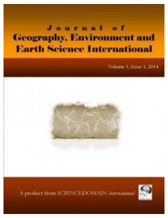

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Lithologic, Hydrothermal Alteration and Structural Mapping of Okemesi Folds and Environs Using LandSat 8 OLI and ASTER DEM

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Authors' contributions

This work was carried out in collaboration between both authors. Author JOO designed the study, sourced and analyzed the statistics. The interpolation and rasterization was carried out by authors JOO and AAO. Supervision was done by author AAO. The paper was coordinated by author AAO. The manuscript was done and edited by author JOO. Both authors read and approved the final manuscript.

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ABSTRACT

Structural and tectonic studies of an area, help in the understanding of the magmatism, metallogeny, groundwater, seismicity, geothermal and hydrothermal resources of the region. The Precambrian rocks of Okemesi folds and its environs exhibit multiple deformations, repetitive folding, fracturing and metamorphism. LandSat data have been used widely in mapping lithological and altered rocks in geology. Several Red–Green–Blue colour combination images and specialized band ratios, prepared from Landsat-8 bands coupled with Band ratios derived from image spectra, helped in delineation of altered rocks, lithological units and vegetation. Aerial photographs have limitations because of their dependence on natural east-west solar illumination paths which highlight north-south linear features, perpendicular to the solar illumination; therefore hillshade generated from

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digital elevation models (DEMs) are an alternative source for identification of lineaments. In this research, a procedure for extracting lineaments from hillshaded ASTER DEM was applied; the results of this study illustrate the effectiveness of extracting lineaments from hillshaded DEMs. The final interpreted lineament map was then produced with a total of about 178 lineaments extracted from the ASTER DEM. The azimuthal distribution indicated that most of the lineaments are trending to NE-SW and NNE-SSW with a few E-W and NNW-SSE directions. These directions are distributed throughout the Okemesi fold axis and on most of the rock complexes.

Keywords: Lithologic; hydrothermal alteration and structural mapping; LandSat 8 OLI and ASTER DEM.

1. INTRODUCTION

Major shear zones occur in different tectonic settings and are associated with varying tectonic displacements in various orogenies. Regional scale, steep and generally north-south trending shear zones have been recognized in the western part of the Nigerian basement complex [1,2,3,4,5]. These shear zones have been traced north wards to and correlated with those of the Central Hoggar [3,6]. These zones are marked by mylonites and cataclasites produced by the shearing of the rocks at different crustal levels (temperatures and confining pressures) and fluid phase activities.

Detection of faults in geological exploration is an important parameter in the field of structural, economic and environmental geology; conventional mapping methods used in the mapping of faults require fieldwork investigations. In most cases, fieldwork could be very tasking and time consuming; this usually depends primarily on the area extent and accessibility of the study Physical features such as topography, erosion, over-growth of vegetation, scale, and other factors, control fault determination in the field.

Remote Sensing is an important technology that has the advantage of providing synoptic view of the region; this makes it easier to identify some of the characteristics of structural geological features that extend over regional areas. As opposed to fieldwork investigations, remote sensing along with image processing techniques accounts for a less time-consuming and a more cost-effective method for fault detection. Nonetheless, such techniques in no way replace field investigations, but on the contrary they complement each other.

Faults and fractures are often revealed as linear or curvilinear traces on satellite images. These image lines of different contrast are commonly referred to as lineaments and may extend from a few meters to tens of kilometres in length. Certainly not all lineaments relate to faulting. They could also be attributed to lithological boundaries, boundaries between different land uses, drainage lines or even man-made constructions such as roads. Therefore, it is not easy to interpret the potential structural origin of lineaments based on satellite images only. In addition, groundwater transferred through faults increases the moisture content of soil in relation to the surrounding area and promotes preferential alignments of vegetation; abrupt changes in vegetation canopy and sudden disappearance of a certain plant species could also signify fault structures. Fault lines may form specific drainage patterns easily detected on satellite images. More particularly, streams have a natural tendency to meander. Thus some frequently-found types of stream anomalies, such as straight segments, sudden bends observed along stream courses, displacement or even local disappearance of drainage system into lines of sinkholes could mark a fault line on an image.

Hydrothermal fluid processes alter the mineralogy and chemistry of the host rocks that can produce distinctive mineral assemblages which vary according to the location, degree and duration of the alteration processes. When these alteration products are exposed at the surface, they can be mapped as a zonal pattern. They appear concentrically around a core which has the highest grade alteration and greatest economic interest. The importance of the recognition of such spatial patterns of alteration makes the ‘remote sensing technique’ one of the standard procedures in exploration geology, due to its high efficiency and low cost [7]. The application of remote sensing in mineral exploration was derived from use of aerial photo in reconnaissance survey. Remote sensing and GIS technique are used to update existing maps, to produce geologic maps, locate fractures (lineaments) and also to identify rock alteration zones. Different stages of image-processing techniques were applied to LandSat 8 OLI image of the study area to discriminate the different major lithologies in the area.

In this study, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM, multi spectral LandSat 8 Operational Land Imager (OLI) satellite images were processed, to enhance lineaments which are potential faults, fractures, geological structures, etc. The combination of different processing techniques (Principal Component Analysis, the creation of False Colour Composite images and the intensity-hue-saturation transformation and Band ratio), also contributed to lithologic and hydrothermal alteration mapping.

2. THE STUDY AREA

The study area lies within latitudes 07°27’1.24”N and 07°54’18.67’’N and longitudes 004°43’41.96”E and 05°07’47.14’’E respectively. It covers parts of the topographic map sheet numbers 243 Ilesha, 244 Ado Ekiti, 264 Akure, and 263 Ondo. The study area covers part of Ekiti, and Osun States respectively, while a little portion falls in Ondo State, Southwestern Nigeria, with a total surface area of 1665.5 km^2. The major towns in the area include: Ilesa, Oke-Ila, Okemesi, Ilupeju, Soso, Oba-Sinkin, Ayegunle, Kajola, Ijero, Ibokun, Ikogosi, Igbara Ado and Ajindo (Fig. 1).

The Okemesi fold belt and its environment have a closely developed drainage system (Fig. 2). The drainage pattern is generally related to the geology of the area. It is roughly trellis indicating the influence of the structures of the underlying rocks. The major streams namely the river Shasha, Obabu and Mokuro commonly flow through the low lying portions between the topographic highs. Northwest and southwest parts are drained by the tributaries of these rivers. The northeast and southeast areas are drained by the tributaries of Rivers Ora and Osun. These streams which are mainly sandy along their upper courses are often composed of mudflats rich in organic matter derived from bamboo, palm trees and shrubs occurring in the stream valleys.

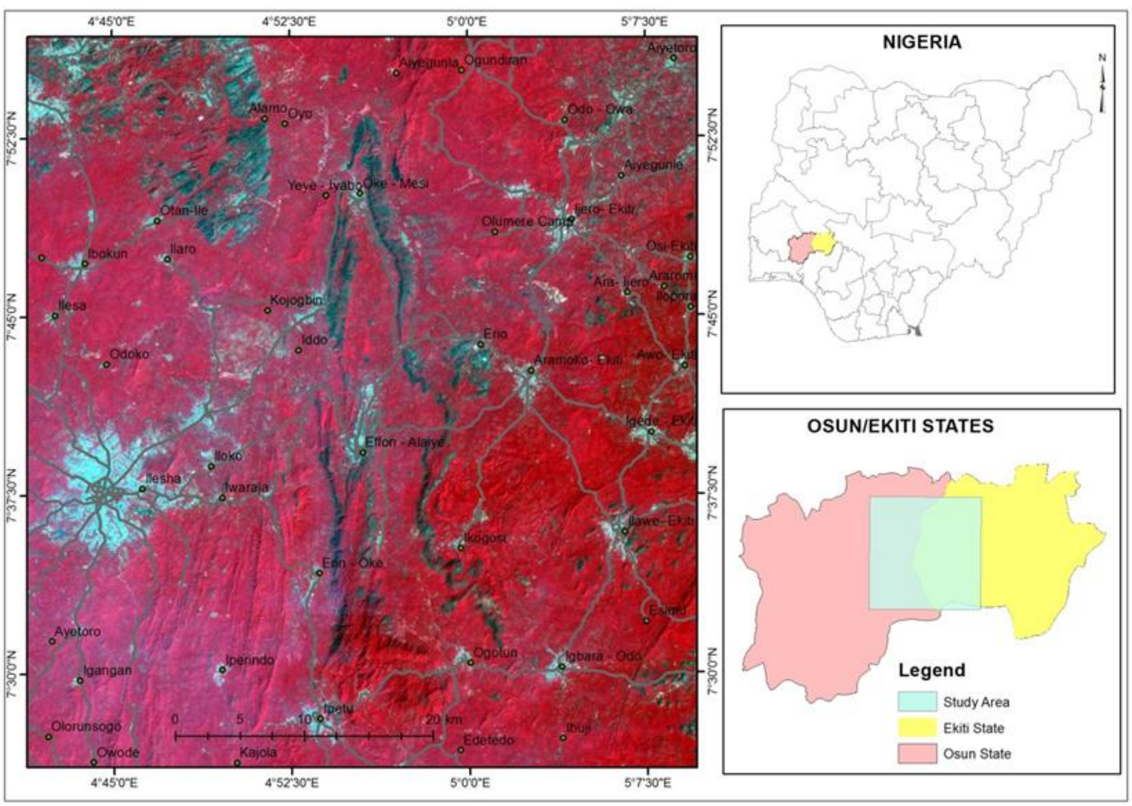

Fig. 1. Map of study area

The area of study consists of an undulating terrain with elevations ranging from 221 m in the western portion underlain by muscovite-quartz schist and pegmatites, through 799 m in the middle to the eastern portion underlain by amphibolites and undifferentiated migmatite gneiss complex and schist (Fig. 2).

The study area lies within the Ilesha schist belt; it is underlain by crystalline rocks of the Precambrian Basement Complex of Southwestern Nigeria, which is also part of the Basement Complex rocks of Nigeria (Precambrian-Paleozoic). The study area is also part of the regional Dahomeyide fold belt defined by [8], and so it is not an exception to the structural and deformational episodes that pervaded Nigeria's Precambrian Basement Complex.

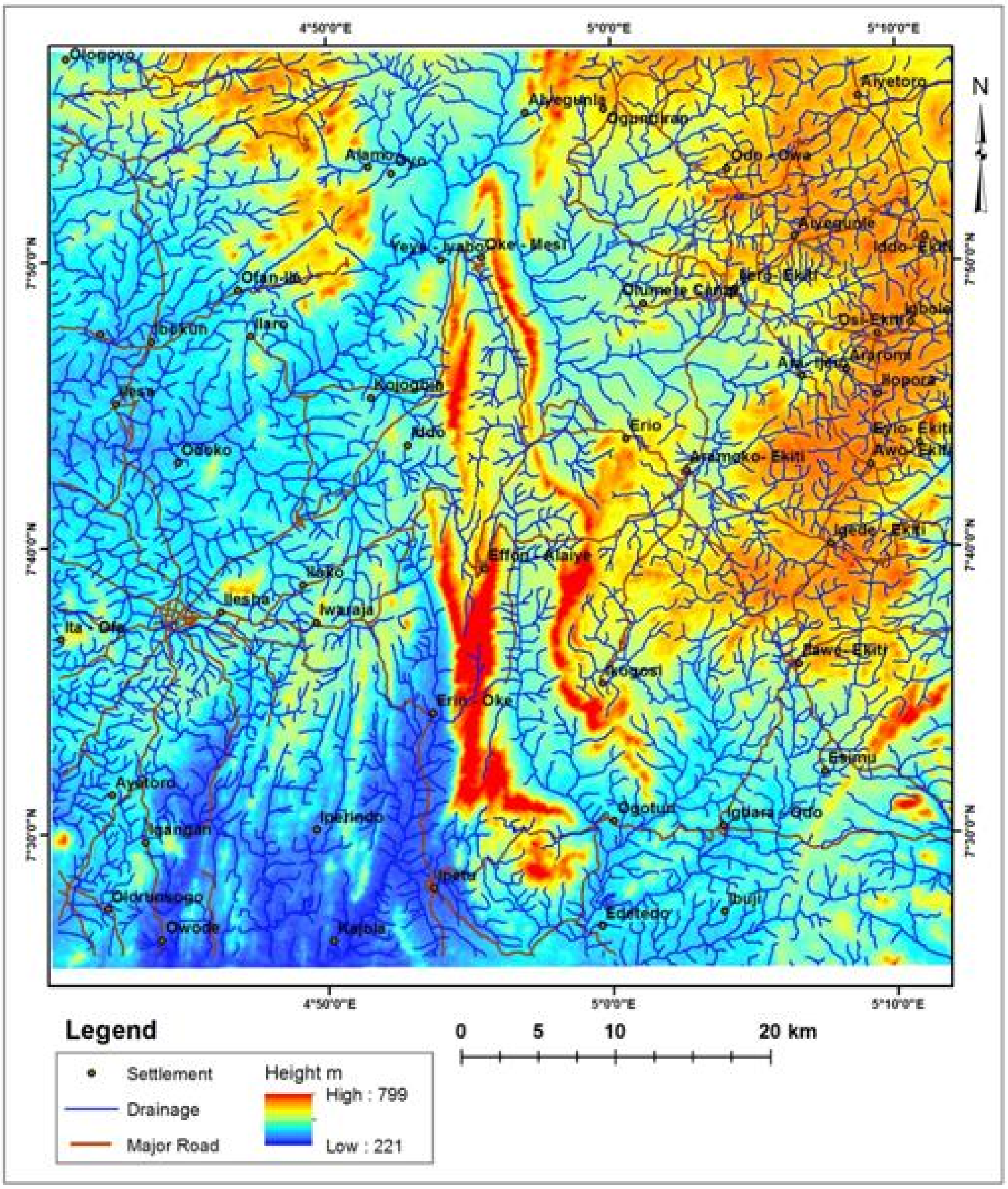

Fig. 2. Drainage and topographic map of the study area (from DEM)

For many years, the Ilesha district within the Precambrian basement complex of southwestern Nigeria (Fig. 3) has been widely known for the substantial production of gold [9,10]. Gold workings are concentrated in two major geologica1 zones; these include the district characterized by occurrences of essentially elluvial and alluvial deposits, covering much of the western and northern parts of Ilesha. Here, the underlying and possible source rocks are mafic-ultramafic units and metasediments [11]. In the other zone which is to the southeast of the area, primary gold mineralization occurs in felsic veins hosted in granite gneiss.

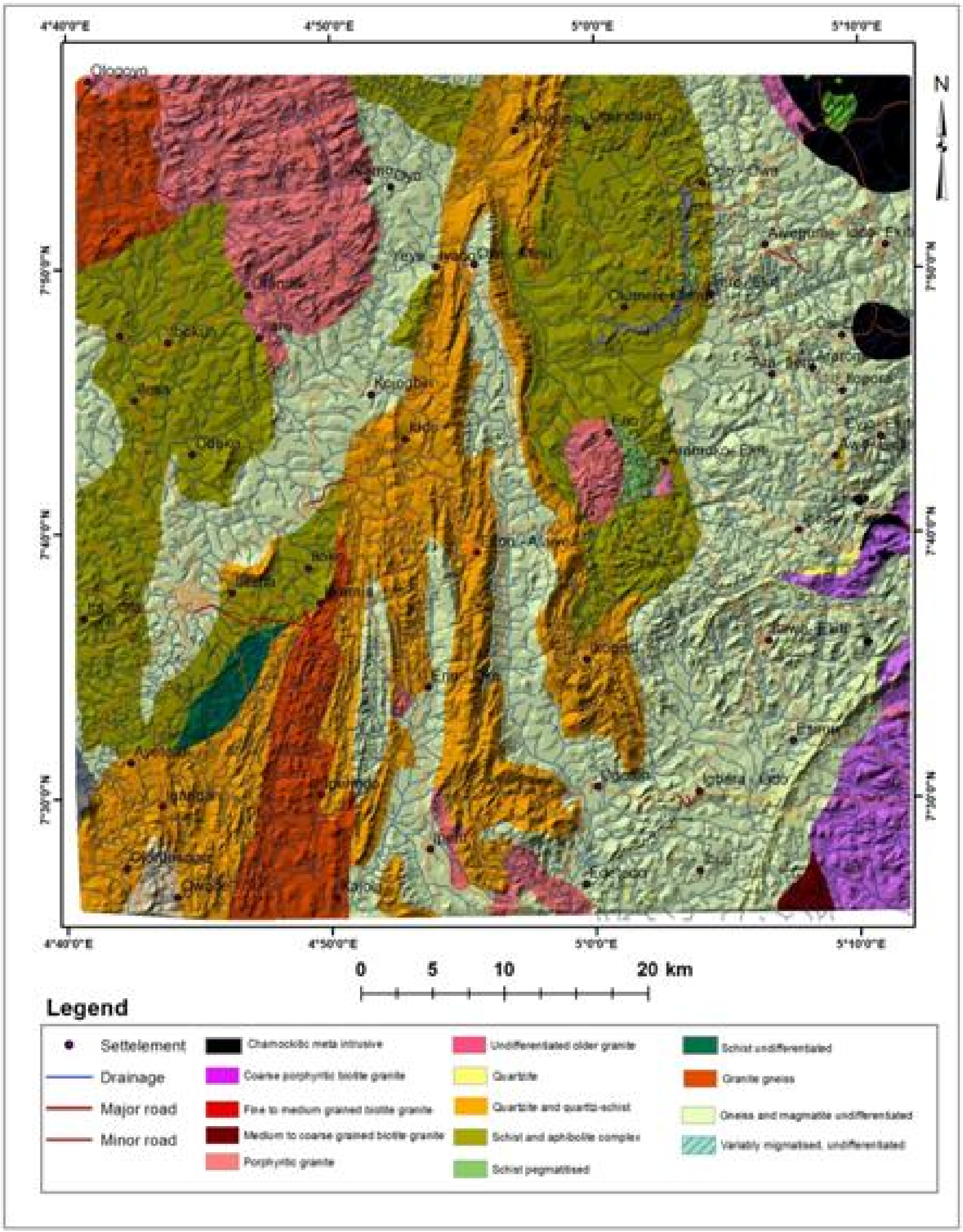

Fig. 3. Geologic map of study area, modified after geological survey (1972)

The major rock associations of the Ilesha area generally belong to the Proterozoic schist belts of Nigeria, which are prominently developed in the western half of the country. Apart from gold, other mineral resources of the schist be1ts include nickel and chrome ores, talc, magnesite, asbestos and iron ores. In terms of structural features, lithologies and mineralization, the schist belts of Nigeria show considerable similarities with Achaean greenstone belts. However, the latter usually contain much larger quantities of mafic and ultra mafic bodies and assemblages of lower metamorphic grade [11].

The Ifewara fracture zone separates the rocks of the Ilesha schist belt into two structural units of contrasting lithologies namely the eastern and western segments [12,13,14,4]. The western segment is underlain by amphibolite, amphibolite schist, quartz schist, associated with pegmatite and gneisse: the eastern segment of the schist belt (in which the study area lies) is referred to as the "Effon Psammite Formation", made up of quartzite, quartz schist and quartzo-feldsparthic gneisses with minor iron rich schist and granulite. The formation has a general NNE-SSW direction showing thickness of quartzite due to overthrusting of the Effon Psammites. Other authors ([15,16,17,18]) have provided evidences in support of the existence of the structure as well as its significance in terms of tectonic movements [19].

On the basis of field relationships and petrological features, the rocks of the Ilesha district may be broadly grouped into gneiss-migmatite complex, mafic-ultramafic suite complex, metasedimentary assemblages and intrusive suite of granitic rocks. A variety of minor rock types are also related to these units. The gneiss–migmatite complex comprises migmatitic and granitic gneiss, calcareous, and granulitic rocks. The mafic–ultramafic suite is composed mostly of amphibolite, oolitic schist and minor meta–ultramafics. The metasedimentary assemblages, chiefly metapelite and psammitic units are found as quartzite and quartz schist. The intrusive suite consists essentially of Pan-African (ca. 600 Ma) granitic units. The minor rocks include garnet-quartz-chlorite bodies, biotite-garnet rock, syenitic bodies, diorite and dolerite. The association of volcanic and clastic rocks suggests a eu-geosynclinal environment of deposition [20,9,21]. However, the quartzites are oolitic, metamorphosed from sandstone and tend to form good topographic features with bands of long-hogback ridges around Okemesi through Itawure and extending to Aramoko, with an elevation of approximately 100m above the surrounding terrains (Fig. 3).

3. MATERIALS AND METHODS

The following data sets were employed in the present research work: LandSat 8 OLI, ASTER DEM, existing geological maps covering the area of study and other ancillary data. Please see table below for summary of materials used.

Table 1. Summary of data source and material

1. Satellite Image Data			
Image type	**Source**	**Date of acquisition**	**Resolution(meter)**
LandSat 8 OLI, VNIR, SWIR, TIR	USGS	17/12/2015	30
ASTER DEM	USGS	15/12/2010	30
2. Materials			
Type		**Description**	
Instrument		Handheld GPS, Camera, Geologic Hammer, Compass clinometers, Hand lens, Sample bags, Tapes, Marker.	
Software		ArcGIS 10.4, Erdas Imagine 2014, Envi 5.3, Georient, Hyppy, Geomatica.	
3. Other Data			
Data type/Scale	**Area**	**Sheet**	**Source**
Topographic map, 1:50,000	Ilesha-Okemesi	Ilesha NE/SE, Ondo NE Ado-Ekiti NW/SW and Akure NW	Federal Survey Topographical Sheets
Geological Map, 1:250,000	Ilesha-Okemesi	Iwo and Akure Sheets	Nigerian Geological Survey Agency

LandSat 8 Operational Land Imager (OLI) images consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9, the resolution for Band 8 (panchromatic) is 15 meters; LandSat 8 (OLI) was chosen because of its spectral discrimination of a variety of characteristics that are required for the study. One full scene of LandSat 8, of path 187 row 65 having a swath width of 185 km, covers the study area. Band 7 (2.11 - 2.29 micrometers); shortwave infrared, is useful in the extraction of geological formations and rock features. Although previous lineament extraction studies using LandSat had made use of Thematic Mapper (TM), Enhanced Thematic Mapper (ETM) and ETM+ sensors; the corresponding short wave infrared band in OLI was used in this research.

LandSat-8 data was converted to surface reflectance using the FLAASH in ENVI. During the atmospheric correction, raw radiance and DN data from imaging spectrometer is re-scaled to reflectance data. Therefore, all spectra are shifted to nearly the same albedo. The resultant spectra can be compared with the reflectance spectra of the laboratory or field spectra, directly. The panchromatic and cirrus cloud (band 9) bands have not been used in this study. Remotely-sensed spectral information was obtained from LandSat 8 OLI image, and the area of study was subset from a full scene covering parts of Southwest Nigeria. The scene was corrected for atmospheric, geometric and radiometric effects. Image enhancement was performed to extract lineaments that would not have been apparent from the images. The lineaments were digitized and the rose plot for the lengths of and directions of the lineaments plotted. Shear zones were digitized.

Digital spatial operations were carried out on the LandSat 8 OLI image covering the area. Contrast and edge enhancement filters were applied to the image to enhance the visual quality, and principal component analysis (PCA) operations were also carried out on the image; Band ratio operations were also carried out. Lithology variations were established, areas hydrothermally altered were also mapped out. The lineaments seen on the image were digitized to produce a lineament map based on lineament density.

Lineaments were extracted using the automated extraction process. Different sets of parameters were used in the processing: the extracted lineaments were compared to each other visually. These lineaments were cleaned visually, by overlaying roads present in the area, and automatically by removing all straight edges coinciding with boundary of the subset image.

The manual extraction was a two-fold process involving digitizing lineaments from existing geological maps and from visible lineaments and faults in the image composite of LandSat 8 and ASTER DEM in the four principal directions. The second step involved passing four directional filters through the LandSat 8 Band 6 covering the area.

The DEM technique for structural interpretation is based on the shaded relief image with various elevations. In addition, enhanced techniques such as different vertical exaggeration with varying sun azimuths and angles can improve elevation image for interpretation. In order to achieve the objectives, the following steps were undertaken: (1) image enhancement techniques, with different vertical exaggeration and shading, were first applied to raw data of the DEM image; (2) the enhanced image data were interpreted using visual justification to produce a lineament map; (3) the information obtained from interpreted lineaments were plotted in rose a diagram; (4) the major trends were obtained interpreted from interpretation of the geological structures; in addition, some of the linear features observed from the DEM image were considered to be faults and fractures.

4. RESULTS

The geological maps, including lineaments, lithology and landforms for Okemesi folds and its environs, were produced from the image processing techniques implemented on LandSat 8 OLI image and ASTER DEM data. Integrated field ground truthing and remote sensing techniques proved to be useful for lithologic and structural analysis of the study area. False-Colour Composite (FCC), band ratios, principal component analysis (PCA) are some of the important imagery techniques used for the determination of lithologies, structures and areas hydrothermally altered.

4.1 Colour Composite

This is a spectral process that creates a raster dataset containing subset of the original raster dataset bands. This is used to create a new raster dataset with a specific band combination and order. The order that the bands are listed in the Multi-value Input control box will determine the order of the bands in the output raster dataset. Generally, the output raster dataset takes the extent and the spatial reference of the first raster band with a spatial reference in the list.

Various false colour composite models were proposed in this study for LandSat 8 OLI covering the area under study (Fig. 4A, B and C). These models were considered based on their correlation coefficient, where the most uncorrelated bands are combined in RGB.

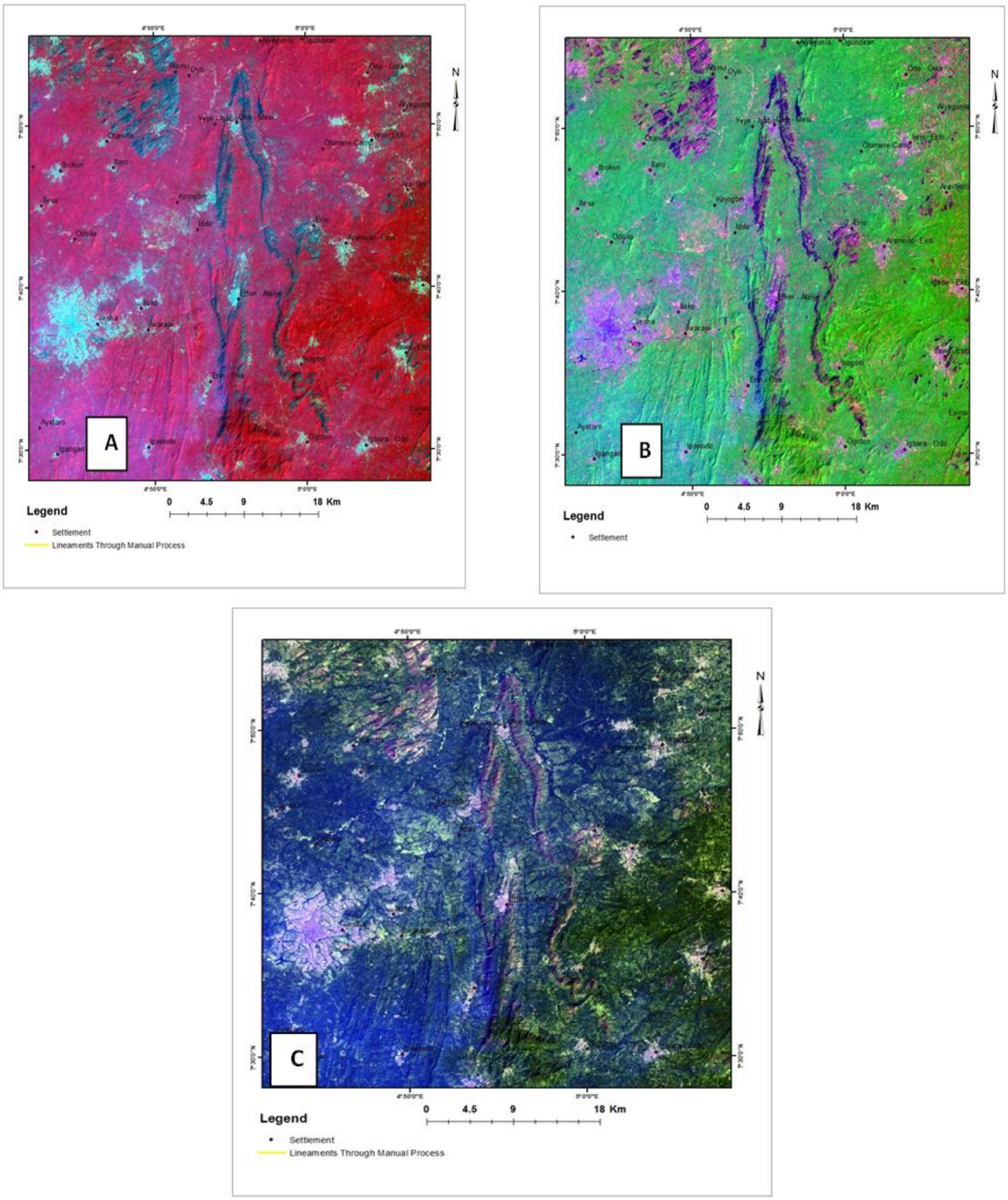

Fig. 4. LandSat 8 OLI false colour composites with band combinations; (A) 5 4 2 (B) 6 5 2 and (C) 7 6 2

An automated technique was applied using Geomatica software to extract lineaments from the 6 5 2 OLI band composite (Fig. 6). The lineaments were checked and edited, artefacts were removed from the back ground, the resulting lineaments were plotted into a rose diagram. The major trends observed are NE–SW and a few NNE–SSW and NEE–SWW (Fig. 7Dii). Lineaments were also extracted manually from the OLI 652 composite, by manually tracing the interpreted linear features. The manually extracted lineaments were also plotted into a rose diagram, both lineaments extracted through automated and the manual processes were laid over each other and compared. A good correlation between the results derived from both processes of extraction was observed; consequently, a resulting lineament density map was produced (Fig. 8B) from the combined layer (Fig. 8A).

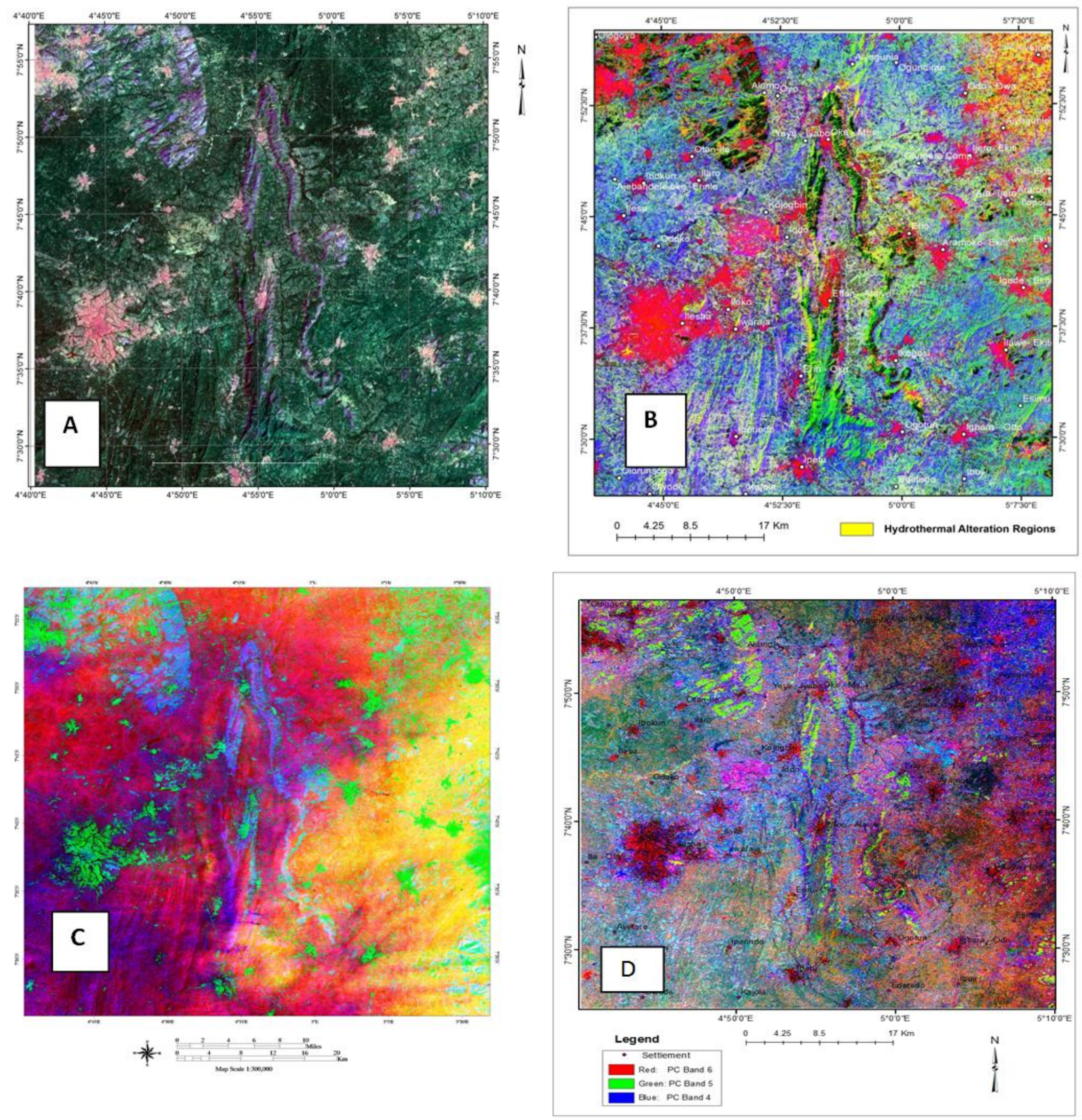

Fig. 5. Images of (A) LandSat OLI Band ratio combination 4/3, 6/2, 7/4, (B) LandSat OLI Band ratio combination 4/2, 6/7, 5, (C) LandSat OLI PCA 4,3,2, and (D) LandSat OLI PCA 6, 5, 4

4.2 Band Ratio

Band ratioing is a very effective technique. Although may seem simple, it combines different wavelengths in different representative bands simultaneously to reveal useful information. For identification and classification of lithology and structures, ratio images were prepared for the study area. The ratio images were created by dividing the Digital Number (DN) in one band by the corresponding DN in another band for each pixel, stretching the result value and plotting the new values as an image. Band ratios of LandSat OLI b4/b3, b6/b2, b7/b4 (Fig. 5A) and b4/b2, b6/b7, b5 (Fig. 5B) in RGB were also prepared. Structures, lithology and regions of hydrothermal alteration were enhanced: the band ratio b4/b2, b6/b7, b5 in Fig. 5B shows the hydrothermally altered region as yellow to the yellowish region of the image (Fig. 9D).

The band ratios of LandSat OLI b4/b3, b6/b2, b7/b4 in RGB and the OLI 762 composite (Fig. 4C) are similar in texture and tone, and seem to have equal ability to enhance structures. Here, the major trending structures are strongly discriminated, and lineaments were extracted from ratio of OLI b4/b3, b6/b2, b7/b4 as seen in Fig. 9(A) and (B). A rose diagram was plotted for these structures, the major trend observed is ENE–WSW and a few NE–SW and E–W trending structures (Fig. 9C). Subsequently, lineament density analysis which is a spatial statistical analysis that calculates the intensity per unit area from lineament features that fall within a radius around each pixel was carried out and a lineament density map was produced.

4.3 Principal Component Analysis

PCA is a statistical method that allows for the transformation of intercorrelated variable data set that are multivariate in nature into a data set consisting of new uncorrelated variables [22,23]. The first principal component largely, accounts for as much of the variability in the new data as possible while each of the succeeding components accounts for the remaining variability. PCA is then a widely used enhancement technique in which the information content of the different bands become compressed and confined within the first few bands. The LandSat OLI was normalized in order to reduce errors usually encountered as a result of various effects such as sensor quality and difference of dynamic range [23]. The PCs were calculated for the normalized 7 OLI bands. The individual PC image or any three of the resulting components were then enhanced linearly and displayed as single or composite images for further interpretation of lithology, structures and hydrothermal alteration. Statistics were computed for the individual images and percentages of data variations were produced. The OLI PCAs of PC bands 432 and 654 were generated as seen in Fig. 5(C) and (D). The OLI PCs 432 and 654 were compared, they both discriminated lithology, the lithologic discrimination in OLI PC 432 gave a more broad category of lithology grouping, while the OLI PC 654 gave a more detailed lithology variation and structural enhancement (Fig. 5D). The PC 658 was further reclassified and filtered: consequently, a resulting image showing a better defined lithology was derived (Fig. 6A), and five major rock types could be identified from the resulting image; i.e porphyritic granite, coarse porphyritic biotite-granite, schist and amphibolite region, quartzite and quartz schist, and gneiss and migmatite undifferentiated. Compared to the geologic map of the area, the above image shows very strong correlation as seen in Fig. 6A & B.

4.4 Dem Interpretation

Elevation data provides the topographic expressions of an area. They have been applied for structural interpretation by various investigators in the past [24,25,26]. Elevation data can be represented in different forms: among them, the grid forms (DEMs) are preferably useful for interpreting linear geologic structures which have topographic expressions due to offset of the surface. The ability of producing different shaded relief images because of the freedom to select illumination from any angle [24], makes DEM selectively useful over Arial photographs [27,25,28,26]. According to the authors, solar elevation and azimuth are important elements to examine topographically-related and dependent features. DEMs could also be fused with other multispectral images to increase interpretability and obtain more information than can be derived from each of the single image alone [26]. The various image enhancement techniques including directional, edge and sobel filters can be applied to DEM to enhance different linear structures [24]. Therefore, this technique was also considered for extraction of surface lineament, to assess their general pattern and density to decipher structural information of the area.

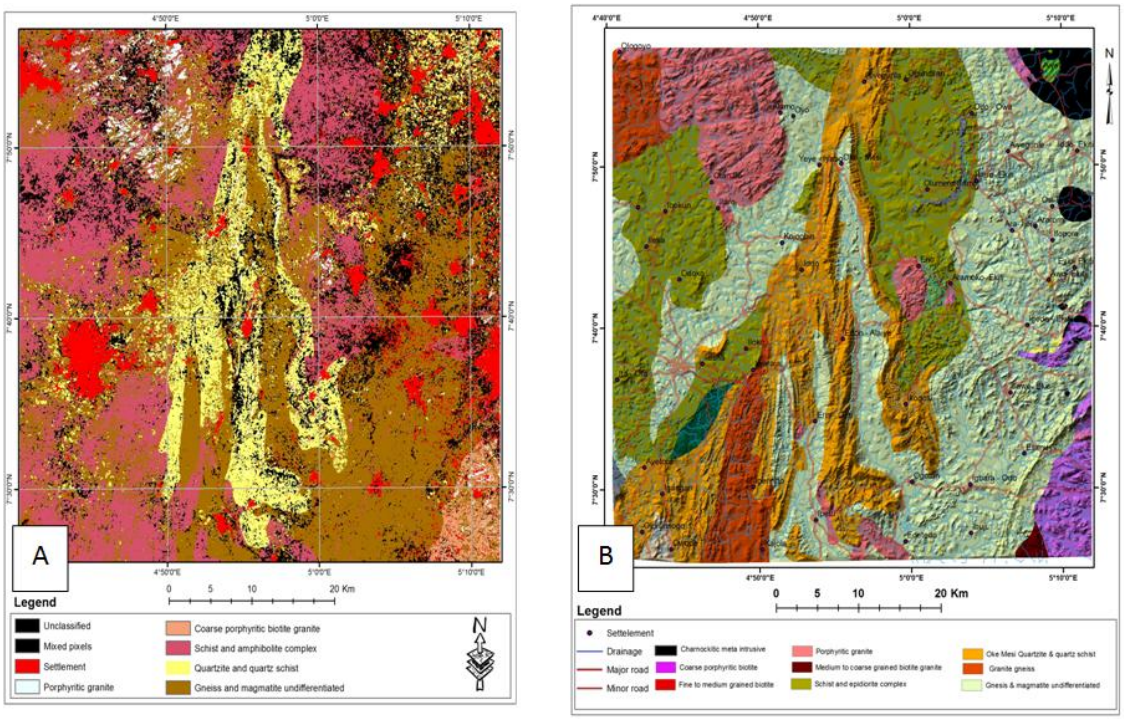

Fig. 6. (A) Reclassified OLI PCA 658 image showing the discriminated major lithologies of study area, (B) Existing geologic map of study area

The ASTER DEM of the Okemesi folds and its environs having a resolution of 30 m provided useful topographic and structural information for analysis of the lineament in the area. The extraction of lineaments from ASTER DEM in the area involved three steps: (1) shaded relief images were produced, (2) shaded relief images were fused with multispectral data and (3) linear vector features were extracted from the processed images. Shaded relief images were produced from four different Azimuth directions namely, NE, SE, SW, and NW. These relief images were helpful for enhancing the size, height, and slope variations of the morphology. Different sun angles like, 15°, 30° and 45° were tried to get more information. Among them, 30° was finally selected for its better interpretability (Fig. 10A, B, C). Fig. 11A, B, C and D shows the images produced by combining the different shaded relief images facing to the same direction. The shaded relief images with illumination directions N, NE, E were stacked and stretched to enhance E-W, N-S and NW-SE lineaments (Fig. 11). The other shaded relief image was produced by combining N, NW and W direction relief images to enhance E-W, N-S and NE-SW lineaments (Fig. 11). These shaded relief composite images in general led to better interpretation of lineaments since they superimpose the information contained in various single shaded relief images. Fused images were generated by multiplying the LandSat 8 OLI band 6 with the stack of shaded relief images with illumination directions N, NE, E and N, NW and W produced earlier; the resulting image is seen Fig. 12A. Band 6 was selected because of its better information on topography and boundary delineation as compared to other bands.

The final interpreted lineament map (Fig. 12B) was then produced with a total of about 178 lineaments extracted from ASTER DEM. Lineament density of the lineament extracted from the DEM was also derived (Fig. 12D). The azimuthal distribution shown by the rose diagram (Fig. 12C) indicates that most of the lineaments are trending NE-SW and NNE-SSW, with a few NNW-SSE directions, and distributed throughout the Okemesi fold on most of the rock complexes.

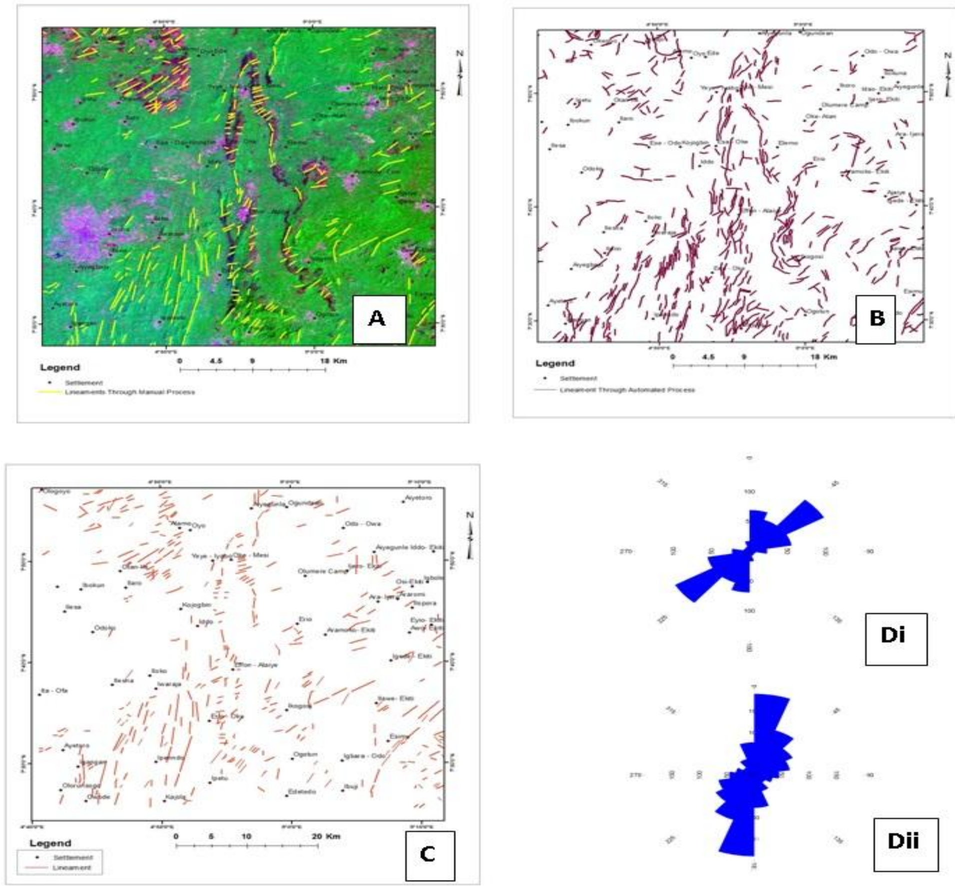

Fig. 7. (A) LandSat OLI colour composite with band combination 6 5 2 where lineaments were manually extracted, (B) Lineaments automatically extracted, (C) Lineaments manually extracted, (Di) Rose diagram for manually extracted lineaments, (Dii) Rose diagram for lineaments extracted through automated process

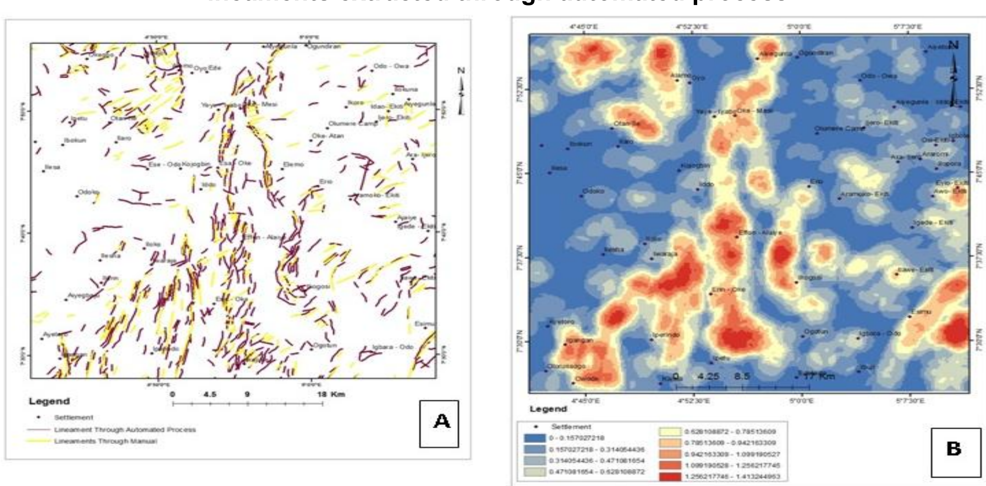

Fig. 8. (A) Combination and comparison between lineaments extracted through automated and manual process, (B) Lineament density map, showing the spatial concentration of lineaments per unit area

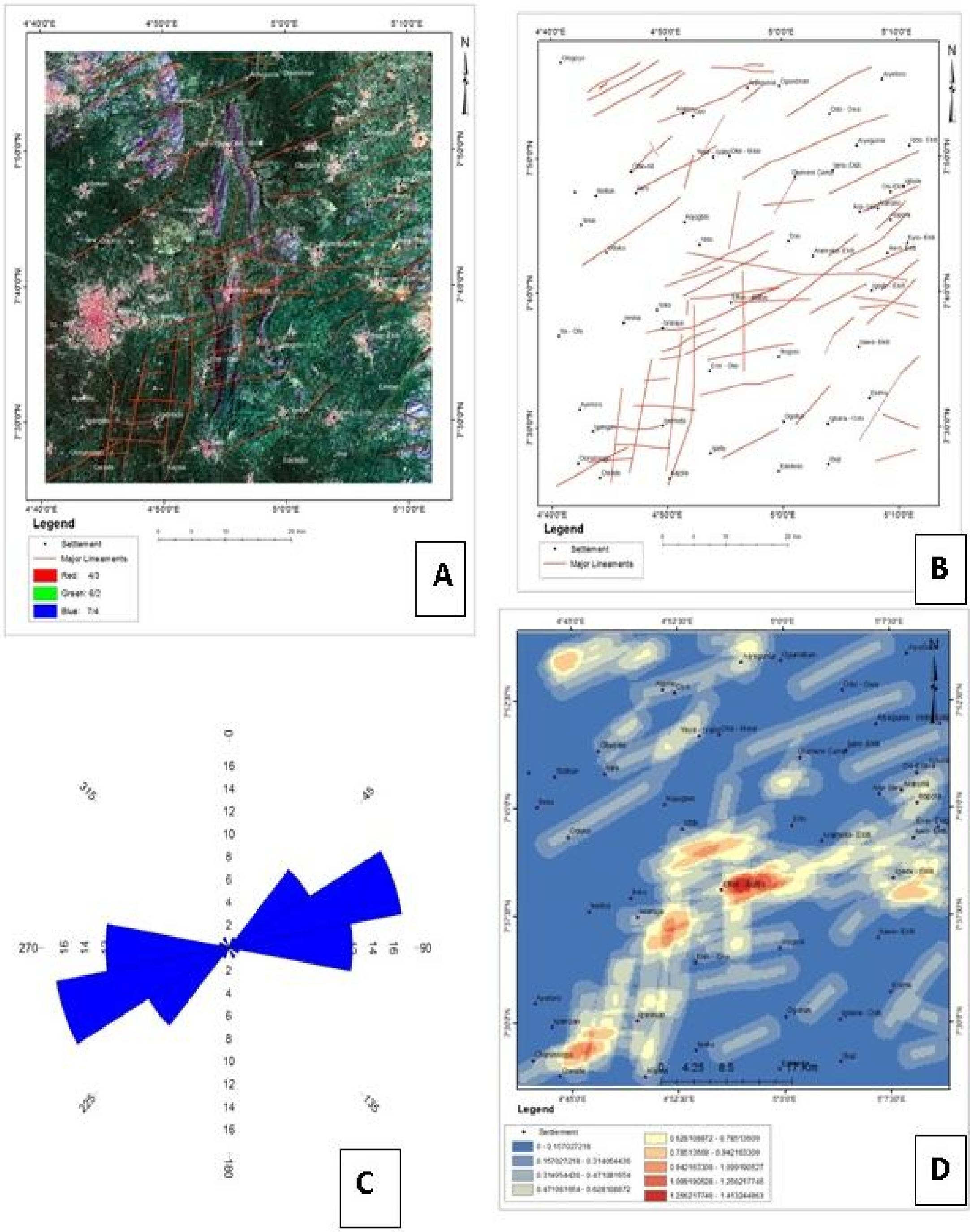

Fig. 9. (A) LandSat OLI image with Band ratio combination 4/3, 6/2, 7/4 and major lineaments, (B) Major trending Lineaments Extracted from OLI band ratio image, (C) Rose diagram for major trending lineaments, (D) Lineament density for major trends extracted from OLI band ratio 4/3, 6/2, 7/4 image

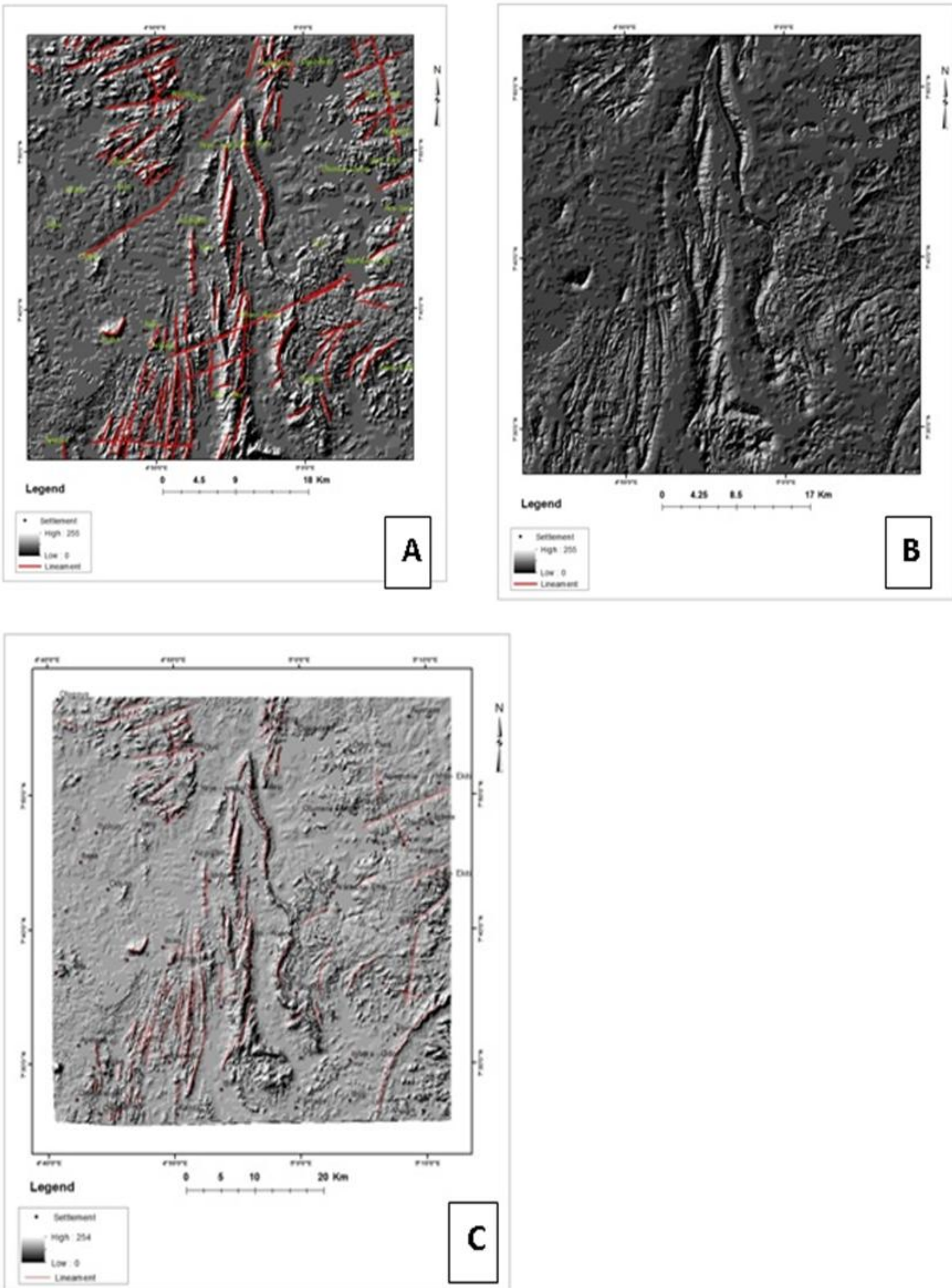

Fig. 10. (A) shaded relief image with sun angle of 15°, and azimuth angle of 315°, (B) shaded relief image with sun angle of 30° and azimuth angle of 135°, (C) shaded relief image with sun angle of 45° and azimuth angle of 315°

Fig. 11. (A) Image stack of shaded relief images 315° sun azimuth, (B) Image stack of shaded relief images 225° sun azimuth, (C) Image stack of shaded relief images 135° sun azimuth, (D) Image stack of shaded relief images 45° sun azimuth

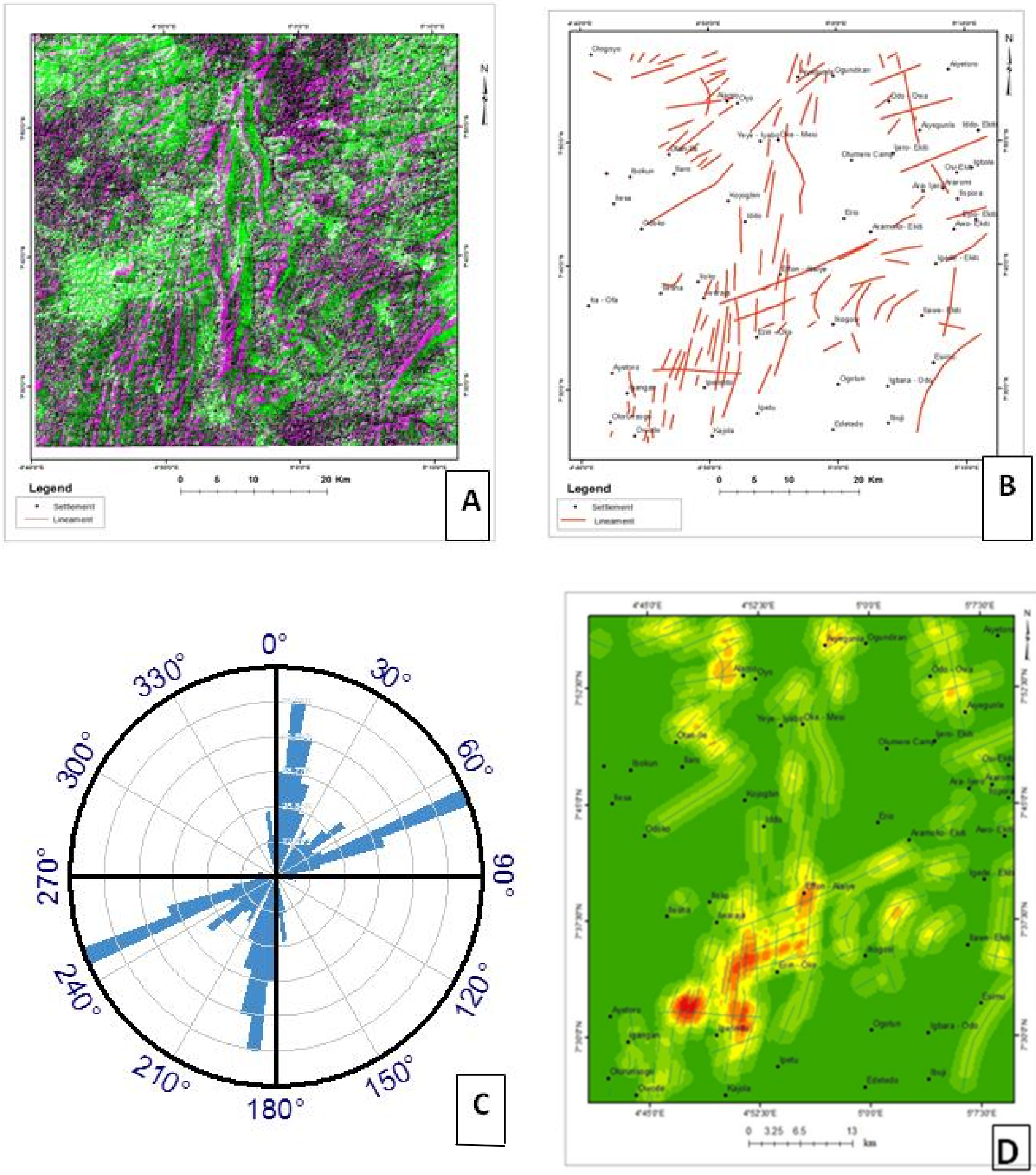

Fig. 12. (A) Composite of corresponding shaded relief images multiplied by band 6 of OLI, (B) Final lineaments extracted from the ASTER DEM, (C) Rose diagram showing azimuthal distribution, (D) Lineament density of the lineament extracted from the DEM

5. CONCLUSION

The qualitative interpretation conducted on relations between lithologies and structures in Okemesi Folds and its environ showed remarkable results. Major structures were interpreted with respect to the regional structural corridors, particularly the NNE-SSW, NNW-SSE trending structures and their intersection. In this study, all the available data sets provided useful information. Satellite and ASTER DEM data were found to be an invaluable aid, which together with modern enhancement and integration techniques assisted in the visualization and discrimination of lithological units of the area. Among the various image enhancement techniques, image PCA and band ratioing resulted in better lithological differentiation and discrimination of hydrothermally altered regions in the area (Figs. 6A and 5D). On the basis of similar spectral signature, different Precambrian basement lithologies including schist, gneiss, granite, amphibolites and the migmatites could be identified and mapped. The ASTER DEM of the area revealed topographic and structural information of the Okemesi Folds and its environs.

The combination of multi-spectral remote sensing data and ASTER DEM is an effective tool for lineament and structural analysis around the Okemesi Folds and its environs. Subsequent extractions of surface lineaments were carried on multispectral, ASTER DEM data. The orientation analysis revealed three dominant lineament orientations, which determine the tectonic grain of the area, (NNE-SSW, ENE-WSW and NE-SW). These orientations were found consistent with the two major regional tectonic trends. NE–SW was considered as a main lineament direction and NW–SE striking as a secondary lineament direction. The E–W and N–S directions are less represented. Non-orientation density analysis applied on the individual surface lineaments indicated that the metasediment rocks were highly affected by surface lineaments. The results of lineament analysis in the Okemesi Folds and its environs, obtained from remote sensing data were in agreement with previous studies carried out on the area by previous researchers. The SW part of the study area has undergone intense shearing, the area include Iwaraja through Iperindo, Oke-Ayo, Oloruntedo and other settlements, the shearing in these areas can be associated with Ife-Wara fault.

Furthermore, the detailed surface lineament interpretations and analysis carried out on ASTER DEM, depicted that the quartz and quartzite schist group of rocks were affected by high lineament density along a narrow zone (Fig. 12B and D). It was also observed that this high density lineament continued further to the north following a narrow zone trending NNE. The orientation analysis proved the existence of three tectonic patterns, namely: NNE-SSW, NE–SW, and ESE-WNW. These tectonic patterns were found consistent with the regional Pan-African tectonic grain.

In this study, lineaments were extracted through visual method from LandSat OLI and ASTER DEM images of the area. Elevation data was used for interpreting linear geologic structures which have topographic expressions due to offset of the surface. The data were used to produce different shaded relief images because of the freedom to select illumination from any angle [24]. ASTER DEM was also fused with other multispectral images to increase interpretability and obtain more information than can be derived from each of the single images alone [26], (Fig. 12).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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