

Application of Remote Sensing in Mapping Hydrothermal Alteration Zones and Geological Structures as Areas of Economic Mineralization in Mwitika-Makongo Area, SE Kenya

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Abstract

Remote sensing investigations combined with Geographical investigation systems (GIS) have become more important for the study of geological mineralization and structural geology like lineaments. Automatic extraction of lineaments from satellite imagery help in giving an overview of the tectonic events in the study area. The main objective of the study was to map hydrothermally altered rocks and geological structures that may be associated with mineral deposits in Mwitika-Makongo area. The study involves the use of Landsat- 8/OLI image. The satellite images were classified using ENVI 5.3 and ArcGIS 10.5. PCI geomatics 2016 was used for extraction of lineaments while Rose diagram was generated using Rockworks 16. Different remote sensing techniques, such as colour composite, band ratio and principal component analysis were applied to identify geological units and features related to economic mineralization. Colour composite band combination (5, 6, 7) showed hydrothermally altered geological units as blue. Band ratio combination (4/2, 6/7, 6/5) showed the areas that were hydrothermally altered as blue. Lineament mapping was done using PCA, with the first three PCs having the highest percentage of Eigenvalues. A lineament density map showed higher values in Makongo hill followed by Kalima Kathei hill. The structural trend from the rose diagram is in the NE direction. The results of image analysis and lineament extraction show that the economic minerals like iron ore are located in areas of hydrothermal alterations where intrusive rocks like Pyroxenite were found.

Keywords: Colour composite, Geographical investigation systems, Landsat- 8/OLI, Lineaments, Principal component analysis, hydrothermally altered.

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1. Introduction

The Mwitika-Makongo study area occurs within the Neoproterozoic metamorphic belt rocks of Kitui East sub-county, South Eastern Kenya. The rocks of this area are highly deformed due to regional tectonics and high-grade metamorphism that led to the formation of potential economic mineral resources. Previous geological surveys within the area have established the occurrence of several mineral resources of economic potential like iron ore, magnesite, coal and various gemstones. However, these previous geological surveys were conducted using field observations through various sampling techniques and limited use of technology at that time. This has led to a vast majority of the area's local geology is poorly understood. With the current advancement in technology, unearthing the details of the area local geology could be key in unlocking the vast mineral potential and exploration prospectivity.

The current advancement in Remote Sensing technology like the introduction of Landsat-8/OLI with a higher number of bands and narrow bandwidth has led to an improvement in geological mapping. Landsat-8/OLI bands was considered in this research as they differentiated geological units and structures in understanding and defining of specific remote sensing data attributes useful for geological discrimination in Mwitika-Makongo study area.

An image subset of Landsat-8/OLI data year 2019 scenes LC81670612019025LGN00 was downloaded from the USGS website page. The downloaded data was processed using ENVI 5.3 and ArcGIS 10.5 software. The satellite image processing techniques such as colour composite, principal component analysis (PCA), and band rationing were applied to achieve the main purpose of this study.

The results of this study showed new geological structures and lithology that were missing from previous research works. Band rationing and principal component analysis enhanced lineament mapping that was an important part of structural geology as they revealed the tectonic history of the area. Automatic lineament extraction through PCI Geomatica 2016 software of Landsat-8/OLI bands PC1, showed that the drainage in the area is lineament guided. Geological features like lineaments and faults are the major tectonic events that control mineral formations and drainage patterns in the study area.

2. Geology of the Study Area

Located in the Kitui East sub-county, the study area is bounded by longitudes 38° 18'E and 38° 26'E and latitudes 1° 22'S and 1° 32'S (figure 1). Kitui county constitutes part of the East African orogenic belt which extends from

Saudi Arabia and ends in Mozambique (Africa). Stern 1994, suggested that this belt comprises of the Arabian-Nubian Shield (ANS) in the north and the Mozambique belt in the south. The Mozambique belt is a major N-S trending metamorphic and lithotectonic domain (900 to 550 Ma) that resulted from the oblique collision between two Gondwana fragments, (Key *et al.*, 1989) and (Stern, 1994). The entire study area is part of the Neoproterozoic Mozambique mobile belt in Kenya. The oblique collision that occurred during this belt formation, resulted in the development of large shear zones parallel to the main collision phase. These shear zones are widespread in Kitui especially around the study area comprising of Yatta and Mutito shear zones. The geology, structures and tectonic history of Mozambique belt especially within Kitui County have been reviewed by various researchers; (Biyajima *et al.*, 1975; Gaciri *et al.*, 1993; Key *et al.*, 1989; Mathu and Tole, 1984; Mathu *et al.*, 1991; Mathu, 1992; Mosley, 1993; Nyamai *et al.*, 1999, 2003; Opiyo-Aketch and Nyambok, 1984; Waswa, 2015; Waswa *et al.*, 2015).

The metamorphism in the region range from amphibolite to granulite facies. Presence of granulite-facies rocks like; garnet-bearing gneisses, calc-silicate rocks, quartzites, amphibolites and norites were indicators of a high-grade metamorphic terrane. The complex and strongly metamorphosed granulite facies rocks contain a diverse chemical and mineralogical composition depending on the parent rocks.

Originally this Neoproterozoic Mozambique belt consisted of sedimentary rocks that were later metamorphosed. The presence of repetition bedding in granitoid gneiss and vein structures in migmatites of the area are proof of a sedimentary origin being retained. Granitoid gneisses and migmatites dominate most massive bodies like Makongo hill within the study area with intercalations of pegmatites and quartzo-feldspathic veins. The lithologic units of the study area consist of high-grade metamorphic Neoproterozoic rocks, basic and ultrabasic intrusive and Pleistocene to recent sediments. The granitoid gneisses, migmatites, amphibolite, biotite gneiss and marbles comprise the Neoproterozoic rocks. Olivine norite and gabbro (basic intrusive), peridotite and pyroxenite (ultrabasic intrusive) accompanied by other intrusive like pegmatites and quartz veins. The last lithological grouping includes the kunkar limestone, reddish-brown sandy soils and black cotton soils that form the recent sediments.

An attempt has been made to update the geology of Mwitika-Makongo area to fill the gap left by the research work from previous geologists. The current research work established extensive pyroxenite rocks (ultrabasic intrusive) from the area mapped by Saggerson, (1957). Some tectonic structures that affected the rocks of the area were also established from the area mapped by Sanders, (1954). They include open joints and faults within Makongo hill that were missing from his report and geological map.

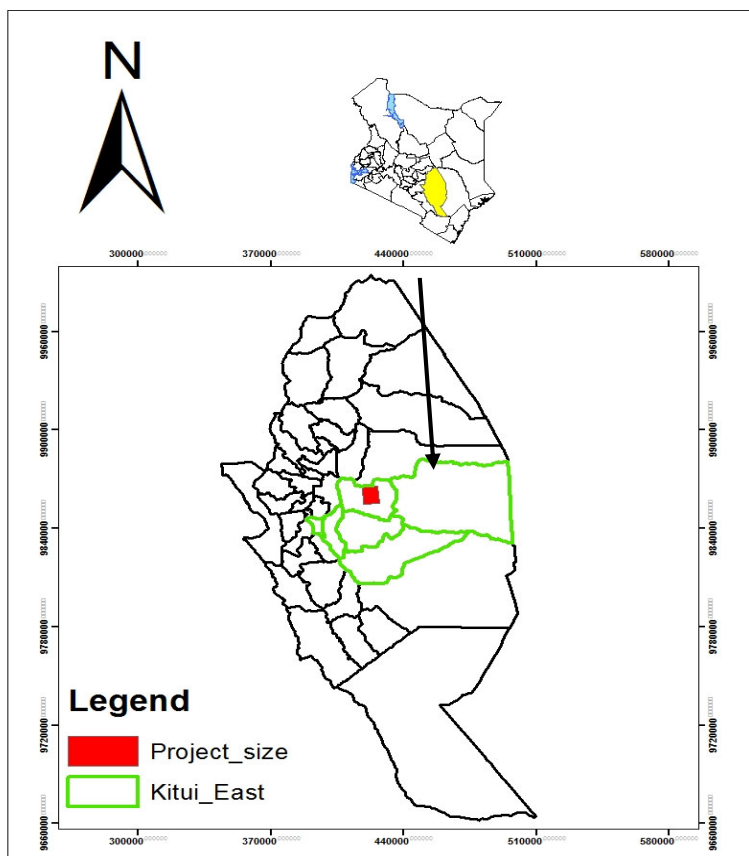


Figure 2. Location of the study area.

3. Materials and Methods

The methodology adopted in this study was aimed at achieving the two main objectives of this research; (i) Map hydrothermally altered zones that can be related to economic mineral resources in the area, and (ii) Extract geological structures like faults and lineaments occurring within the area. Landsat bands are known for particular application especially in geology (band 7 and 5) and therefore Landsat-8/ OLI data set was preferred in this research. A level 1T (terrain corrected) Landsat-8/ OLI imagery with a spatial resolution of about 30m was downloaded from USGS website. Atmospheric correction was not done on the data since it had already been done by the data provider. The data provider (USGS website) had also projected the images to the required WGS-84 datum, UTM zone 37 South and projection units in meters. Only sub-setting of the data by clipping with a shapefile of the study area was performed. The processing techniques and analysis used in this study are discussed in the following sections. The techniques were performed using ENVI 5.3, ESRI ArcGIS 10.5, ILWIS, RockWorks 16 and PCI GeoAnalyst 2016 programs.

3.1 Colour Composite

Since satellite images for a given area are captured in black and white bands, a composite image is generated by blending information from two or more bands to enhance energy levels from a greyscale image to an RGB image. The comparison of spectral characteristics of land features in multiple bands (colour composites) therefore gives a better separation/contrast between different surfaces when displayed as a Red, Green and Blue image. The image is called false-colour composite (FCC) and has an advantage of preserving morphological features as well as displaying different lithological units in different colours (Al-Nahmi et al., 2016). A false-colour image is formed by combining visible bands with other bands like infrared bands or combining only the infrared bands thus enhancing the spectral characteristics of the bands. Another composite called a true colour composite can be created by combining three visible bands of the spectrum corresponding to red, green and blue. In colour composite, bands are assigned based on the spectral properties of the rocks and alteration minerals to be revealed.

3.2 Band Ratio

In remote sensing, band ratio is used to effectively display spectral variation and enhance the contrast between materials. Sabins (1999), discussed the band ratio as a technique where the digital number (DN) value of one band is divided by the digital number value of another band. These ratios are very useful for highlighting important features like lineaments that cannot be seen in the raw band. Band ratios also convey the spectral or colour characteristics of image features regardless of variations in the scene illumination conditions (Omwenga, 2018).

Different types of band ratios can be used for various applications like lithological mapping or alteration discrimination, depending on the purpose of the study. The choice of the bands also depends on their spectral reflectance and its positions of the absorption mineral being mapped. In this study, for instance, to enhance alteration zones from various intrusions in the area, Landsat-8 bands with a high spectral reflectance especially for iron minerals was used.

3.3 Principal Component Analysis

According to Vincent (1997), Principal component analysis is an image enhancement technique for displaying the maximum contrast from several spectral bands with just three primary display colours. The principal component analysis is a way of identifying patterns in data and expressing them in such a way as to highlight their similarities and differences in that data, (Chasia, 2014). Multispectral image data is usually strongly correlated from one band to the other (Bishta, 2009), causing data redundancy (high correlation of spectral bands) due to similar visual appearance for different bands. Principal component analysis (PCA) is a statistical technique used to reduce this data redundancy by transforming the original data onto new orthogonal principal component axes producing an uncorrelated image with much higher contrast than the original bands (Kujjo, 2010). The number of output principal components (PCs) is the same as the number of the input spectral bands. PC1 highlights features common to all input bands (topography) and often display important structural information. PC2 is orthogonal to PC1 in n directional space and highlights the spectral differences between visible and the infrared spectral bands (Kujjo, 2010). PC3 includes the third most variability and is orthogonal to the other two PCs.

3.4 Structural Mapping and Lineament Extraction.

Lineaments can be simply defined as linear or curvilinear edges that may be related to geological structures like faults and joints. They display lines of weaknesses within the land surface. Lineaments can also be related to features that occur within the land surface that are not related to the geology of an area. Examples of such lineaments are those related to geomorphological features like cliffs, tonal contrast due to vegetation or rock composition, or due to human activities like construction of roads and buildings. Satellite images have in the past been used to extract lineaments for different purposes, like defining geological structures and tectonic fabrics.

4.0 Results

4.1 Colour Composite

Several different spectral bands of Landsat-8/ OLI data were selected and combined in an RGB colour system. This was done to come up with the best colour composite Landsat-8 image for extracting useful information about the land surface such as discrimination of hydrothermally altered zones using bands 5,6,7 (Figure 2) and 7,6,2 (Figure 3). These combinations involved bands from each spectral region except for first spectral band 1 which is designed as a deep-blue band for coastal water and aerosol studies. Hence, band 1 was excluded from RGB colour combinations in this study using ILWIS software, although its OIF ranking was higher.

Only two False Color images were created using bands 5,6,7 and 7,6,2 in RGB combinations. These band combinations allowed better differentiation between vegetated areas and good exposure of hydrothermally altered outcrops. In false-colour image 5,6,7, red colour represents healthy vegetation, the light blue colour represents outcrops, bare land and sands, the dark blue colour represents hydrothermally altered rocks, and the light green represents unhealthy vegetation. In false-colour 7,6,2 image, dark green colour represents healthy vegetation, yellow colour represents sands and outcrops, light green represents unhealthy vegetation and brown colour represents hydrothermally altered rocks.

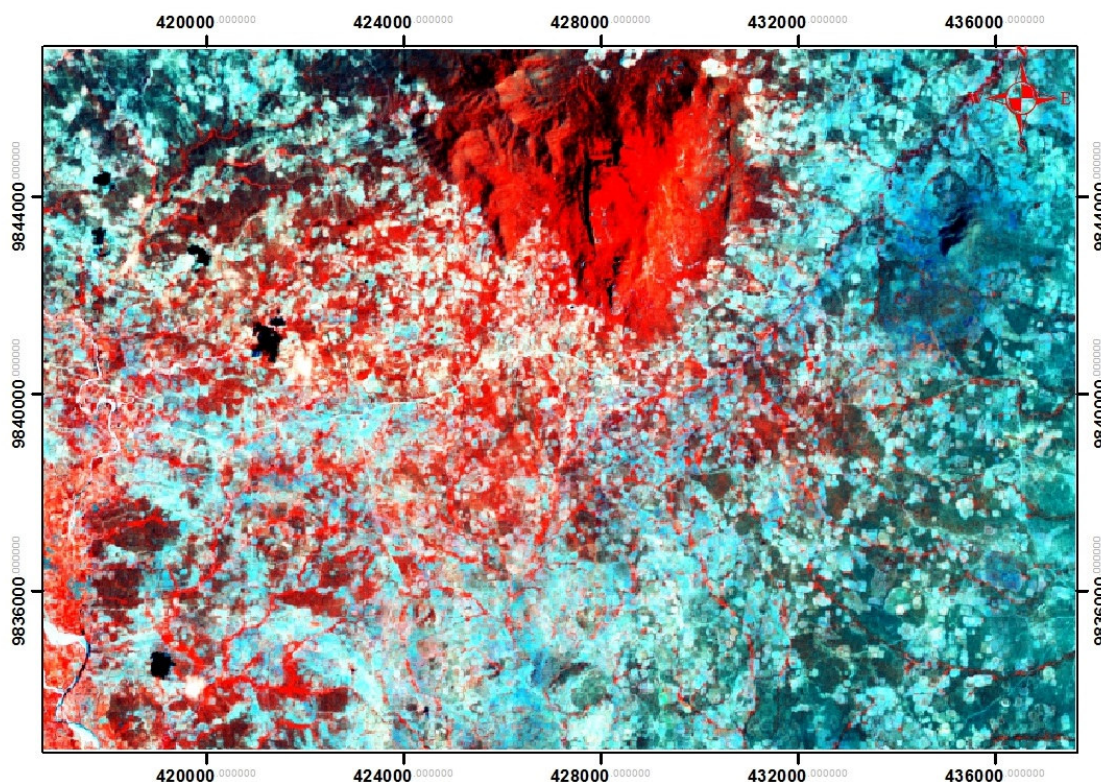


Figure 3. FCC RGB bands (5,6,7) dark blue colour represents hydrothermally altered rocks.

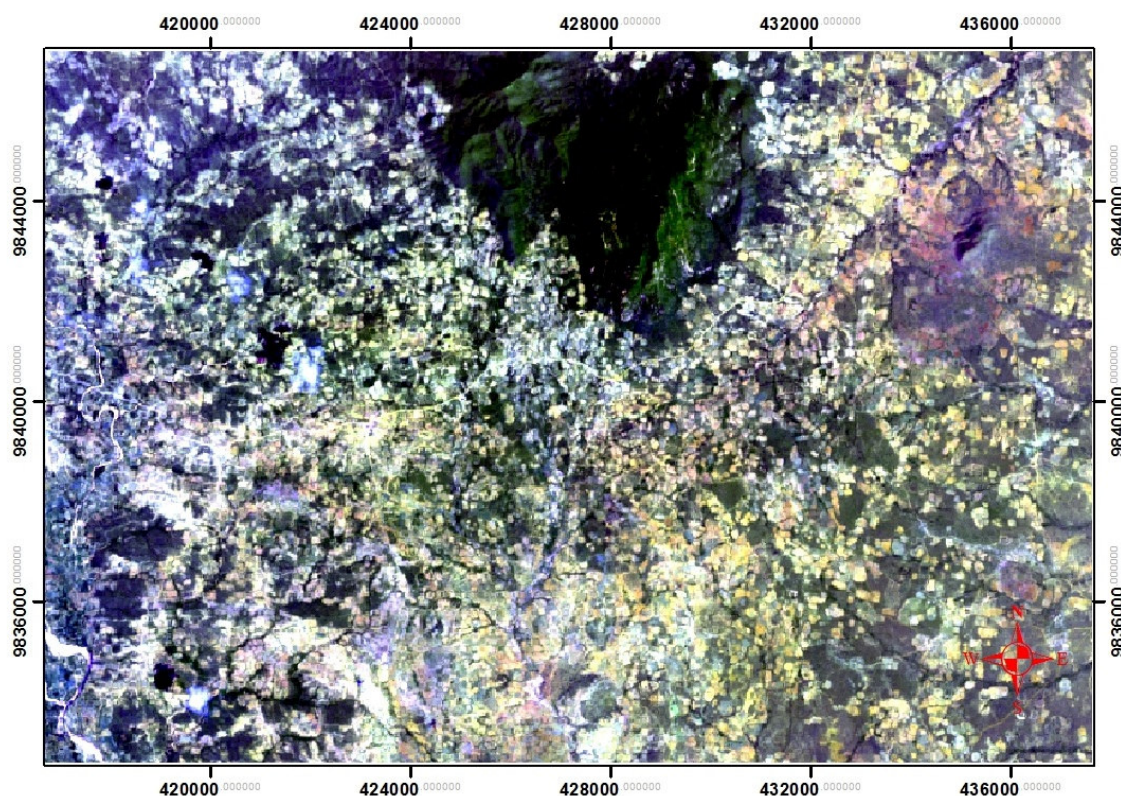


Figure 3: FCC RGB bands (7,6,2) brown colour represents hydrothermally altered rocks.

4.2 Band Ratio

To enhance hydrothermally altered rocks, band ratios with distinctive reflection features were produced. Minerals that are directly associated with hydrothermal alteration areas in Neoproterozoic Mozambique rocks were considered in the choice of the band rationing. An example is the use of ratio B4/B2 that is needed to enhance Ferric-ion bearing minerals (Hematite, Goethite, etc.) in Landsat-8 OLI (Figure 4) displayed in red colour.

The operations were performed by selecting the bands with a high reflectance for a mineral as the numerator and a band with high absorption as the denominator in ENVI software band ratio interface. Different band ratios were combined and assigned to RGB but the most appropriate ratio combination was found to be (4/2, 5/6, 6/7) and (4/2, 6/7, 6/5). Band 5/6 displayed greenish areas as being dominated with Fe-Mg silicate minerals like olivine and pyroxene useful in delineating intrusive rocks in the area. Frutoso (2015), used Landsat-8 OLI ratio 4/2 (greyscale) to highlight areas with bright tones corresponding to iron mineralization. This was used to confirm the deduced information displayed in ENVI interface (Figure 5). Image incorporation of bands 4/2, 6/7 and 6/5 was used to discriminate altered from unaltered outcrop and highlight areas where intrusive rocks occur. In Figure 6, olive green colour represents vegetation, purple colour represents altered rock outcrops and pink colour represents sand/unaltered rock outcrops.

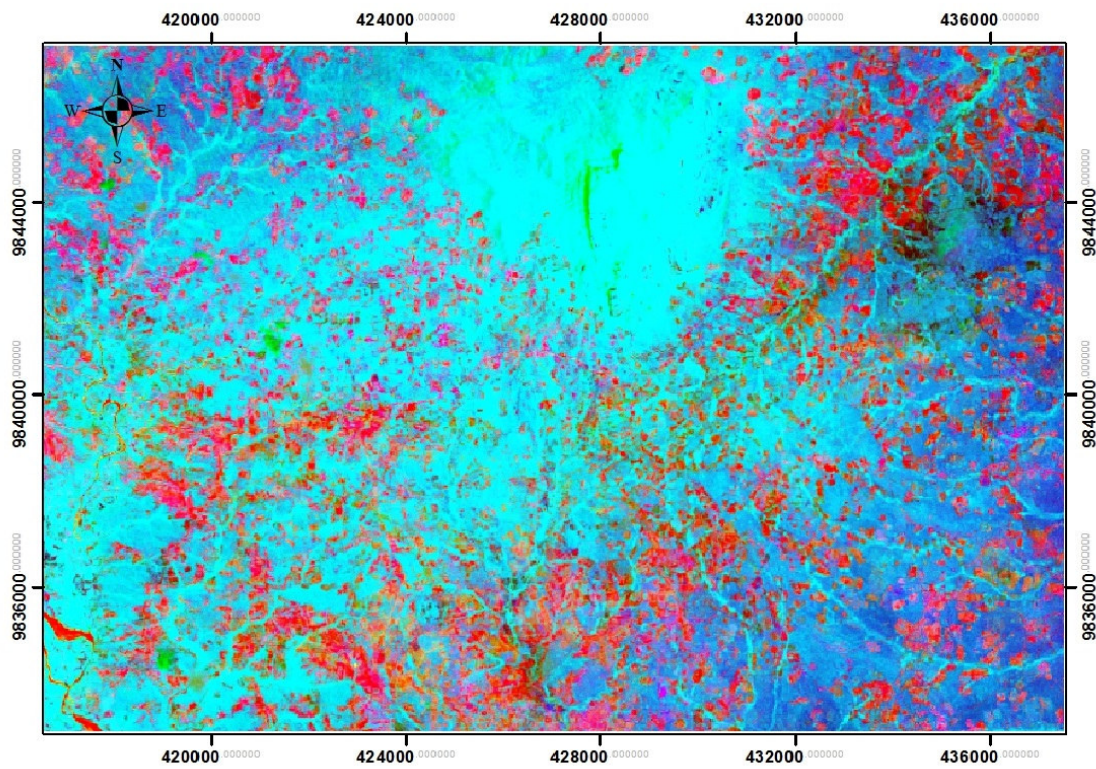


Figure 4: Ferrous iron displayed as red in RGB 4/2,5/6 and 6/7

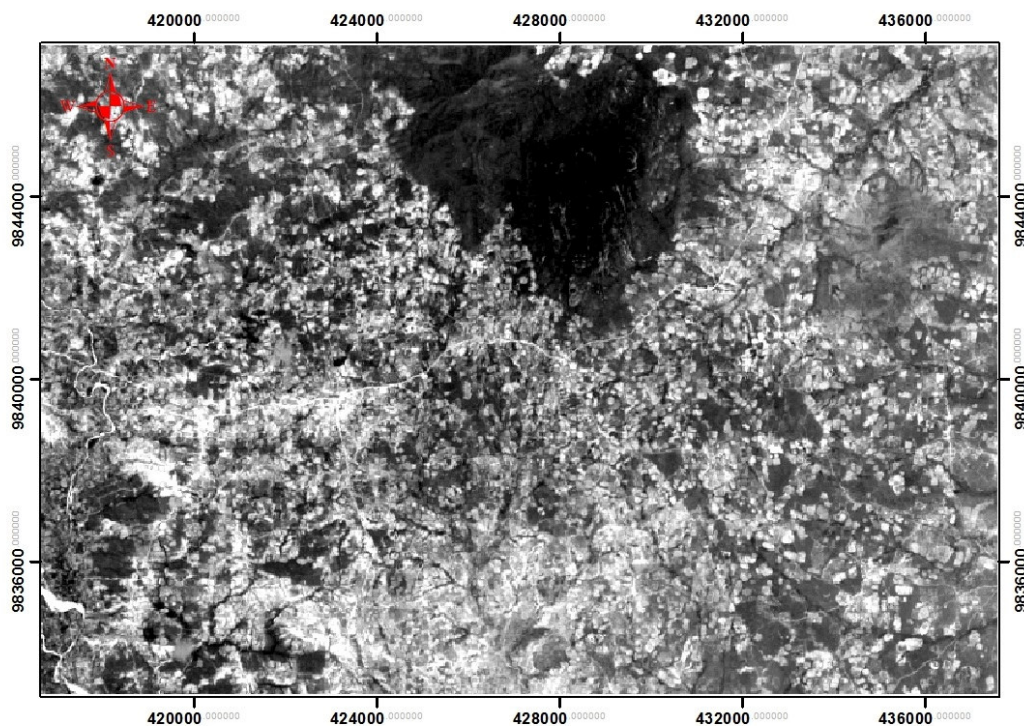


Figure 5: Ratio 4/2 in greyscale displaying iron oxide minerals as bright pixels

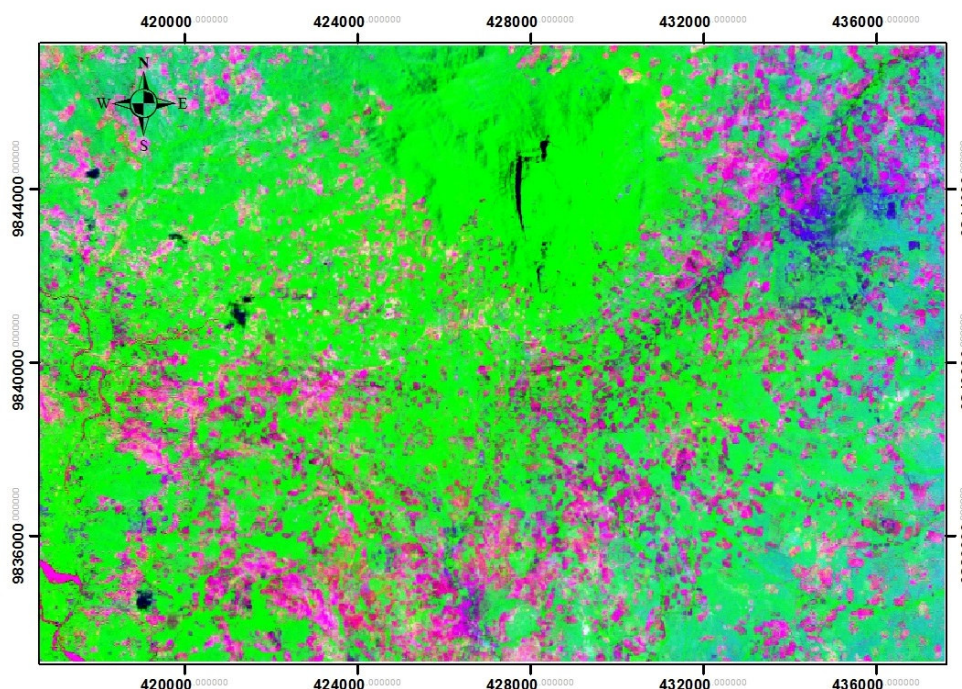


Figure 6: FCC band ratio (4/2, 6/7 and 6/5) RGB, the blue colour represents altered rocks.

4.3 Principal Component Analysis

The principal components are blended in RGB colour composite image, with the result containing information from all n bands, a characteristic that helps in displaying boundaries between terrain units (Kujjo, 2010). In the present study, the area is composed of several rock types among which quartzites, marbles and granitoid gneiss are light-coloured and thus there is a plausible correlation of bands of image data. PCA technique was applied to reduce the number of correlated bands of an image to a few uncorrelated bands to enhance on visual interpretation of ground features like alterations and lineaments. Seven Landsat-8/OLI bands (1,2,3,4,5,6 and 7) were applied for this process. The output eigenvector matrix values are represented (Table below).

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
BAND 1	0.37753	-0.27791	-0.02365	0.66155	0.01288	0.31128	0.49494
BAND 2	0.37578	-0.34621	-0.06167	0.26833	-0.06688	-0.04901	-0.81009
BAND 3	0.36802	-0.32353	-0.05767	-0.20162	-0.08367	-0.78630	0.30107
BAND 4	0.38429	-0.29868	-0.25805	-0.63762	0.21877	0.48748	0.06680
BAND 5	0.43649	0.23426	0.83778	-0.15787	-0.13463	0.09801	-0.00852
BAND 6	0.38671	0.59167	-0.22147	0.12883	0.63502	-0.16834	-0.05619
BAND 7	0.30507	0.45174	-0.41809	-0.04022	-0.72051	0.08277	0.02144
EIGENVALU ES	589325712.1 5340	15622793.4 6466	3216151.7 0666	345466.7 5395	147855.4 8721	21219.72 298	8931.78 952
PERCENT OF EIGENVALU ES	96.8190	2.5666	0.5284	0.0568	0.0243	0.0035	0.0015
ACCUMULA TIVE OF EIGENVALU ES	96.8190	99.3856	99.9140	99.9708	99.9950	99.9985	100.000 0

Table 1: Eigenvectors and eigenvalues of PCA on Landsat-8/OLI imagery.

According to Crosta and Moore (1989), the magnitude and sign of each eigenvector loading in each PC correspond to the spectral properties of the surface materials such as rock, soils and vegetation. PC1 explains 96.82%

of the total variance of the data, as shown in the table above. This PC is composed of positive values of all 7 bands and is being responsible for the overall scene brightness. PC2 contains 2.57% of the original data variance and PC3 represents just 0.53%.

The first three PCs with most data variance were combined in RGB composite (Figure 7 below) and it was used for lineament and lithological mapping. Purple colour represent healthy vegetation, olive green colour represents outcrops, sands and bare-land, while the blue colour represents hydrothermally altered rocks.

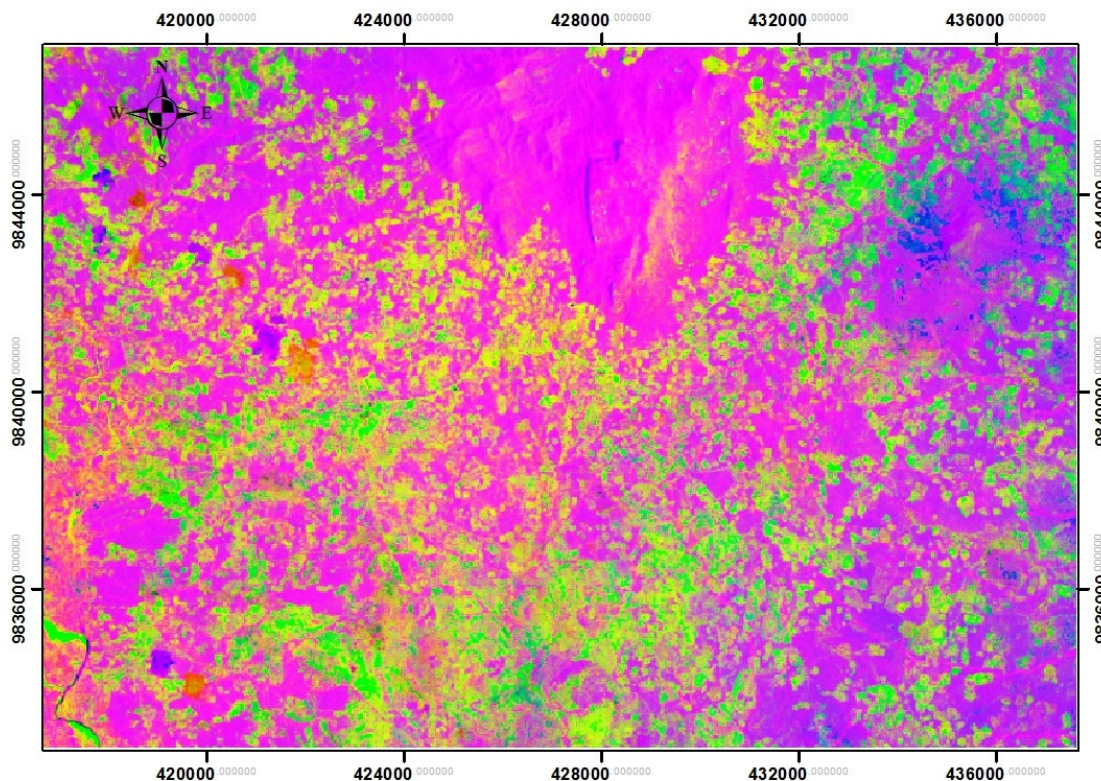


Figure 7: RGB Composite PC3, PC2, PC1 best for displaying hydrothermally altered zones.

4.4 Structural Mapping and Lineament Extraction.

In the study area, lineaments have a strong topographic expression and can easily be detected on satellite images. There is a close relationship between lineaments and the drainage pattern in the area implying that the drainage pattern could be guided by lineaments. During geological field mapping, this was ascertained as the majority of the streams in the area occur to originate from areas of high elevation like Makongo hill and flow downhill through fracture zones and faultlines (Figure 8), UTM 9842083 and 428002. The lineaments were visible in band combination 7,4,2 and band ratio 7/5, 6/4, 4/2. However, the first principal component image (PC1) of Landsat 8 pan-sharpened reflected bands had good visualization of linear features due to it carrying most information from all the bands. PC1 was therefore preferred and suitable for lineament extraction of the study area.



Figure 8: Structurally controlled drainage in Makongo hill

The obtained total lineaments in the study area from automatic lineament extraction from PC1 were visually edited to extract only the structural lineaments that were necessary for this study. A rose diagram of Lineament showed that their predominant trend is NE (Figure 10).

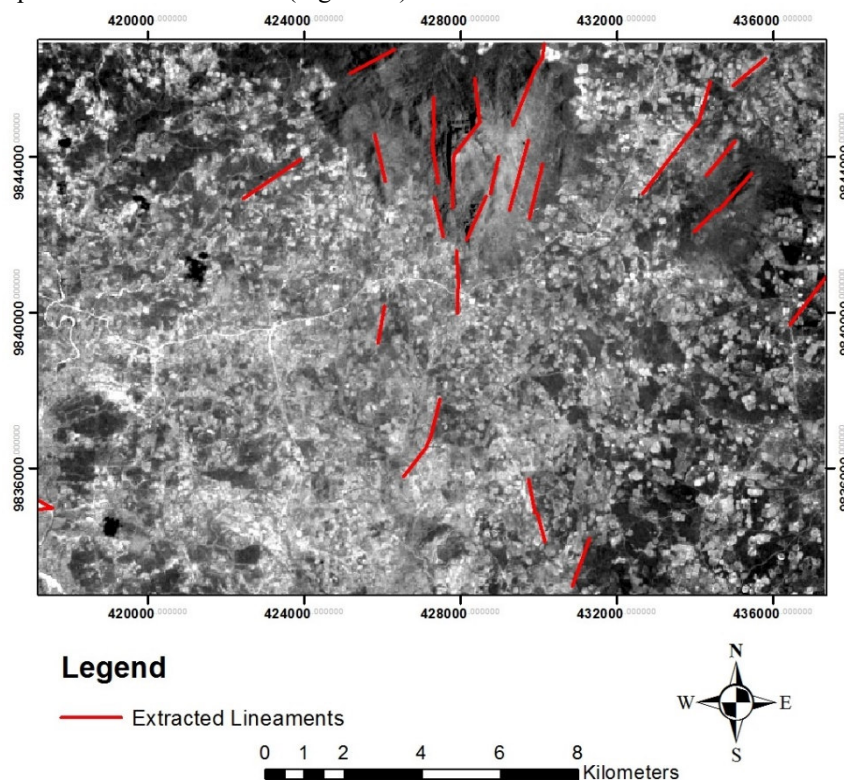


Figure 9: Lineation map of Mwitika-Makongo area

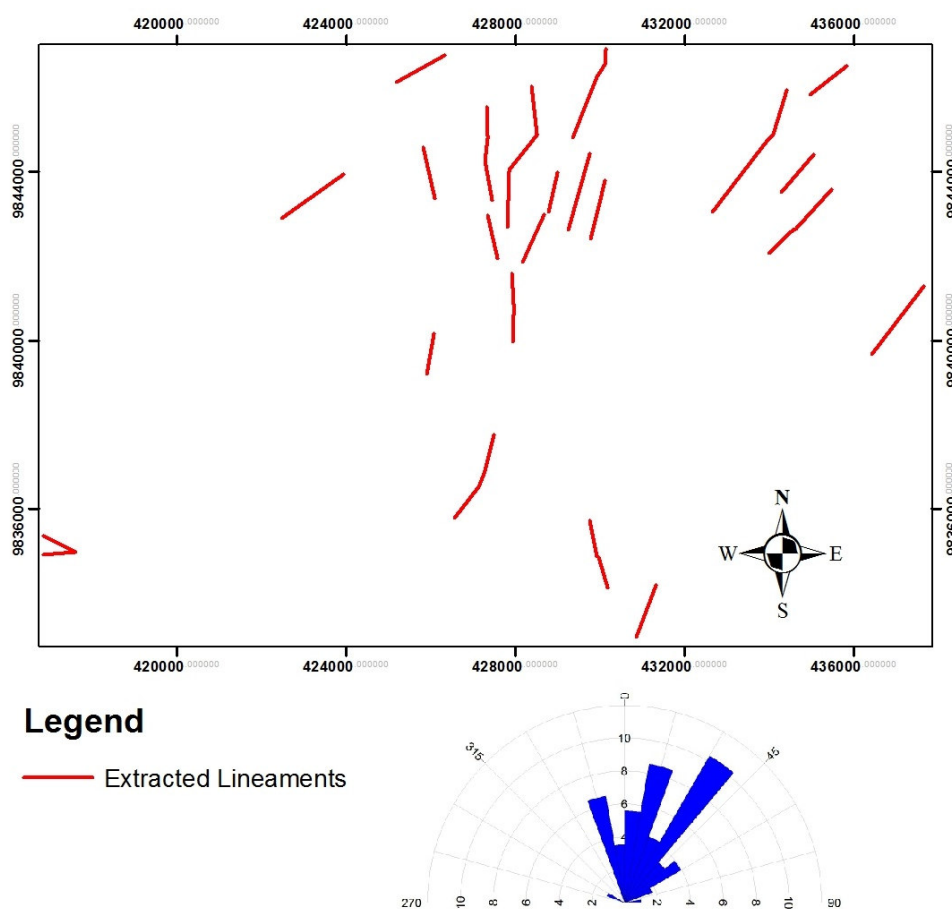


Figure 10: Automatically extracted lineaments and a rose diagram of the study area.

5. Discussion

Interpretation of the results from colour composite was compared with other research findings on hydrothermal alteration mapping. Frutuoso (2015), used colour composite bands 5,6,7 in mapping hydrothermal altered rocks. The altered rocks appeared as blue and were related to gold mineralization. Omwenga (2018), used bands 5,6 and 7 when mapping for hydrothermal alteration zones in Eburru. His research work highlighted areas in blue colour as hydrothermally altered, hence related to geothermal activity in the area. It is evident from this research work and others that have previously been carried out, that colour composite can be used to map hydrothermally altered zones and mineralized areas. In this research work, the areas that were highlighted as hydrothermal altered were confirmed for iron ore minerals during geological field mapping. The presence of intrusive rocks like pyroxenites around hydrothermal areas was an indication that the iron mineralization observed was formed when these bodies rose to the surface carrying hydrothermal fluids rich in ferrous minerals.

Band rationing is a remote sensing image processing technique that involves the division of one spectral band by another. Band ratio images are known for enhancing spectral contrasts among the chosen bands in any ratio operation. Band ratio has been successfully used in mapping hydrothermal alteration zones, (Kujjo, 2010), (Frutuoso, 2015), (Achieng, Mutua, Mibei, Olaka, & Waswa, 2017) and (Omwenga, 2018). An image incorporating band ratio (4/2, 6/7, 6/5) was used to discriminate altered from unaltered outcrops and highlight areas where the concentration of iron ore occurs. A greyscale image ratio 4/2 was used for mapping iron oxide minerals such as heavy mineral sands in dry river beds, as high reflectance regions with blighter pixels.

When mapping hydrothermally altered rocks using band rationing, vegetation density is always a limiting detection factor that should be considered. It is for this reason that principal component analysis was considered to minimize such effects and in lineament extraction. Frutuoso (2015), used digital elevation models to extract geological and morphological lineaments that were important control for gold mineralization in Chaves, Portugal. Achieng *et al.*, (2017) also used digital elevation models to prepare a structure (fault) map with eruption centres when mapping hydrothermal minerals related to geothermal activities in Paka volcano, Kenya.

Lineaments can also be extracted from satellite images using both manual visualization and automatic lineament extraction through softwares such as PCI GeoAnalyst, Geomatica and Matlab (Kamel, Youssef, Hassan,

& Bagash, 2016). Waswa et al., (2015) used GeoAnalyst-PCI package to extract structural lineaments in Ikutha area. A comparison of Landsat 8 (OLI) and Landsat 7 (ETM+) in mapping geology and visualizing lineaments by Mwaniki et al., (2015), deduced that Landsat 8 performed better at discriminating more lithologic units of central region Kenya than Landsat 7. He concluded that the extraction of lineaments depended on the ability to enhance texture which was better in band ratios 5/1 and 6/2 for Landsat 7 and 8 respectively. In this study, geological structures like lineaments were considered important indicators of hydrothermal fluid movements, hence controlling mineralization in the area. The geological structures extracted were also interpreted to control drainage pattern in the area especially around Makongo hill.

6. Conclusion

This study aimed to use Landsat-8/OLI imagery and remote sensing techniques to map areas of hydrothermal alterations and extract geological structures. The study site was in the Neoproterozoic Mozambique belt, where economic minerals have been sited before. The surrounding areas have also been investigated by various geologists earlier and geological structures delineated. However, through advancement in technology, it was deemed necessary to use Landsat-8/OLI to extract geological units that might have been erroneously left out during previous works. The achievement of the objective of the application of remote sensing techniques to extract geological structures led to the identification of iron-bearing rocks based on different colour combinations and band ratio especially around Kalima Kathei hill.

Band ratio (4/2) of Landsat-8/OLI displayed in greyscale was used to highlight areas with a high concentration of ferrous minerals. These areas appeared in bright pixels around hydrothermally altered areas and dry river beds. The association of faults and hydrothermally altered rocks indicate that mineralization in these areas can be related to fluids that come through these open spaces. Mineralization of iron ore in Kalima Kathei area can be explained through this process. Another association of lineaments with drainage pattern and vegetation in the area indicate that streams and rivers in the area chose areas of weakness to flow while vegetation grew in areas with adequate water.

The study concludes that the use of Landsat-8/OLI was an effective method of mapping hydrothermal altered outcrops and geological structures in Mwitika-Makongo area. However, the use of remote sensing in mapping mineralization areas should be followed up by systematic rock sampling to reveal the lithology and geochemistry of the hydrothermally altered areas. The analysis of Landsat-8/OLI imagery in this research showed that remote sensing is effective in highlighting hydrothermally altered areas and in the extraction of lineaments. This study shows the area has the potential for economic minerals associated with hydrothermal alteration especially iron ore.

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