are the most modern in the low folded zone in Iraq because of it contain a lot of recent sediments as well as the overall shape of these features are relatively small compared with the other alluvial fans in this zone. The vergence of Shaikh Ibrahim anticline is southwest. The dip is higher in the southwestern limb and ranged about (60-70°) compared with northeastern limb which is ranged (15-25°). Southwestern limb has deeply eroded compared with northeastern limb. According to the (Numan and Al- Azzawi, 1993; Al-Azzawi, 2003) most of the folds of the Foreland Belt of Iraq are geographically, orientationally and genetically related to the Listric faults as well as these folds exhibit major longitudinal high angle normal faults along the steeper limbs of the anticlines.

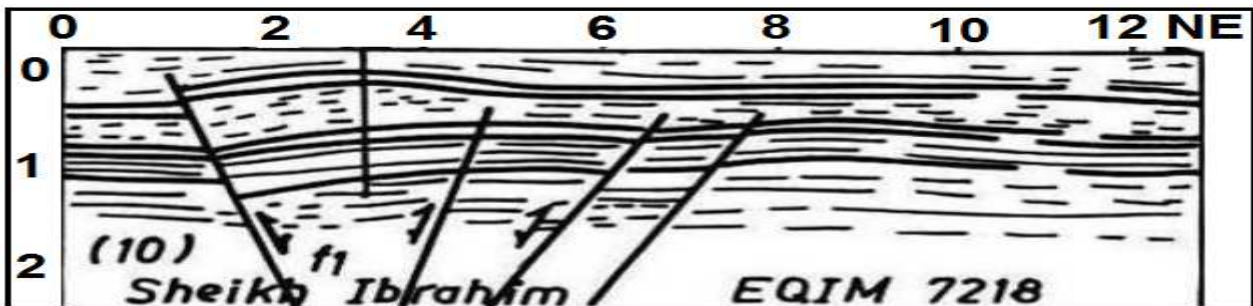
In Shaikh-Ibrahim anticline, southwestern limb located directly over the Listric fault therefore is to be steeper compared with northeastern limb.in this context, on the other hand the Listric fault ruptures the southwestern limb which mean the fault is reaches to the surface (fig.9). Consequently, the displacement on the Listric fault plane lead to down the strata of hanging wall and then change the activity of alluvial process and erosion after that all materials are transmitted to the down slope. Furthermore, the steep ridges and hills respectively located at the top on the core towards the southwestern limb and some of these ridges define the main fault scarp of this part. As shown in (fig.8), in the southwestern parts of Shaikh- Ibrahim anticline the zone of elevation are much closed. On the contrary, the same zones in the northeastern parts are diverging.

The closed elevation in the southwestern parts led to abrupt decrease of gradient of a stream especially, in the elevation zone (360-369m) which is includes the most of intersect drainage points (fig.7-D).This is the main reason why fans along the northeastern limb of Shaikh-Ibrahim anticline are not well developed, as compared to those along the southwestern limb. Displacement variations on the Listric fault plane in Shaikh Ibrahim anticline lead to forming variations also in the uplifted areas in this anticline. As shown in (fig. 8), the Maximum uplift recorded through the digital elevation model in the central core in the southeastern part of Shaikh Ibrahim anticline (near of southeastern plunge) ranged about (525-574m). the maximum uplift lead to activate the initial process in alluvial fan forming and this activation contribute composing a series of

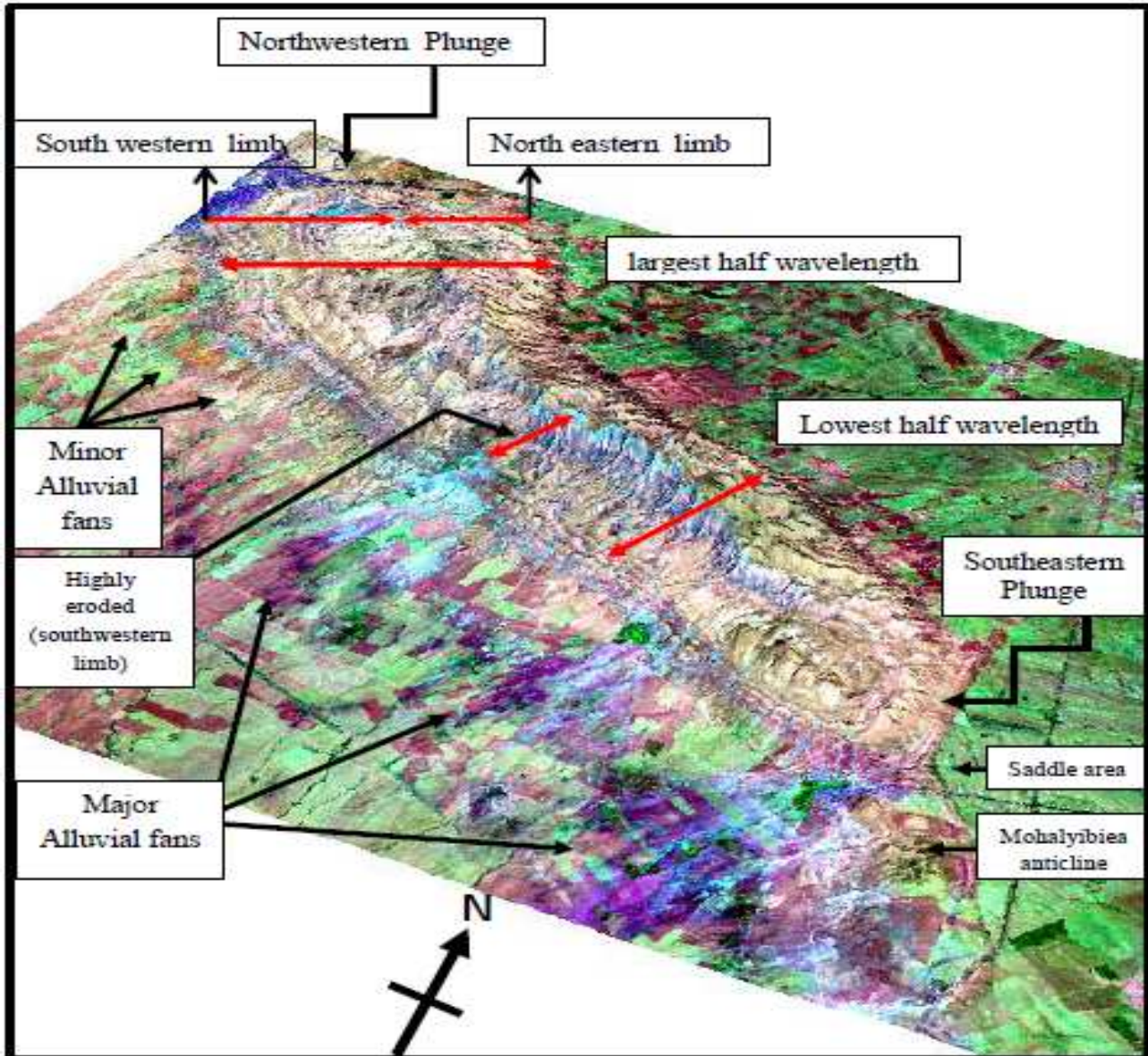
alluvial fans towards downslope (i. e. to the southwestern limb), and this may give the interpretation about why that most of the alluvial fans are located in some part in the southwestern limb.

On the other hand, some of alluvial fans have been created as a result of the geometry of the en'echelon system between Shaikh- Ibrahim anticline and Al-mohalabiya anticline. The southeastern plunge of Shaikh Ibrahim anticline and the northeastern plunge of Al-mohalabiya anticline are clearly topographically younger, and their parts expressed as a rounded surface with little modification. The plunging noses of these anticlines can be delineated by the consequent streams which are radiating and recurved in plunge area. As a result of en'echelon system between these two anticlines, the area between them became a drainage water divide because of the new uplift has been growth. The alluvial fans controlled also by the structural framework of Shaikh Ibrahim anticline. The southeastern part of this anticline characterized by low half wavelength compared with northwestern parts. In order to clarify this, False color composite image of bands (741) draped over the digital elevation and then 3-D view image of the Shaikh Ibrahim anticline was created (fig. 10) The 3-D image displays the structural framework of whole anticline as well as, enhancing the main geological characteristics, furthermore, alluvial fan features are clearly visible with their extensions. It can be noticed also, some of small alluvial fans have been created at the southwestern part of Shaikh Ibrahim anticline specifically near of northwestern plunge (fig. 10) These small fans are derived from the area which is characterized that is covered the largest half wavelength area at this anticline.

The maximum elevation of this area ranged from (488-498m) (fig.8), and towards the southwestern limb the zones of elevation are divergent compared with the same zones towards the southeastern plunge of this anticline. This is the typical reason why fans along the southwestern limb of Shaikh-Ibrahim anticline are varied in size. Furthermore, the variety in the spectral of the alluvial fans in Shaikh Ibrahim anticline reverts to the presence of hydrocarbon seepages. In this context, (Thannoun, 2012 and Thannoun et al., 2014) confirmed existence of hydrocarbon seepages evidence and supported that by geochemical analysis and Spectral curve measurement of plant and soil by laboratory work with ASD field spectrometer analysis.



Figuer-9: seismic section showing the subsurface faults in Shaikh Ibrahim anticline (Marouf, 1999)



Figuer-10: 3-D oblique view image (looking north west) of Shaikh Ibrahim anticline.

Prepare alluvial fans map

Based on remote sensing images and digital elevation analysis, alluvial fans locations were generated and they were plotted over the Landsat image by using geographic information software (fig.11). About (15) major and minor alluvial fans have been mapped. Different data layers of these landforms were delineated using polygon features to visualize the location of the alluvial fans in Shaikh Ibrahim anticline and understanding the relationship between them.

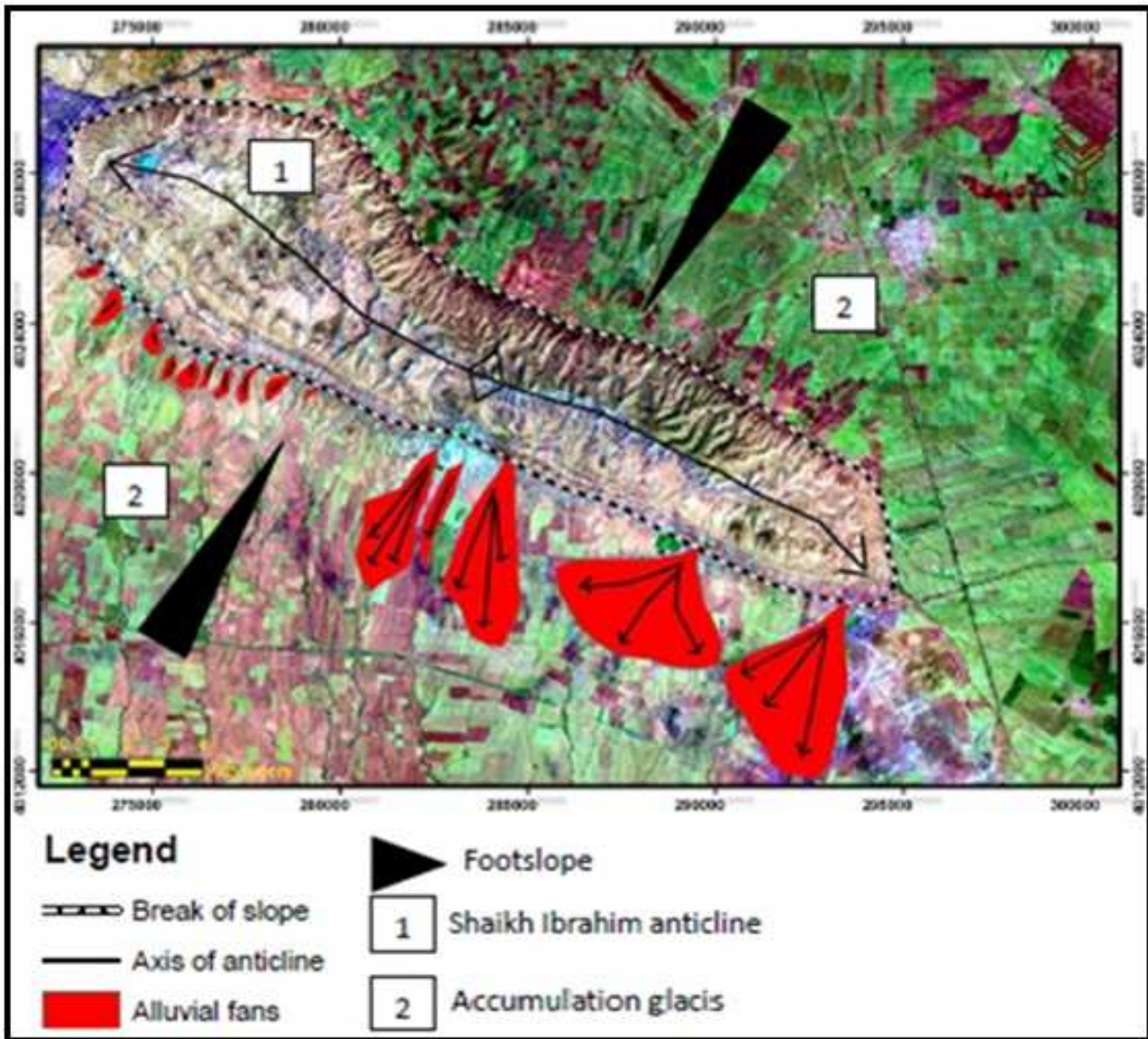


Figure-11: Alluvial fans in Shaikh Ibrahim anticline.

Conclusions

Principal components analysis, Band ratios and false color compositions were used to spectrally enhance the alluvial fans features. They allowed the identification of the accurate places at Shaikh Ibrahim anticline. This paper has introduced a new methodology for the extraction alluvial fans, in this context the flowchart of this study is an efficient way for extracting these features from Landsat ETM+ and digital elevation models. This study confirms the relationship between the occurrence of alluvial fans and the tectonic setting based on the knowledge of structural geology of Shaikh- Ibrahim anticline.

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