Hydrothermal Alteration Mapping in Ijio, Oyo State, Nigeria using Satellite Imagery & Remote Sensing Technique

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ABSTRACT

Landsat ETM+ imagery were used in the analysis and identification of zones of hydrothermal mineralization in and around Ijio town, Oyo state, Nigeria.

Three transformation methods were applied for mineral detection i.e. false colour composite, band ratioing and Crosta Technique. False colour composite of bands 4:7:2 was applied on ETM+ to delineate a generalized location of hydrothermal alteration zones in purple hues. Then band rationing technique was applied in order to obtain a more specific location of mineralized areas by spectral signatures of iron oxide, hydroxyl and clay minerals in the alteration zones. Alteration map was produced based on the band ratio techniques produced from Sabin's band ratio colour composite image (bands 5/7, 3/1 and 3/5 in the R G B, respectively) where potential areas of mineralization were depicted in a greenish hues around SE, SW and NW. However, the accuracy of the resulting image was less than expected due to the interference of vegetation. Therefore, a more robust method known as Crosta technique was applied by finding the Principal Component Analysis of two particular sets of images (i.e. band1347 and 1457). Areas of mineralization were delineated in sky blue, white and ash hues around SE, SW and NW. This statistical technique resulted in a more accurate image due to its ability to supress interference from vegetation and other external sources.

KEYWORDS: *Crosta technique, Band Ratio, alteration zone, Oyo state, mineral deposit, Nigeria.*

I. INTRODUCTION

Nigeria is a country blessed with enormous mineral resources deposited all over the country (Ezekwesili, 2005). However, since the discovery of petroleum in Nigeria in the 1970s,the interest of government is focused on oil exportation as it brings instant cash flow. Meanwhile, the exploration of other mineral resources such as gold, gem stones, coals etc. are carried out mostly by artisans and majority of these operations are carried out illegally (Adekeye, 1999; Nwosu, 1999).

Most of the illegal miners are mostly untrained and un-educated, thus, their activity causes loss of lives due to mine cave-in, environmental degradation and contact with hazardous substances. For instance in Zamfara state, North-Western Nigeria there was a tremendous loss of lives (more than 400 children) due to lead poisoning caused by illegal artisanal mining where thousands more were infected by lead poisoning (Doctors Without Borders, 2012). Moreover, in almost all the locations where mining activity has taken place, there was always no plan of decommissioning abandoned mines, which leads to loss of valuable arable lands (Gutta et al., 2012). The tailings from mining sites were in some cases used by residents to build houses; thus, causing cancer to the residents due to the presence of radioactive materials in the sand used for constructing those houses (Adiuku et al., 1991; Abimaje, 2014).

Nonetheless, it is imperative that environmental degradation and danger posed to human health be eliminated or at least reduced considerably so as to maximise profit obtain from mineral exploration. To achieve this objective, there is a need for the government to create stringent policies, monitor and mitigate already existing mine site and future potential mine locations (most especially locations of potential mineral deposit that are yet to be explored) (Ndace and Danladi, 2012).

Therefore, in order to move the focus of the Nigerian government from crude oil to solid mineral exploration (which has as much income potential as much as crude oil), it is essential that faster and less costly mineral mapping methods such as remote sensing be implemented in-order to detect and map mineral deposits. The result will aid lawmakers in making informed decisions such as creating stringent mining policies that will govern both illegal and licenced miners.

Considering that about 50 different types of mineral deposits are found in about 500 locations all over the country (Adegbulugbe, 2007), traditional method of mineral mapping can be costly and time consuming. A more modern method involves the use of remote sensing for the detection, identification and mapping of hydrothermally altered rocks which are a pointer to the locations of mineral deposits (Crosta et al., 2003). Remote sensing is the acquisition, processing and interpretation of images and related data which are acquired from airborne objects and satellites that record the interaction between object/phenomena and electromagnetic energy (Sabins, 1997). Remote sensing can detect and map hydrothermally altered mineral which lie beneath the earth's surface. Large areas of interests are mapped at a relatively fast pace while at the same time keeping the financial costs down (Mia and Fujimitsu, 2012).

Hydrothermal mineral alteration is a process which alters the mineralogy and chemistry of the host rocks resulting in producing mineral assemblages which vary according to the location, degree and duration of those alteration processes (Mia and Fujimitsu, 2012). These minerals are unique in the way they absorb or reflect light along the electromagnetic spectrum due to their different chemical composition, thus making it possible for minerals to be detected and mapped using remote sensing techniques. Hydrothermally altered minerals (e.g kaolinite, allunite, muscovite etc.) are in most cases indications of a deposit of precious or economically viable mineral deposits (Torre et al., 2012).

Several authors have analysed and interpreted the remotely sensed hydrothermally altered mineral deposit data through band ratioing. For example Abdelsalam et al., (2000) used ETM+ band ratios (5/7, 4/5 and 3/1) in RGB to map the Beddaho alteration zone in northern Eritrea. Madani, (2009) used Landsat ETM+ data for mapping gossans and iron rich zones exposed at Bahrah Area, Western Arabian Shield, Saudi Arabia. He found out that 4/5 ratio discriminate well between the gossans and iron-rich zones. Ratio 4/5 was also used to differentiate between the gossans, iron-rich rocks and surrounding rocks. Loughlin (1991), Bennett et al. (1993), Crosta&Rabelo (1993), Ramadan and Kontny (2004), and Salem (2007), all utilized remote sensing technique for mapping hydrothermally altered minerals which are knownto be associated with mineralization in hydrothermally altered rocks

In Nigeria, there has been very little research in using remote sensing techniques to identify mineral deposits. One of the few carried out was (Kudamnya et al., 2014) who applied band ratio technique and colour composite to map location of hydrothermal alteration within the Maru schist belt of Northwest Nigeria.

Mineral deposits are in most cases related to alteration zones. The extent of this alteration zones determines if the minerals are of economic value for exploration. For this reason, it is essential that the alteration zones are detected and mapped within a short period of time and at low cost. To achieve this objective, this research aims to explore the potential of remote sensing satellite data (e.g. Landsat ETM+) for mineral detection and mapping due to its previous success in mineral exploration.

I.1 Study Area

Ijio area is located in the North-West of Oyo State in Nigeria, on an elevation of 311 meters above sea level. It has a coordinate of 7.30' – 8.00' E and longitudes 2 40' – 3 00' 00' N. it lies in an inland state in south-western Nigeria with a relief that is generally low and adequately drained. The area is underlain by granite complex associated with undifferentiated schists, gneisses and migmatites. Petrographic study of the granite shows abundance of plagioclase feldspars, orthoclase feldspars quartz and others. There is a thick lateritic cover over these rocks believed to be the result of intense weathering of the underlying rocks that are rich in feldspars and quartz among other minerals.

The lithological aspects of the area is characterised by the assemblage of rocks which are typical of the basement complex terrain in Nigeria. The following lithological units were observed in the area of study: biotite granite, granodiorite, banded gneiss, granite gneiss, migmatite gneiss, amphibolite schist and pegmatites.

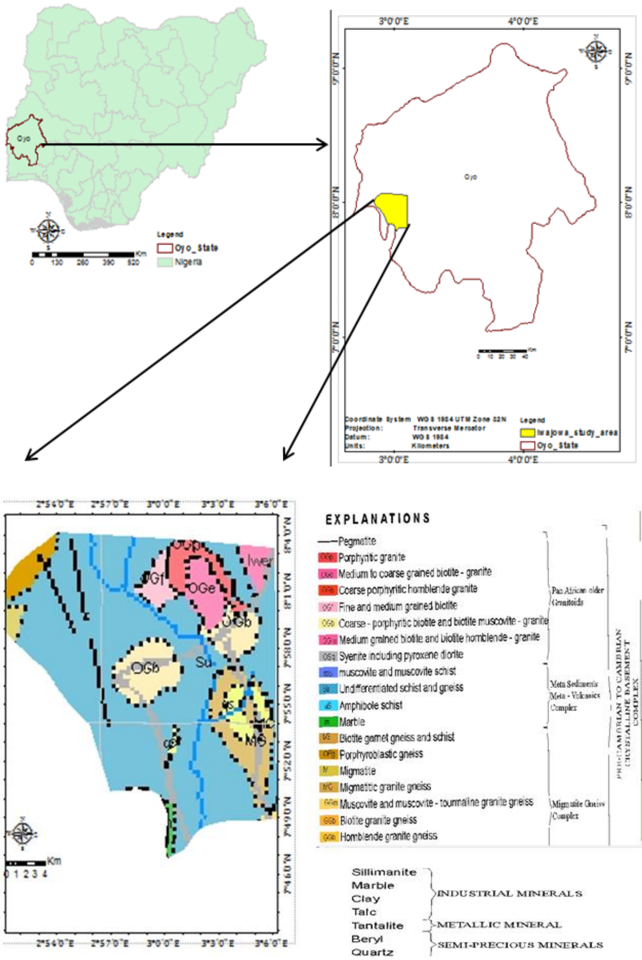

Fig 1:Geological Map of the study area (adapted from Geological Survey Agency of Nigeria)

large width between bands (i.e. as opposed to narrower bands found in hyperspectral images) (Extension, 2008).

However, the group of minerals which are index minerals of hydrothermal zones and their spectral features are in the near infrared and middle infrared range could be identified (Pourmirzaee, 2010; El Khidri and Babikir, 2013).

III.TECHNIQUES ADOPTED TO PINPOINT MINERALIZED ZONES

The techniques adopted to pinpoint mineralized zones by their spectral signatures of the alteration mineral products is summarised in the following steps:

A false colour composite of the study area was displayed in RGB 4:3:2 respectively as a first step to detecting the hydrothermally altered rocks. A simple linear contrast was applied to enhance the composite image. Areas of potential mineralization were then examined.

Band Ratio

Band ratio (BR) is a technique where the digital number (DN) value of one band is divided by the DN value of another band. Band ratios are very useful for highlighting certain features or materials that cannot be seen in the raw bands (Inzana et al., 2003). This tends to enhance spectral differences and suppress illumination (topographical) differences. Ratios can be used to differentiate objects if those objects have characteristic spectra. Selected ETM+ VNIR and SWIR bands are used for Band ratio BR in this study (i.e. formula 1). Iron oxides (both ferrous oxides and ferric oxides) minerals are indicated by band ratio 3/5 while band ratio 5/7 is used for detecting high values of the hydroxyl-bearing minerals (e.g. kaolinite, allunite, muscovite, epidote, chlorites, amphiboles) and ratio 4/5 is used for detecting clay minerals (Gupta, 2003; Abdelsalam et. al, 2000). Simple linear stretching produces sharper grey-scale images (El Khidri and Babikir, 2013). These alteration zones are evidently depicted by grey scale images of the band ratios. A false coloured image was created by combining the results of band ratioing in the form of (R=3/1, G= 5/7, B=4/5), called Sabin's ratio coloured image).

$BV_{i,j,r} = \frac{BV_{i,j,k}}{BV_{i,j,l}}$ Equation (1)…………Formula adapted from (Kudamnya, 2014)

Where;

$BV_{i,\,j,\,r}$ = output ratio for the pixel at row *i* and column *j;* BVi, j, r, has a DN value ranging from 0 to 225.

$BV_{i,\,j,\,k}$ = brightness value at the same location in band *k*

$BV_{i,\,j,\,l}$ = brightness value in band L

Crosta Technique

Crosta technique utilizes the principal component transformation which is a multivariate statistical technique that selects uncorrelated linear combinations (eigenvector loadings) of variables in such a way that each successively extracted linear combination or principal component (PC) has a smaller variance (Crosta and Moore, 1989). Combinations of ETM bands 1,4,5&7 and 1,3,5&7 respectively were used to represent the F-image for iron-oxide and an H-image for hydroxyl rich minerals through transformed unadjusted principal component analysis. The eigenvectors of PCAs 3 & 4 were examined to see if they contain significant loadings with opposite signs from input bands of 1&3 and 5&7, since these bands are expected to have opposite response for iron and hydroxyl-rich minerals respectively (Loughlin, 1991). Usually,in principal componenttransformation, the first and the second components are excluded, since they contain the most information especially on albedo and topography for the first PCA and the second component differentiate between the VNIR bands against the SWIR bands (El Khidir and Babikir, 2013).

IV. RESULT AND DISCUSSION

False Colour Composite

The contrast stretched bands 4:7:2 false colour composite was examined for areas of potential mineralization. It was found that the stretch enhanced the detection of the hydrothermal alteration zones which showed up as purple hues (Fig 2). However, because of the large spectral width between ETM bands, detection using this band combination is more of a generalization of the hydrothermal alteration zones. Therefore, band ratio and Crosta technique was applied in-order to pin-point more precisely the areas with the greater likelihood of mineralization.

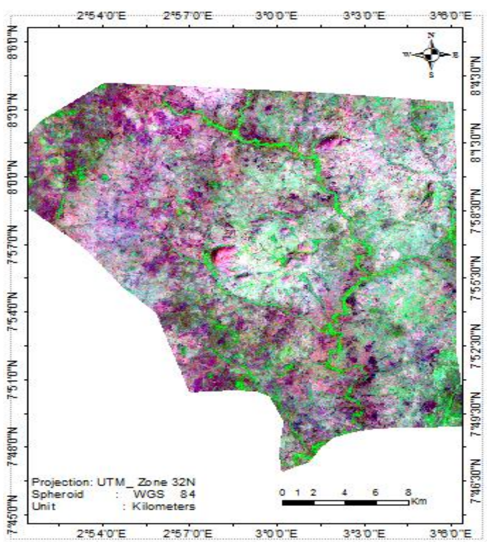

Fig 2: RGB colour composite of study area in Bands 7, 4 and 2 respectively.

Coordinates: 7^0 48′ 15.15″ to 8^0 1′ 49.26″N and 2^0 52′53.49″ to 3^0 5′ 45.63″E

Band Ratio

The results obtained from band transformations process in (Fig 3a), shows the band ratio 3/5 in grey-scale, the image depicts high iron oxide minerals in bright pixels which appear over the whole image. This is because iron-oxide mineral is ubiquitous and is found in most places in Ijio landscape which is attributed to the ferruginous capping of the granite complex associated with undifferentiated schist supracrustal. On the other hand, hydroxyl-bearing minerals (Fig 3b) are confined to certain zones depicted by the white patches in SW, SE and NW. Clay mineralization is also detected using band ratio 5/7 as bright pixels covering most of the image (Fig 3c) with cluster of small white patches in NW and SS. However, in both Fig 3b&3c vegetation showed up as bright pixels which will certainly interfere with the accuracy of the mineral detection. Vegetation can be distinguished from the hydroxyl and clay minerals because it is delineated by the drainage pattern, in other words they grow along the river channels. The produced Sabin’s rationing colour composite image (band ratios 3/5 in red, 5/7 in green and 4/5 in blue) displays target zones in distinguishable sky blue hues (Fig 4). Some of these alterations are attributed to the alteration zones and others related to weathering products of the granite complex associated with undifferentiated schist supracrustal. Nonetheless, it is clear that the interference of vegetation signature in band ratioing reduced the accuracy of the resultant mineralized locations; therefore, a more robust technique (i.e. Crosta technique) is applied below to increase the accuracy of mapping mineralized location by removing the interference of vegetation.

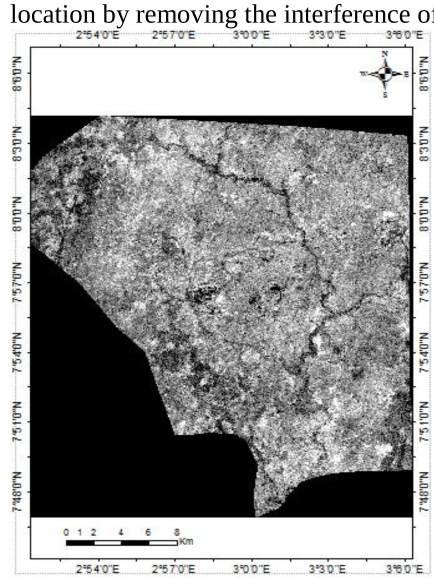

Fig.3a: Grey scale image from band ratio 3/5 depicting iron-oxide in white pixels

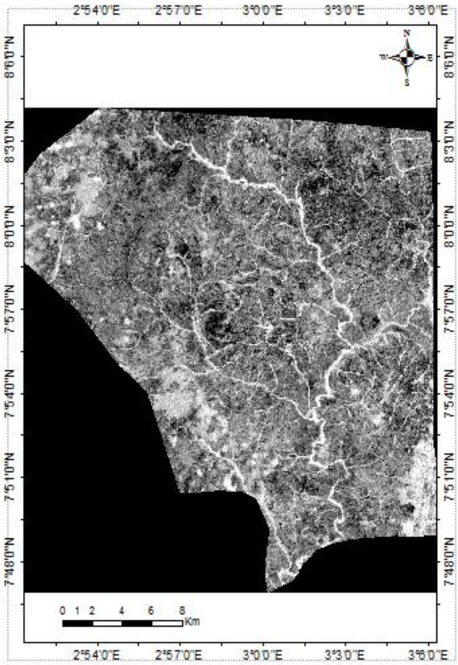

Fig.3b: Grey scale from band ratio 4/5 showing Hydroxyl in whitepixels.Vegetation also appears white along the drainages.

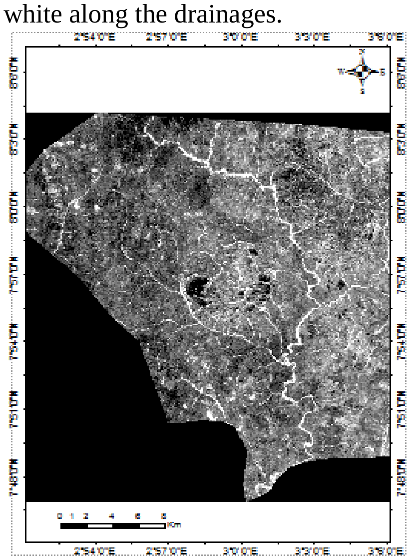

Fig. 3c: Grey scale from band ratio 5/7 showing clay mineralization in white pixels. Vegetation also appears white along the drainages.

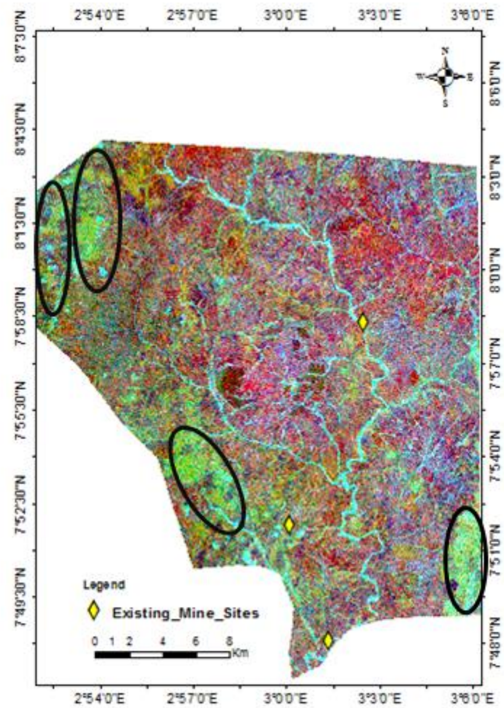

Fig 4: RGB Colour composite of band ratios5/7, 3/1 and 4/5 respectively.

Principal Component Analysis

Statistical results of eigenvectors loading of the Principal Component Analysis (PCA) for the four selected bands 1, 3, 4 and 7, show that the PCA4 in (Table 1) has good contrast in the values between band 3&1(where band 3 is reflectance and band 1 is absorption) with eigenvalue **-0.750697** to differentiate areas with high content of iron-oxide minerals (dark pixels) of alteration zones. To represent the iron-oxide mineralization in bright pixels the negative of the image is taken resulting in Fig 5a; this image is called **F-image**. On the other hand, **H-image**which defines the hydroxyl-bearing minerals was generated after the Principal Component analysis has been applied to the selected bands 1, 4, 5&7. Statistical analysis showed that the PC3 in

Table1: Eigenvector of covariance matrix (bands 1: 3: 4:7), for mapping the iron taken; the result is shown in (Fig 5b).oxide minerals alteration zones in the study area.

Eigenvector	Band 1	Band 3	Band 4	Band 7
PC1	0.181890	0.314461	0.677584	0.639460
PC2	0.054816	0.127362	-0.717768	0.682337
PC3	0.740490	0.566875	-0.153487	-0.326755
PC4	0.644660	-0.750697	0.046156	0.136885

(Table 2) with eigenvalue of **-0.747851** has good contrast in the values between band 5&7 (where band 5 is reflectance and band 7 is absorption) to differentiate areas that contain hydroxyl mineralization. Since the eigenvalue is negative, the hydroxyl mineral are represented in dark pixels. Therefore, to represent hydroxyl minerals in bright pixels, the negative of that image is taken; the result is shown in (fig 5b).

Table 2: Eigenvectors of covariance matrix (bands 1:4:5:7) for mapping hydroxyl-bearing minerals in the study area.

Eigenvector	Band 1	Band 4	Band 5	Band 7
PC1	0.145319	0.540995	0.651369	0.511786
PC2	0.039366	-0.760282	0.122375	0.636746
PC3	0.182687	0.340952	-0.747851	0.539534
PC4	-0.971575	0.114221	-0.038236	0.203797

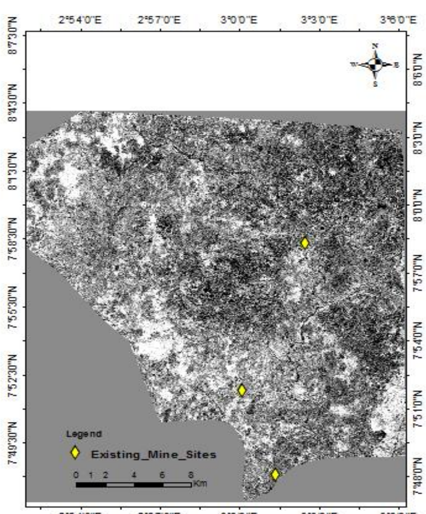

Fig.5b: Grey scale image from negative PC4 of PCA1457 representing (H-image) hydroxyl mineral.

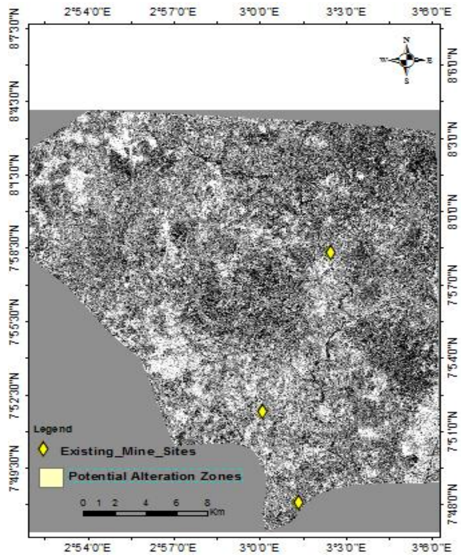

Fig.5c: Grey scale image representing the addition of F and H images (F + H-image)

False colour composite of the images corresponding to F-image, H-image and the sum of H and F images are displayed in RGB channels known as Crosta technique (i.e. F-image (R), H-image(G) , F+H(B)) to allow the identification of altered rocks.

The Crosta's colour image portrays the suspected alteration zones in sky blue, white and ash hues (Fig 6).

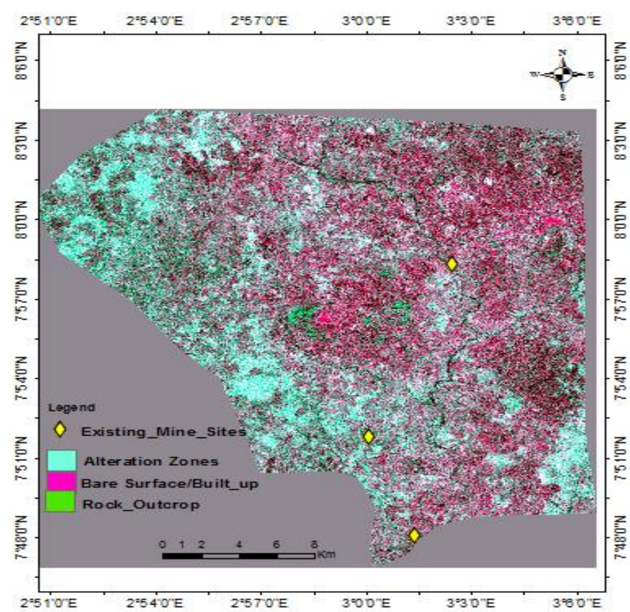

Fig 6: Colour composite of R-(H-image, G-(F-image) and B-(H+F image), Hydrothermal alteration zones appear as sky-blue in the image.

V.CONCLUSIONS

Landsat ETM+ imagery and geological mapping of rock units were used in the geological analysis of structural elements and identification of special geological features related to mineralisation such as alteration minerals (e.g., iron oxides, hydroxyl and clay).

The techniques used in this research found the location of potential mineralization which was mostly in the SW, SE and NW region of the image. The particular mineral deposit in these locations can be determined by using hyperspectral images.

This work further demonstrates the utilization of remote sensing techniques in geological mapping and mineral exploration. It has proved that digital image processing can afford exploration criteria for quick and fast exploration projects that cover large area.
However, these techniques can be improved by carrying out geochemical analysis on samples collected from the study area since some lithologies are known to possess similar spectral signatures which makes it difficult to differentiate between mineralised and unmineralized rocks.

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