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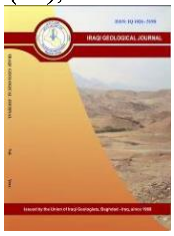

Litho-Stratigraphic Mapping of the Bajalia Anticline, Missan Governorate by Using Digital Image Processing of Landsat-9 Imagery

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Abstract

A combination of digital image processing and field works provides a vision into differentiating between the rock units, in addition to the contacts among them. Landsat 9 was used to plot a detailed geological map of the study area, located in Al-Teeb city at Bajalia anticline, Missan Governorate, Southeast of Iraq. The digital image processing included geometric correction, image enhancement, image classification, use of false-color composite technology and the selection of the best combination represented by RGB 741. Band ratios were applied, which is the most appropriate in detecting the rocks type and determining the dimensions of the geological formations through the spectral reflectivity curve of sandstone. It was the best of them (RGB 4/2, 7/5, 6/2). For the purpose of optimizing the results of band ratio, they were combined into a color image for the purpose of distinguishing the most considerable amount of information, as well as conducting the principal component analysis. These processors were used to increase the spectral differences to facilitate the process of visual interpretation because in most cases the spectral fingerprints of the terrestrial features are similar and difficult to distinguish, in addition to saving the time and effort required to conduct them. After performing the matching process between the results of the digital and field interpretation, the results were good, represented by drawing a geological map of the anticline.

Keywords: Remote sensing; GIS; Bajalia anticline; Band ratio; Al-Teeb

1. Introduction

Satellite image represents the basic element in remote sensing technology, the digital processing of remote sensing data is a modern technology widely used in various fields, including geological studies that are related to exploring the earth's mineral resources and determining geological structures like folds, faults, etc. (Mather, 2004). The rapid development in software has led to diversity and high accuracy in obtaining information through digital processing of multispectral satellite images to produce the digital geological maps, which have become more effective after the availability of modern data such as digital elevation models (DEM). In addition to the presence of Geographic information system (GIS) software (Reddy, 2008). Tectonically, the study area is located within the low folded zone which is part of the Zagros Fold-Thrust belt in the southeastern part of Iraq (Jassim and Goff, 2006) presents the remnants of the low folded zone (Fouad, 2015). The structural analysis describes the Bajalia anticline

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as non-cylindrical, asymmetric, oblique, closed, and strongly inclined. Most of the fractures in this anticline are joints, also reverse faults are located on the southwest limb of the anticline, and these faults are responsible for the inversion of the southwest part of the anticline. It was formed as a result of the tectonic collision between the Arabian and Iranian plates during (Eocene- Recent) (Abdulnaby et al., 2021). There are no comprehensive geological studies in the study area, but this was limited to hydrology, sedimentary, geochemical, and stratigraphic studies, where studies are rare in the study area due to the presence of mines and unexploded bombs. The important previous studies in the field are: (Gad and Kusky, 2006; Al-Samani, 2011; Al-Abadi, 2011; Al-Saad, 2014; Abdul-Qadir, 2014; Al-Abadi, 2015; Ibrahim, 2019; Abdulnaby et al., 2021, Mahdi and Soltan, 2021; Al-Gburi et al., 2022).

The aim of the study is to plot a geological map of the study area. The geological studies carried out by researchers are rare because of the difficulty of access to outcrops and the danger of the area due to the spread of mines. Therefore, image processing and GIS are a perfect solution for plotting comprehensive geological maps and determining the existing formations, based on remote sensing data, these methods are characterized by high accuracy and cover huge areas, in addition to saving time and money. This study is considered the first of its kind in the study area to determine the rock units with stratigraphic contacts among the studied formations (Injana, Al-Mukdadiya and Bai Hassan).

2. Study Area

The study area of the current study comprises:

2.1. Location of the Study Area

The current study is located in the Al-Teeb City, exactly about 60 km Northeast of the Missan, near the Iraq-Iran border, between longitude E 47˚ 33' 30"- 47 ˚ 19' 30" and latitude N 32˚ 12' 34"- 32˚ 23' 10"), it represents one of the five anticlines, most of these folds are located on the Iraqi-Iranian border, and therefore they do not have names until now because they are considered military areas that are difficult to access (Fig. 1).

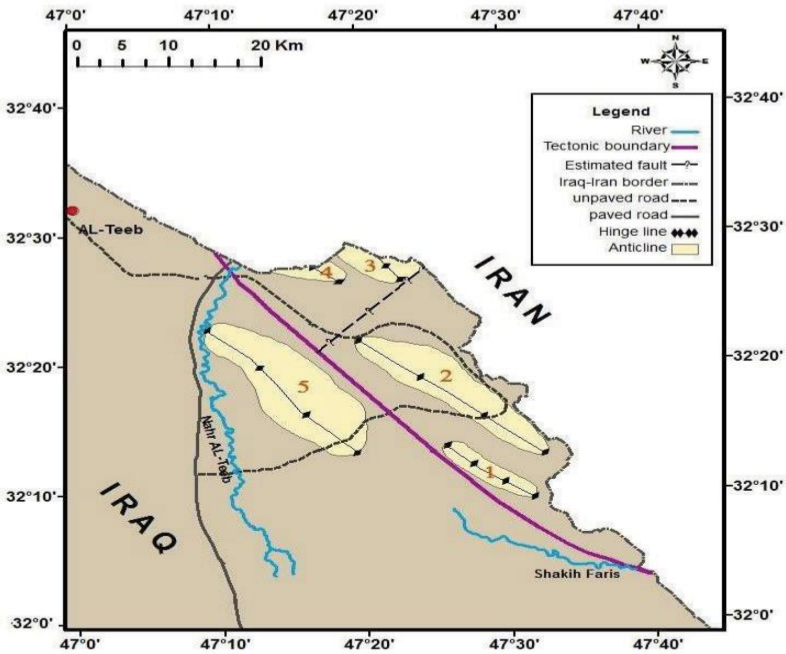

Fig. 1. Geological map of the Al-Teeb City 1,3 and 4 are anticline without names; 2 Bajalia anticline; 5 Band anticlines (Abdulnaby et al., 2021).

2.2. Geological Setting

Bajalia anticline was formed due to the compressive forces that happened during the tectonic collision of the Arabian and Iranian plates in the Eocene age. Three formations were deposited in the study area (Injana, Mukdadiya, Bai Hassan) (Fig. 2). In addition to the Quaternary deposits that cropped out most of the studied area, presented by alluvial fans that formed as a result of seasonal channels that come from Iran towards Iraq (Al-Samaani, 2011).

- *Injana Formation (Late Miocene)*

The old name is Upper Fars and it is difficult to determine the age of the formation due to the disappearance of fossils, so the age of the formation was determined depending on the stratigraphic position above Fatha Formation (Middle Miocene) (Al-Rawi et al.,1992). The Injana Formation is the oldest Formation in the region, the formation consists of successive layers of sandstone with red and green claystone and siltstones, the depositional environment of the formation changes from a transitional marine environment represented by marine evaporites to a Fluvial environment (Jassim and Goff, 2006).

- *Mukdadiya Formation (Late Miocene-Pliocene)*

It is previously called Bakhtiari Formation, it consists of pebbly sandstone. The typical environment for Mukdadiya Formation is a continental environment intertwined with the inland lakes. The formation consists of clastic depositional cycles characterized by Finning upwards, ranging from pebbly sandstone, then sandstone, to siltstone and mudstone, Sandstone layers represent the thickest layers in the formation (Jassim and Goff, 2006).

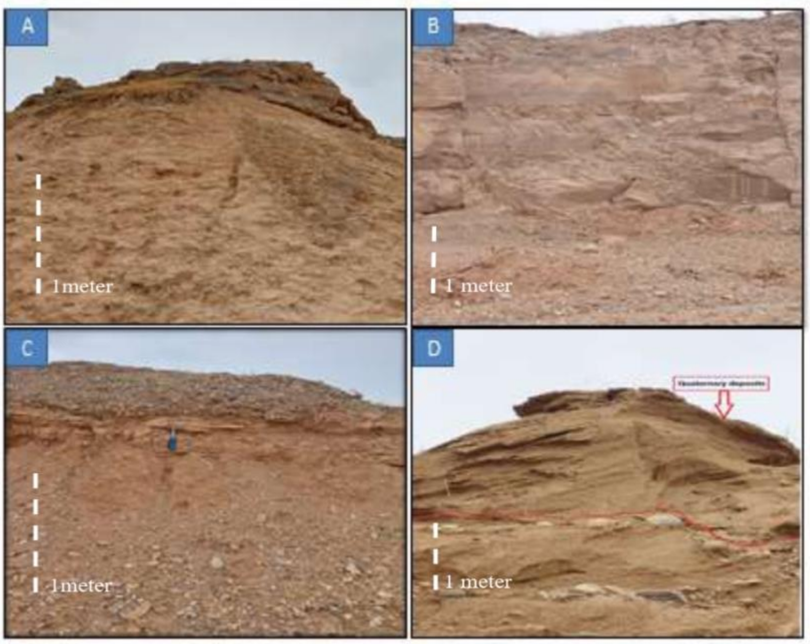

Fig. 2. Injana Formation that composed of sandstone, siltstone and claystone, it is free of pebbles; B) Mukdadiya Formation in the study area, pebbly sandstone cycles and siltstone layers; C) The contact between the Injana and Mukdadiya formations, which represent pebbly sandstone rocks; D) Bai Hassan Formation in Al-Teeb City, it composed of large size of conglomerate with other clastic deposits, the red line illustrates the contact between the Bai Hassan formation and Quaternary deposits.

- *Bai Hassan Formation (Pliocene-Pleistocene)*

It is previously called Upper Bakhtiari Formation and it does not have accurate age until now, so many researchers have suggested this age (Al-Rawi et al.,1992; Sissakian and Al-Jiburi, 2014). This formation is rarely exposed in the study area, it is eroded. The formation consists of different sizes of gravels and conglomerates that have become the contact between the Mukdadiyah and Bai Hassan Formations, the conglomerate layer is made up of gravels ranging in size from 5 to 15 cm. (Abdulnaby et al., 2021).

4. Quaternary deposits

The study area is covered in quaternary sediments, which include a variety of sediments including gravel, sand, silt, and clay that were deposited as a result of the erosion of the three formations (Injana, Mukdadiya, and Bai Hassan). The aeolian deposits are represented by sand dunes and floodplain deposits that consist of silt and clay. The Quaternary sediments represent the surface of a regional unconformable along the collision surface between the Arabian and Iranian plates (Jassim and Goff, 2006).

2.3. Tectonic Setting

The study area is tectonically located within Hamrin - Makhoul subzone of the low folded zone (Fouad, 2015). The zone is characterized by long anticlines with Neogene cores and broad synclines containing molasses deposits (Jassim and Goff, 2006). The tectonic boundary between the low folded zone and the Mesopotamian basin in the current area is represented by the Mandali-Badra-Amara fault, which is a basement fault with an (NW-SE) trend (Fouad, 2015) (Fig. 3).

The Bajalia was formed as a result of the tectonic collision between the Arabian and Iranian plates during the Eocene. The anticline is oblique, asymmetric sub-horizontal, and the southwest limb of the anticline is asymmetric and oblique due to the presence of reverse fault along the limb (Abdulnaby et al., 2021).

3. Materials and Methods

3.1. Data Used

The data utilized in this study is a subset of the spectral band of the Landsat 9-OLI data set (Row-38 / Path-166 dated 03-02-2022). These images also are geo-referenced to the UTM coordinate system, Zone 38 North. The pre-processing of satellite images was carried out using several programs, including ERDAS IMAGINE,2014 and ENVI,5.3, this software was used to perform correction and enhancement of satellite images, and ArcGIS 10.4. utilized to prepare the final digital geological map of the anticline. The digital processing of satellite images aims to improve the visual interpretation of the images by increasing the ability to distinguish between the features of the earth’s surface (Al-Daghestani, 2004).

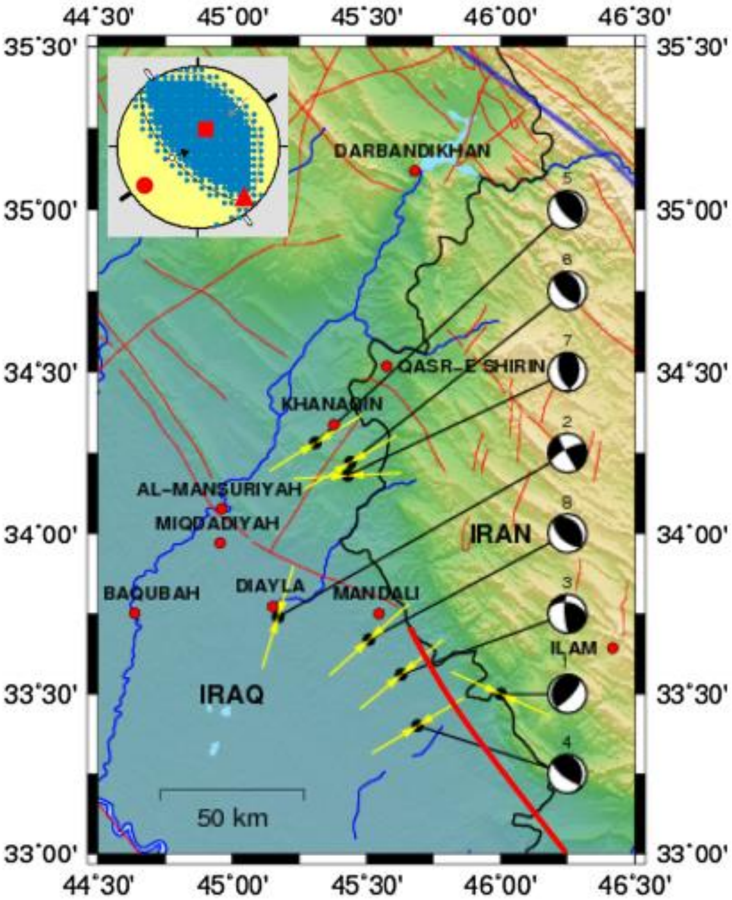

Fig. 3. Mandali-Badra-Amara fault (red line) it presents the tectonic boundary between the low folded zone and the Mesopotamian basin in the current area (Abdulnaby et al.,2016).

3.2. Field Work

Fieldwork was conducted on 17 December 2021 in the accessible areas that are located within the study area. The geomorphology, structural features and sedimentary structures with rock types units in the study area were documented. The coordinates of the important features were taken to take the spectral signature of the formations (Injana– Al-Mukdadiya - Bai Hassan) as well as the most important contacts separating them (Fig. 4).

Fig. 4. The parallel ridges of Bajalia anticline in the northeastern limb, illustrated of the high dip angle to the fold, Missan Governorate.

3.3. Materials and Methods

The methodology comprises of several steps, but it summarized by flow chart (Fig. 5).

3.3.1. Image enhancement

Digital image enhancement is applied to obtain a display or recording of more useful data in preparation for the subsequent visual interpretation that seeks to reach the best integration between the human mind and the computer (Daghestani, 2004). the most important enhancement used in this article are:

- *Layer stack (Color composite)*

The use of colors in displaying and improving digital images is an important concept in processing multispectral digital images so that the image analyst can derive more information when looking at them for interpretation. The color composite method is applied to multispectral images that consist of three or more bands. Through remote sensing software, the color composite images are displayed in the main color system (RGB), which are red, green, and blue, used for three image bands (Paine and Kiser, 2012).

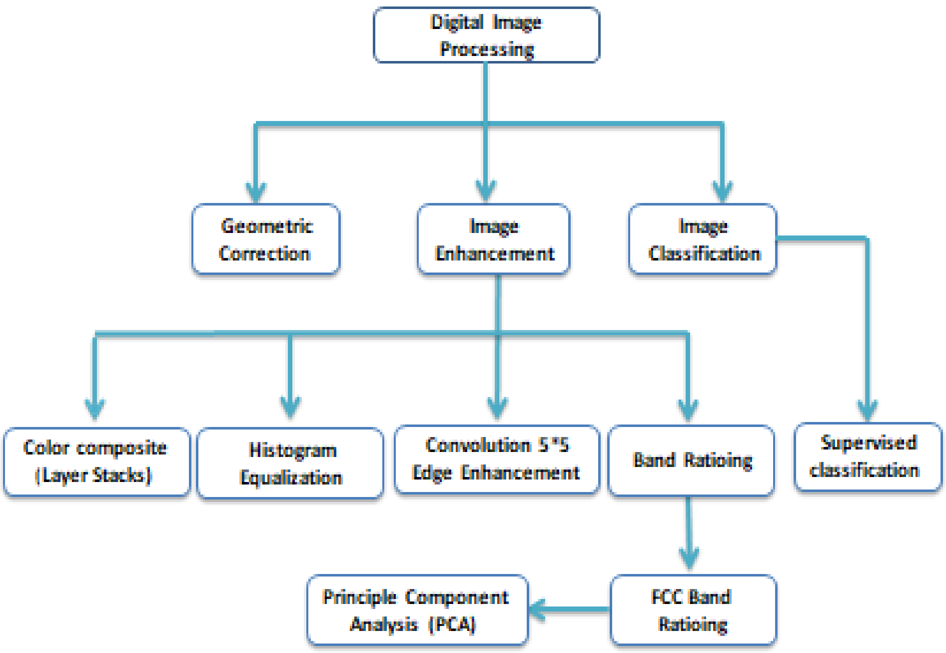

Fig. 5. flowchart of the methodology of the current study

The process of making color composite images is based on several criteria, including the careful selection of spectral bands in order to separate between surface components and because the target formation in this study is sand and what surrounds it also sandy components, it was better to choose spectral bands that distinguish the target formation from its surrounding components. Therefore, in this study, the process of capturing the peaks and troughs of the spectral reflectivity curve of sand was carried out, and then the color combination 741 was adopted as red, green, and blue (Al-Sayed and El- Nadi, 2014) (Figs. 6 and 7). This color composite can be used to determine the extension of most of the geological formations and separate them in the Bajalia anticline, as it was suitable to clarify the extensions of most of the geological formations and the contacts among them.

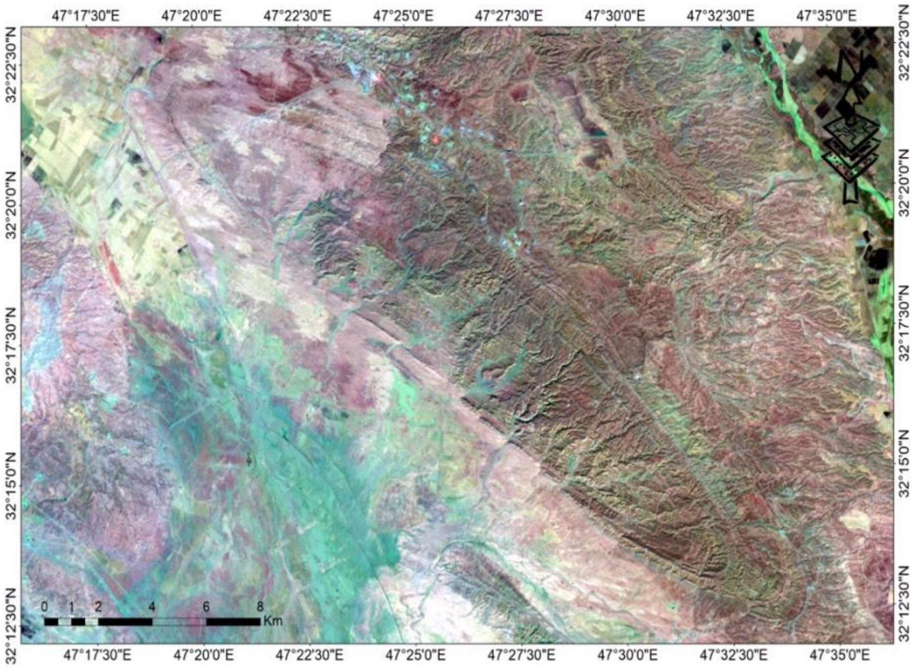

Fig. 6. color composite image of Landsat 9-OLI (RGB 741).

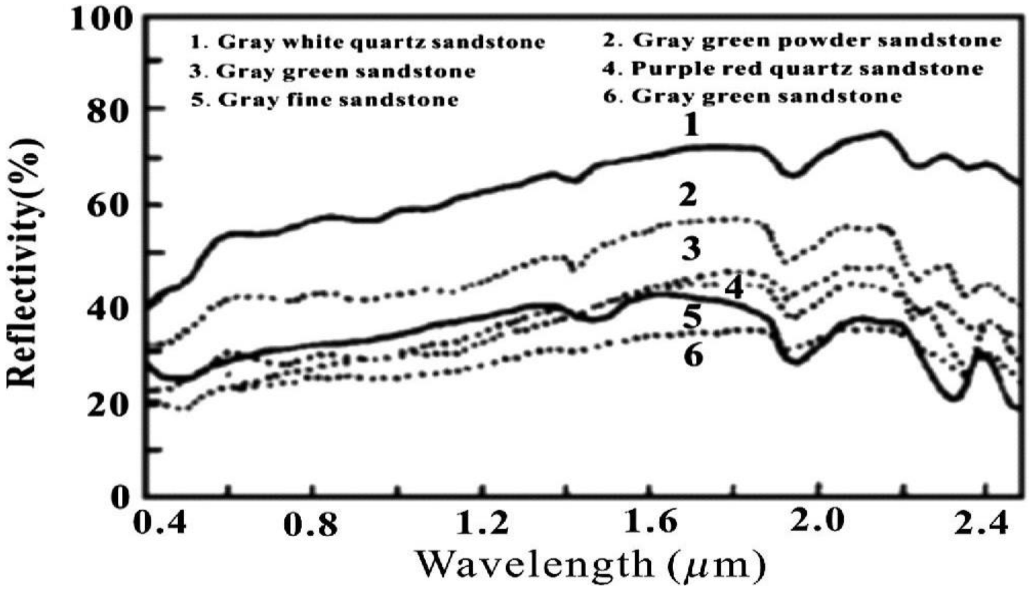

Fig. 7. Spectral signature of sandstone (Zhou et al., 2019).

- *Histogram equalization*

It is a digital processing of the values entered in the image. This treatment is useful in increasing the color contrast between the visible elements and highlighting the contrast between the features of the earth's surface that have an important value for the interpreter, as this technique was used to simplify the digital values homogeneously to cover the entire grayscale (0-255) and thus the satellite image is clear and homogeneous reflections (Al-Hassan, 2007), in this study the result of stretching the value of grade scale shown in Fig. 8.

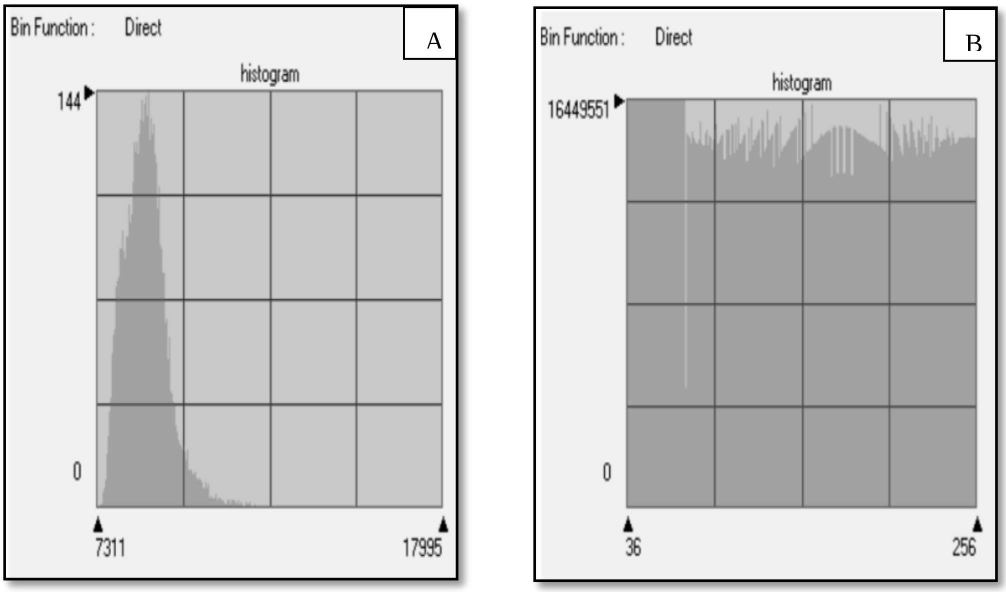

Fig. 8. Histogram Equalization; A) Before applied Histogram on band 4; B) After applied Histogram Equalization on band 4

- *Convolution 5*5 edge enhancement*

The convolution technique is a computational process used to change the spatial frequency of numeric values in the image. This process is used to disperse the noise in the values or to amplify important phenomena, where an arrangement of numeric values that form a matrix and with odd numbers for columns and rows are made to smooth the image or to find and highlight the edges of the important aspects in the images (Al-Assadi, 2012) (Fig. 9).

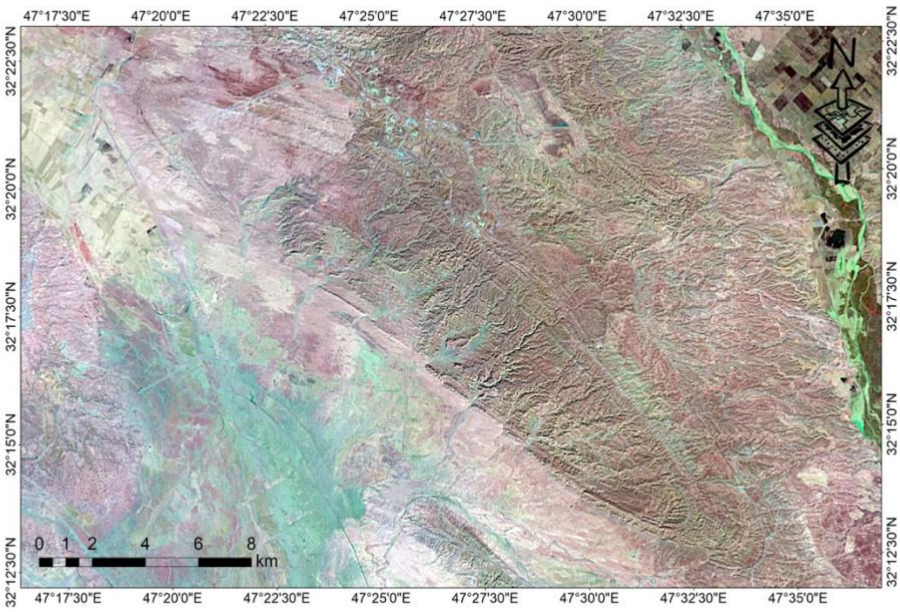

Fig. 9. Convolution 5*5 edge enhancement technique applied on RGB 741 image

3.3.2. Band ratioing

It results from the process of dividing the digital reflectivity values for each element of one band by the corresponding digital reflectivity values for the element of another band of multispectral image and displaying the new image in grayscale. The process of selecting spectral bands depends on the spectral reflectivity characteristics of the components of the Earth's surface that appear on the satellite image, to determine the best spectral bands for applying the spectral ratio process, the rates of the spectral reflectivity values of the rock units were relied upon (Al-Azzawi et al., 2018). Proportional ratio bands are an effective technology to remove the effect of topographic shadows that obscure some spectral information in remote sensing images and it is also useful for distinguishing between different surface components (Jenson, 2005). Many proportional ratio bands were applied, the best and most useful were to determine the extensions of the geological formations and the contacts between them (RGB 4/2, 7/5, 6/2) as in (Fig. 10). To exploit the previous results, the ratio bands were merged into one image by giving each ratio band one of the colors (red, blue, or green). As the false-color composite provides the collection of data in a single image and its display in color thus distinguishing the largest amount of information and making it easier for the interpreter to link the resulting colors with the spectral curves.

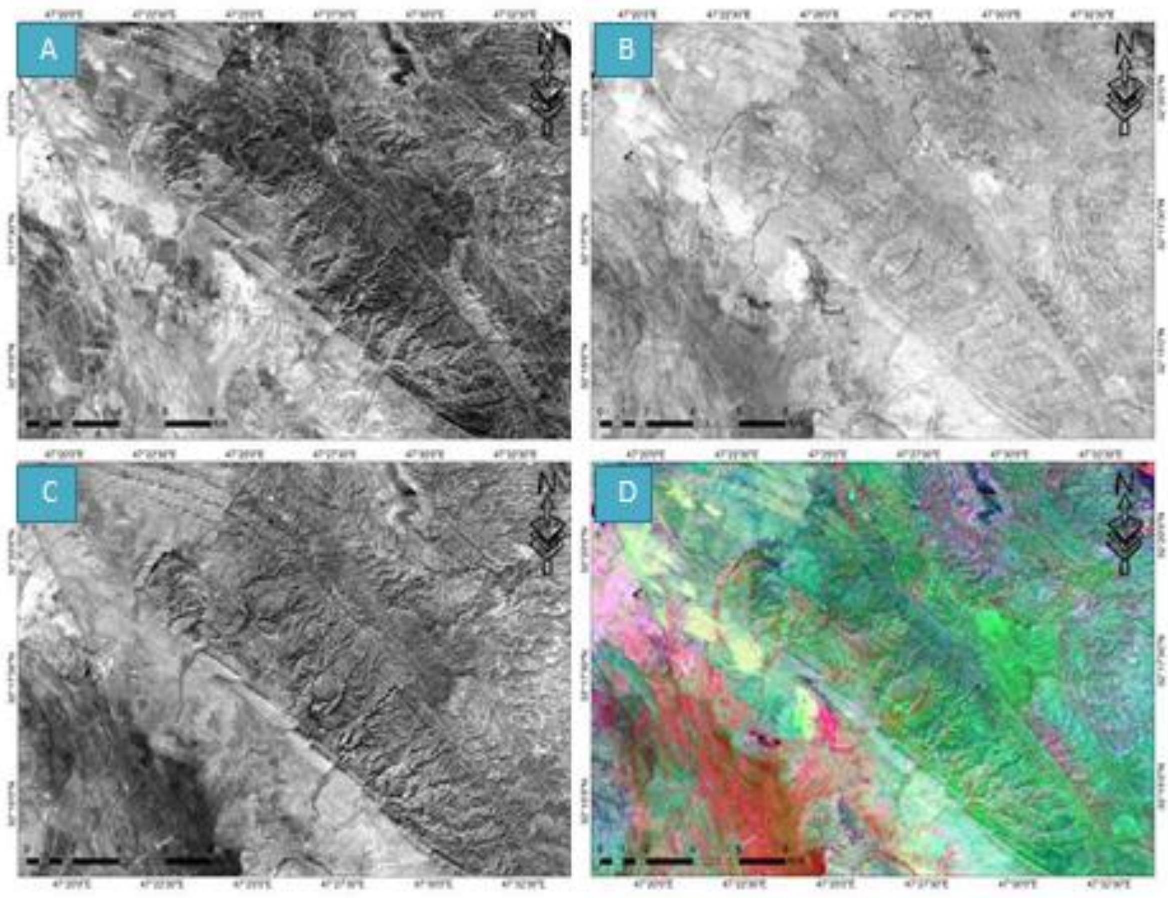

Fig. 10. A-Ratio image (4/2); B-Ratio image (7/5), B-Ratio image (6/2); C- Color Composite of Ratio image

3.3.3. Principal component analysis (PCA)

The method of analyzing the principal component is one of the statistical methods that are used to describe the data by redistributing it on many axes. It is one of the transformational improvement methods, through which the data of highly correlated image bands is converted into new data that does not have any linear relationship between them (Mather, 2004). This technique represents a mathematical method to simplify the enormous data into a smaller number of variables that are not related to each other by transforming the closely related variables, this method is called the principal components. These components are characterized by the fact that most of the information is concentrated in the first principal component, while the rest of the information is concentrated in the second and third components, and the original components are highly connected while the principal components are not linked to each other (Al-Hassan, 2007) (Fig. 11) (Tables 1, 2, 3, and 4).

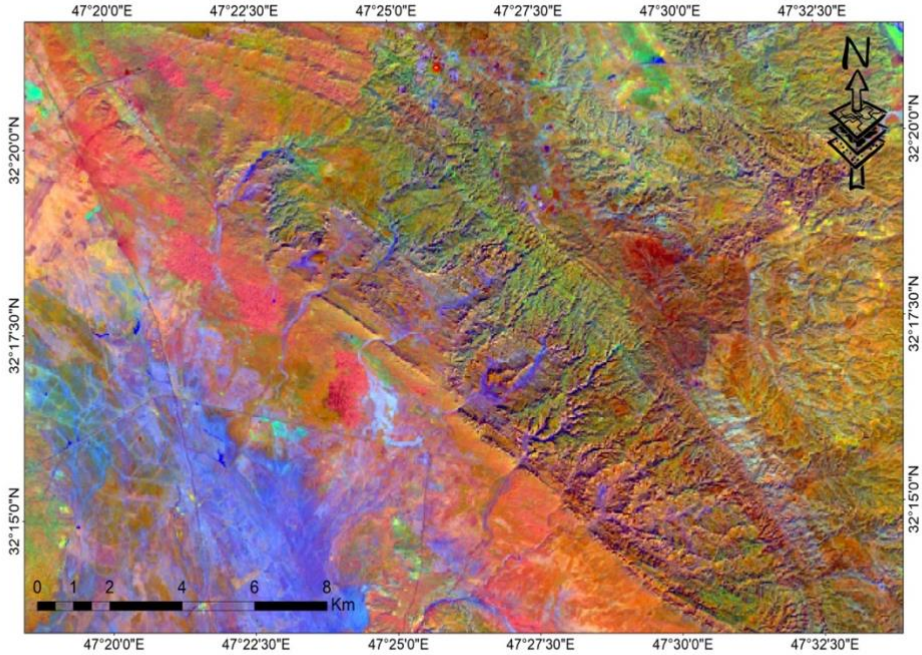

Fig. 11. PCA of color composite

Table 1. Covariance matrix

Layer	1	2	3
1	2609.00492	2033.48852	1351.82114
2	2033.48852	1626.22012	1139.25887
3	1351.82114	1139.25887	1087.01691

Table 2. Correlation matrix

Layer	1	2	3
1	1.00000	0.98722	0.80272
2	0.98722	1.00000	0.85687
3	0.80272	0.85687	1.00000

Table 3. Correlation matrix

Layer	1	2	3
1	1.00000	0.98722	0.80272
2	0.98722	1.00000	0.85687
3	0.80272	0.85687	1.00000

Table 4. Percent and accumulative eigenvalues

PC Layer	Eigenvalue	Percent of accumulative eigenvalues	Accumulative of Eigenvalues
1	5006.30587	94.0639	94.0639
2	300.99166	5.6554	99.7192
3	14.94443	0.2808	100.0000

3.3.4. Image classification

The process of classifying satellite images is defined as the process in which the image is transformed into a map that carries information about the phenomena in the illuminated area by identifying the terrestrial phenomena represented by each image unit (Mather, 2004). The main objective of images classification is to make all the image elements automatically in groups known as training areas to identify what they represent from the different types of land cover, using multispectral data to perform the classification and using the spectral pattern in the data for each pixel as a numerical basis for classification. This means that different types of features show different numerical numbers based on their reflectivity and spectral properties (Lillesand and Kiefer, 2000). Because we relied on digital enhancement methods represented by image rationing image and the method of principal components analysis, the supervised classification method, specifically the Maximum Likelihood classification method was adopted to determine the required rock units (Fig. 12).

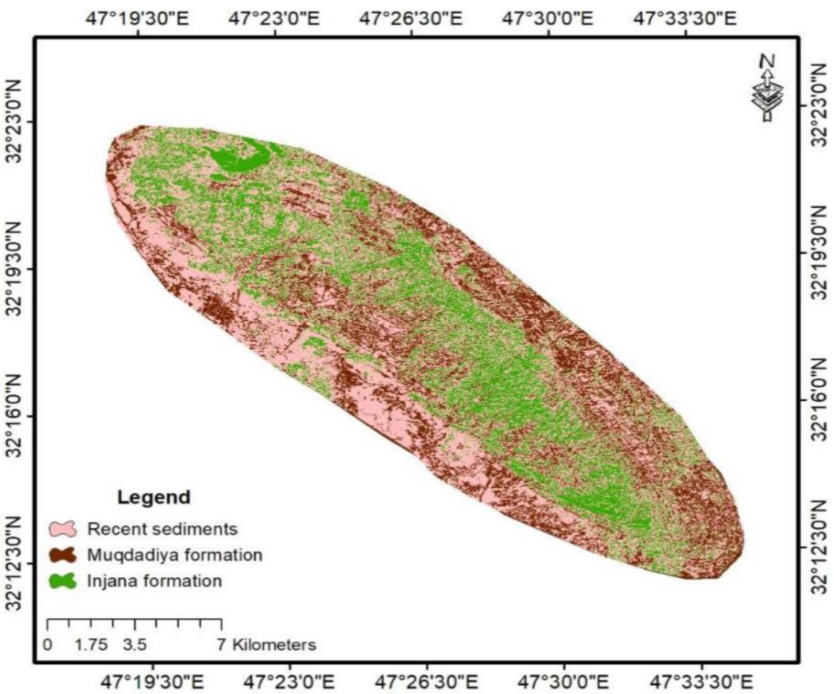

Fig. 12. The final processed image contains the classification results for the Bajalia anticline

Table 5. An error matrix obtained from a data analysis (Randomly sample test pixels)

		Real Data			**Row**
		Injana	Mukdadiya	Recent sediments	Total
	Injana	42	2	4	48
RS Data	Mukdadiya	2	45	3	50
	Recent sediments	6	3	43	52
	Column Total	50	50	50	150

3.3.5 Accuracy assessment

One of the most common means of expressing classification accuracy is the preparation of a classification error matrix (confusion matrix or contingency table). To prepare an error matrix first task is to locate ground reference test pixels or sample collection, based on which an error matrix is formed. There are many mathematical approaches in this regard. Generally, it is suggested that a minimum of 50 samples of each class should be included. Data sampling can be done using various procedures such as: random, systematic, stratified random, stratified systematic unaligned, and cluster. An error matrix compares the relationship between known reference data (ground data) and the corresponding results obtained from classification (Tables 5 and 6).

Table 6. Results of various accuracy measurements

Class	**Omission error**	**Commission error**	**Producer's Accuracy**	**User's Accuracy**
Injana	16%	13%	84%	88%
Mukdadiya	10%	10%	90%	90%
Recent sediments	14%	17%	86%	83%
overall accuracy		87%		

4. Results and Discussion

The digital processing of the Landsat-9 satellite image is illustrated detailed information about the study area, after correction and enhancement for different images with multiple ratio bands such as (RGB 4/2, 7/5, 6/2). The results of processed images indicated on the final geological map, the core of the anticline is formed from the Injana Formation and surrounded by Mukdadiya Formation, then covered with Quaternary sediments. The previous maps that were prepared by the Geological Survey, consider the Injana Formation did not exist at the Bajalia anticline, the Mukdadiya Formation presents the core of the fold, to avoid ambiguity, the authors conducted a second visit to the current study to ensure the accurate data obtained. The second field trip confirmed the presence of two formations as well as Quaternary sediments covering most of the area, the edges of the anticline representing the Mukdadiya Formation, while the core of the anticline is composed of Injana Formation, whereas Bai Hassan Formation disappears in the anticline because it is completely erosion.

5. Conclusions

The current study showed its ability and efficiency to benefit from the data of digital processing of satellite images in the study of the stratigraphy of the region and the process of producing digital geological maps through remote sensing programs and GIS with the help of the field audit, the accuracy of these method reaches to 87%. The results of the digital processing implemented on the raw images that covered the study area proved its efficiency in increasing the ability of visual discrimination in determining the lithology of the rocks compared to the rest of the terrestrial phenomena, through the band ratio and their integration into a color image, which led to an increase in the ability of the human eye to distinguish spectral reflections and distinguish the materials of the earth's surface. The mixture of the sandstone with pebbles that formed of Mukdadiya Formation is separated from the pure sandstone of Injana Formation easily, by depending on GIS technology, both of the formations existed in the Bajalia anticline while Bai Hassan Formation was completely eroded. The studied region was subjected to differential erosion processes, which led to the dispersion of several alluvial fans and morphological phenomena.

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