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Geological Mapping and Economic mineralization prospectivity by Remote Sensing and GIS-based Integration around Keleltu Say Area, West Guji Zone, southern Ethiopia

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Abstract

In recent years, various geological activities different economic mineral prospecting, and exploration programs have been intensified in different parts of Ethiopia to reveal the geological maps and to evaluate mineral potentials. This study is therefore aimed at testing the viability of using remote sensing and geographic information system (GIS) techniques for geological mapping and prospecting for economic mineralization in the study area. Different digital image processing techniques were applied to Landsat-8 Operation Land Imager (Landsat-8/OLI) image to increase the discrimination between various lithological units and to delineate wall rock alteration which represents a potential zone of economic mineralization. Remote sensing methods included; banded combination, band ratios, and lineament extractions to clarify different structures in the study area. Geochemical analysis for mineralized samples followed by Pearson correction matrix of the chemical data gave a strong correlation between Fe2O3, TiO2, Na2O, and MnO indicating that their mode of delivery in the area could be similar, with a likely source from hydrothermal fluids in the area. The results confirmed the findings from remote sensing studies on hydrothermal alteration which could be an indication for economic mineralization. The enhanced satellite images were implemented in the GIS environment to facilitate the final production of the geological map at a scale of 1:50,000. It was therefore concluded that integration of *remote sensing techniques and geological field mapping provide a tool for delineating economic mineralization in the rocks of the study area.*

Keywords: Remote sensing, GIS, Digital image, Landsat-8/OLI, *economic mineralization*

INTRODUCTION

Remote sensing and GIS techniques have been used for geologic interpretations with resounding success. Remote sensing techniques are generally employed because they provide a cost-effective approach resulting from their ability to access difficult terrains and landforms (such as some mountains and forest terrains) and data collection can be done rapidly at frequent intervals on a large scale. This thus opened a new era in the mapping of lithologies and alteration zones.

Previously, geological maps were developed from field observations derived from conventional ground survey studies. The plotting of these maps and extrapolation of details were quite rigorous, leading to some unavoidable errors and inaccuracies. The plotting of these maps and extrapolation of details were quite rigorous, leading to some unavoidable errors and inaccuracies. The advent of remote sensing and GIS operations has resulted in continuous procedural changes in mapping activities. Now remote sensing techniques play an important role in mapping programs [7].

Remote sensing is the science of acquiring, processing, and interpreting images and related data, acquired from aircraft and satellites that record the interaction between matter and electromagnetic energy [12]. The mapping of hydrothermal alteration is based on the examination of the spectral signatures of the mineral veins. It is now known that certain minerals associated with hydrothermal alterations have unique spectral features that allow them to be remotely identified and detected [10]. Lithological mapping and the recognition of hydrothermally altered minerals through the application of remotely sensed data have given encouraging results in the exploration of gold, magnetite, and other ore deposits [3, 4, 11, 17].

Several applications of remote sensing in geological studies involve delineating structures/structural features, mineral resource exploration rock, and soil type discrimination [9]. The Landsat TM and

ETM+data have been used in various geological surveys for lithological discrimination, lineaments, and mineral mapping by using a hyperspectral laboratory [1]. Multispectral remote sensing is essential in lithological mapping and zones of alteration, especially in regions of exposed bedrock and bedrock surfaces.

Previous geological surveys within the study area have established the occurrence of several mineral resources of economic potential like gold, tantalum, base metals, and gem minerals. However, these previous geological surveys were conducted using field observations and limited use of technology. 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's local geology could be key to 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. This study integrates the use of Remote Sensing techniques and geological field mapping in delineating economic mineralization in rocks of the study area. Specific objectives of this study were to map hydrothermally altered zones from satellite imagery, extract lineaments using Landsat-8/OLI bands of the Bule Hora area, geologically map zones highlighted from satellite imagery as economically mineralized, and validate the results from remote sensing investigations with those obtained from the geochemical analysis.

An image subset of Landsat-8/OLI data year 2021 scenes were downloaded from the USGS website page. The downloaded data was processed using ArcGIS 10.5 software. The satellite image processing techniques such as Color composite and band rationing were applied to achieve the main purpose of this study. To validate the results from satellite imagery, rock and mineral samples collected during geological field mapping were analyzed in the laboratory to ascertain their economic potentials.

METHODS AND MATERIALS

The study area is located in Keleltu Say Woreda, West Guji Zone, Oromia Regional National State. It is situated about 470 km south of Addis Ababa. The study area is bounded by UTM coordinates between longitudes 422000mE to 430000mE, and latitudes 617000mN to 624000mN and covering an approximate area of 15 sq. km (Fig. 1). The study area is accessed via the main road that joins Addis Ababa and Moyale through Hawassa-Dila-Bule Hora, a 500 km international asphalted road. Various settlments and villages are connected by networks of foot trails very useful for geological traversing. There is also an airstrip near Shakiso town.

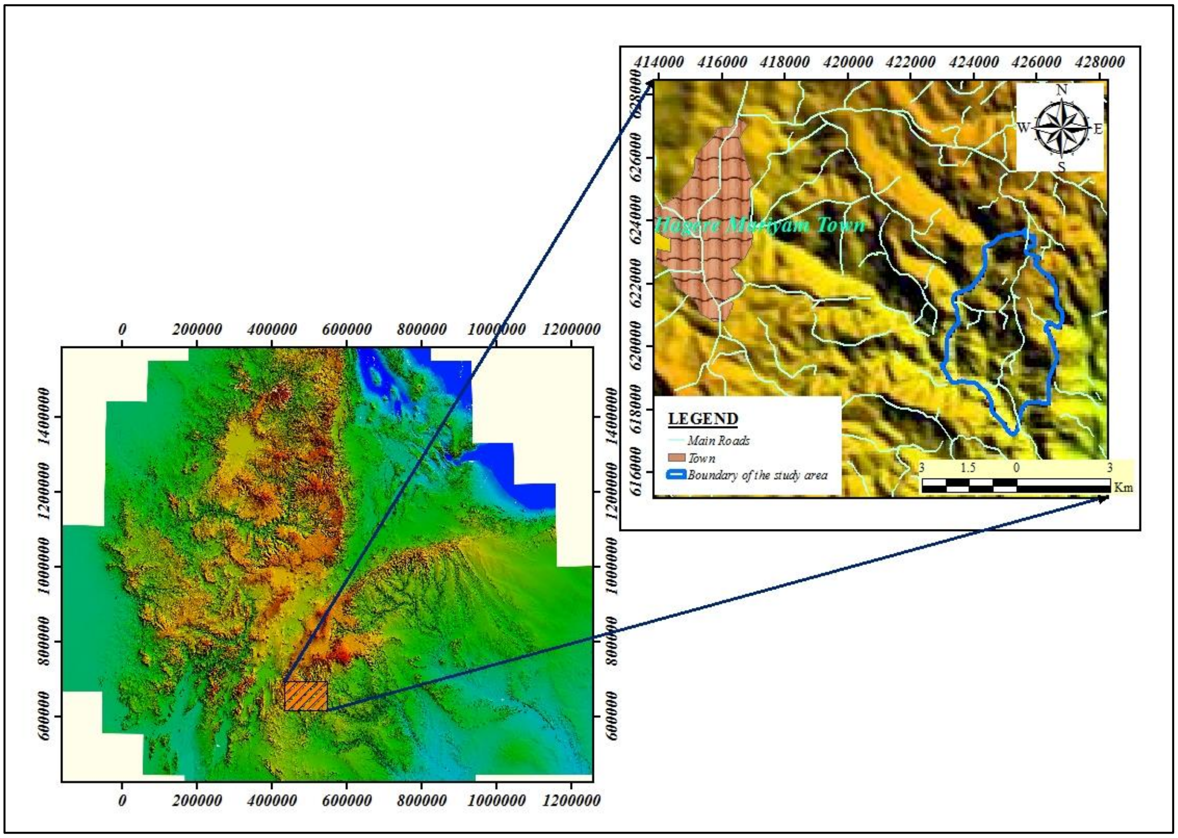

Figure 1. Location map of the study area

The drainage system of the area is irregular, having a dendritic pattern (Fig. 2), and seems to be structurally controlled by shear zone, as well as faults, major joint, and zones of weakness such as foliations. It is represented by many seasonally intermittent streams. They have many tributaries which come from hills and high relief areas.

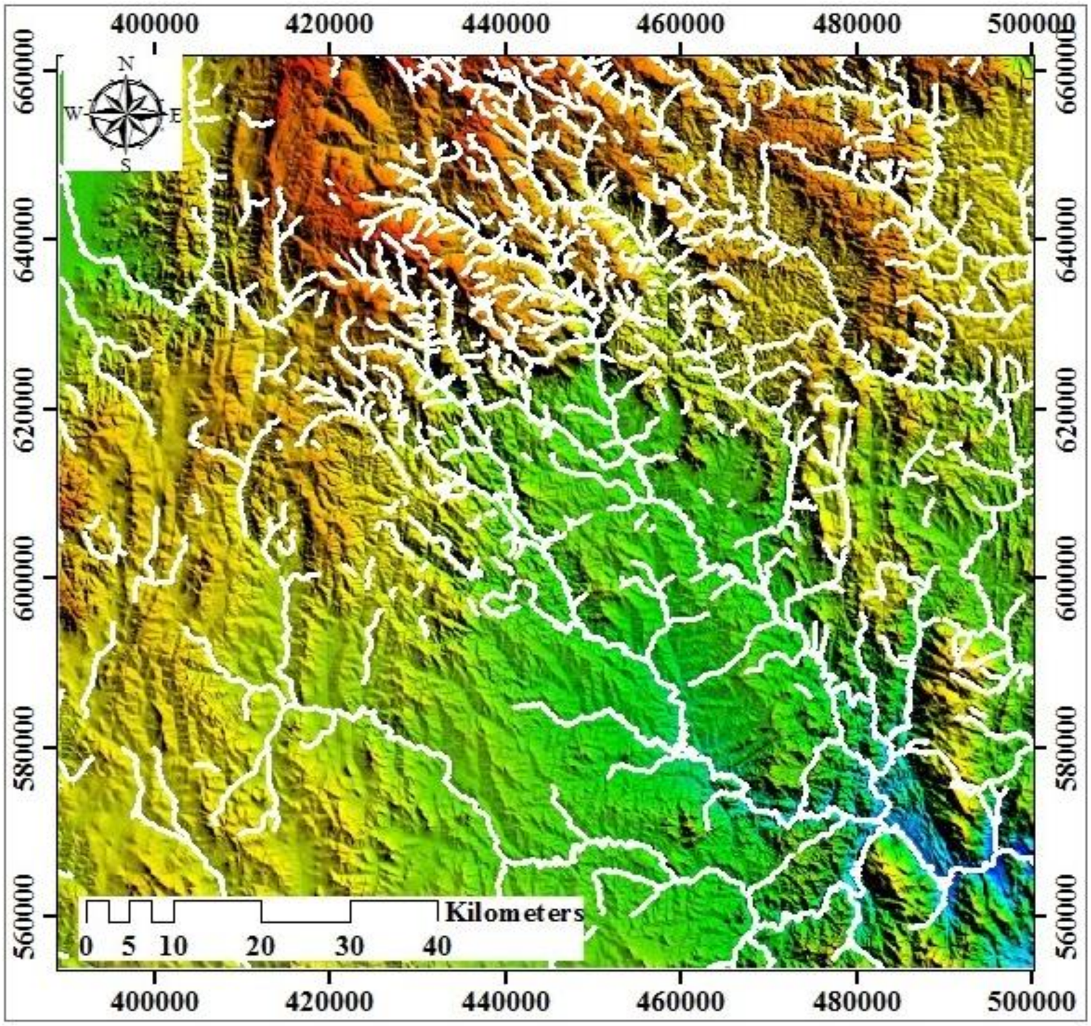

Figure 2. Drainage and digital elevation map (DEM) of the study area

To achieve the study objectives, different materials and methods of data processing have been employed in the study and illustrated as follows.

Operational land imagers (OLI) were downloaded from USGS in a digital format with 16-bit pixel values characteristics which contains 11 bands. Seven bands with OLI were carried to define the main lithological units, major structural elements, drainage patterns and to delineate the zones of gold mineralization. ArcGIS 10.5 was used for Image analysis, data integration, and producing geological mapping to delineate the zone of mineralization.

To identify lithological units that were highlighted from satellite imagery as economically mineralized, geological field mapping and sample collection of rocks and minerals in the area were carried out. Samples were collected along several traverses in a grid on foot. Fresh rock and mineral samples were collected and packaged in bags for further analysis in the laboratory and structural elements were recorded by GPS receiver during these geo-traverses.

For this study to indicate the quality of potential economic rocks and minerals in the study area, samples were collected from areas selected from satellite imagery as mineralized. The geochemical analysis was done through Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). This was done in the laboratory of the Geological Survey of Ethiopia. Samples were prepared by pulverizing using a pulverizing machine (laboratory pulverizer) to grains of 100 microns in diameter. After pulverization, the samples were packed, sealed, and taken through chemical analyses. This was done to find out the presence and concentration of major and trace elements of the analyzed samples. The flow chart diagram of the adopted methodology for the preparation of the geological map of the study area and map of gold mineralization zones is shown in Fig. 3.

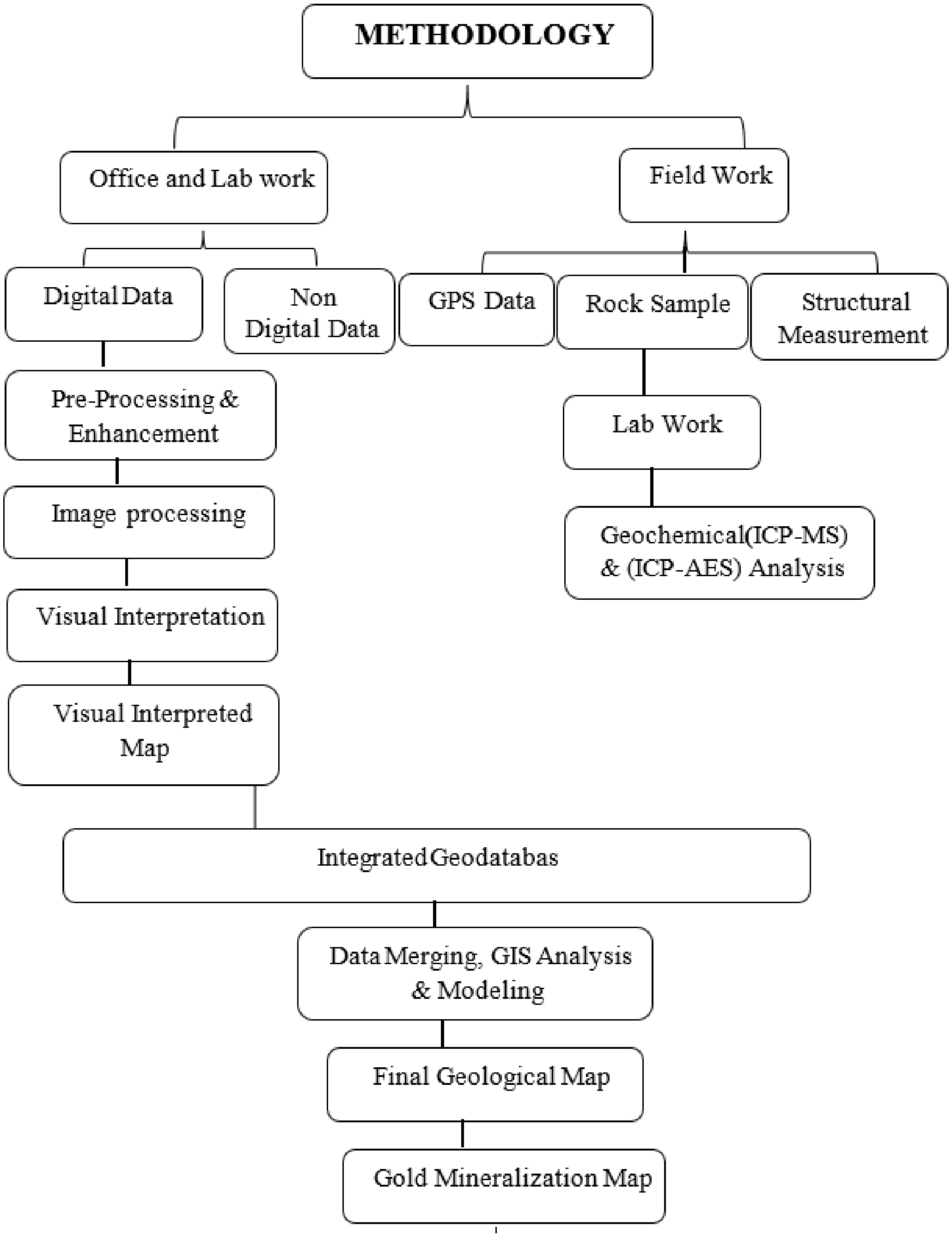

Figure 3.The flow chart of adopted methodology

RESULTS AND DISCUSSION

Color Composite Band Combination

Several different spectral bands of Landsat-8/OLI data were selected and combined in an RGB color system. The high spectral resolution is important when producing color composite images. The rule of color composites is to set the most informative band for a particular purpose in the red, the next in green, and the least informative band in blue filters [5]. The different RGB combinations discriminate the rock types which is useful in geological application. Any three bands of the seven OLI bands can produce a color composite image. A false-color composite of bands 7, 5, 3 in RGB, respectively, were assembled in this work as shown in Fig. 4.

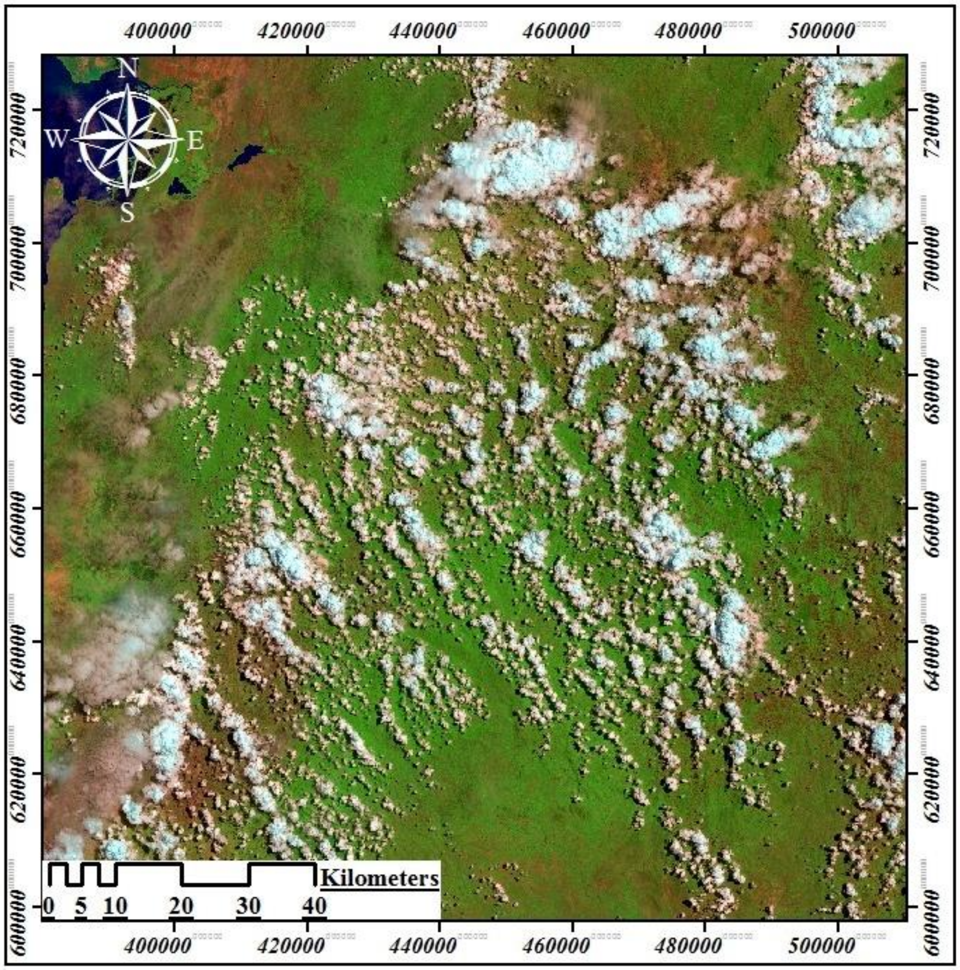

Figure 4. Landsat OLI color composite obtained using bands 7, 5, 3 in RGB, respectively

In this image, the quartz sericite schist appears in pinkish-brown to reddish-brown color and has linear shapes with the general trend of the northwest-southeast (NW–SE), while the actinolite tremolite schist appears in light green color and is highly schistose. The biotite quartz gneiss is greenish and has an augen shape and the porphyritic basalt appears dark grey to greenish-grey in color which makes it easily discernible from other rock units and has sharp contact with the adjacent rock units.

Another color composite was prepared using the infrared bands of the image set. It was composed by employing bands 7, 6, 5 in RGB, respectively, as shown in Fig. 5. This band combination is termed the infrared image.

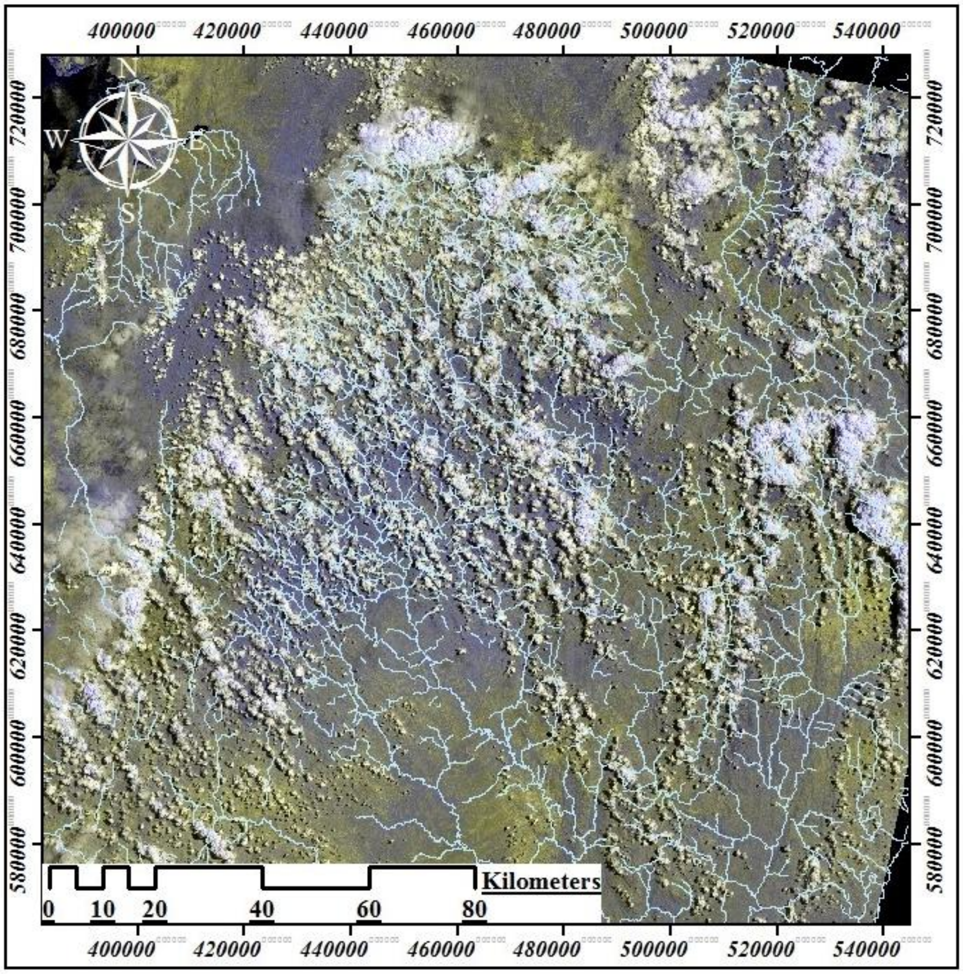

Figure. 5 Landsat OLI color composite obtained using bands 7, 6, 5 in RGB, respectively

Band Ratio Combination

Band rationing is one of the change detection techniques used in remote sensing. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times [15]. Spectral band rationing is a proven technique that allows the identification of geological materials based on the reorganization of diagnostic absorption bands. It minimizes the effect of topographic slope, aspect, and Albedo differences between rocks and enhances the subtle differences in reflectivity between bands which are diagnostic of various surface materials [6]. Ratio images are prepared by dividing the DN (digital number) value in one spectral band by the corresponding DN value in another band for each pixel [13, 2].

Ratio images are known for the enhancement of spectral contrasts among the bands considered in the rationing and have successfully been used in mapping alteration zones [14, 8]. During this study, several ratio images were prepared for geological mapping and alteration zones delineation. Generally, the OLI 4/2 image ratio shows high values for iron-stained hydrothermally altered rock and ferric oxides because iron minerals have low reflectance in band 2 and high reflectance in band 4, while the OLI 6/7 ratio is used to enhance the quartz and alkali feldspars minerals with subordinate amounts of biotite and sericite which can be an indication for gold potentials and distinguishes altered rocks containing clays minerals such like kaolinized and ferruginized. Several OLI bands ratio has been computed: 6/7, 6/5, 7/5, 6/2, 4/2, and 4/5.

Based on the spectral features of ferric, quartz, and alkali feldspars bearing minerals, two ratio false-color composite images were produced by combining three ratio images at a time in RGB. The different combinations of ratio images are shown in Table 1, and this provides the computation suitable for use with Landsat 8 OLI images.

Table1.The different combinations of ratio images

Author	**Landsat 8/ OLI**
Sultan et al. (1987)	6/7, 6/2, (4/5) * (6/5)
Mineral Composite	6/7, 7/5, 4/2
Hydrothermal Composite	6/7, 4/2, 5/4

[16] used OLI 6/2 ratio images because opaque minerals have reflectance features in band 5 and absorption features in band 1.

Sultan's color composite ratio image was obtained by using OLI image ratios as 6/7, 6/2, and 4/5*6/5 in R, G, and B, respectively. The resultant image (Fig. 6) shows that the biotite quartz gneiss appears bluish, the actinolite tremolite schist reddish in color, the quartz sericite schist in deep yellow color, the quartzofeldsphatic gneiss appears brown, and the porphyritic basalt minerals appear in grey. Mineral's composite ratio image was obtained using OLI band ratios 6/7, 7/5, and 4/2 in RGB, respectively.

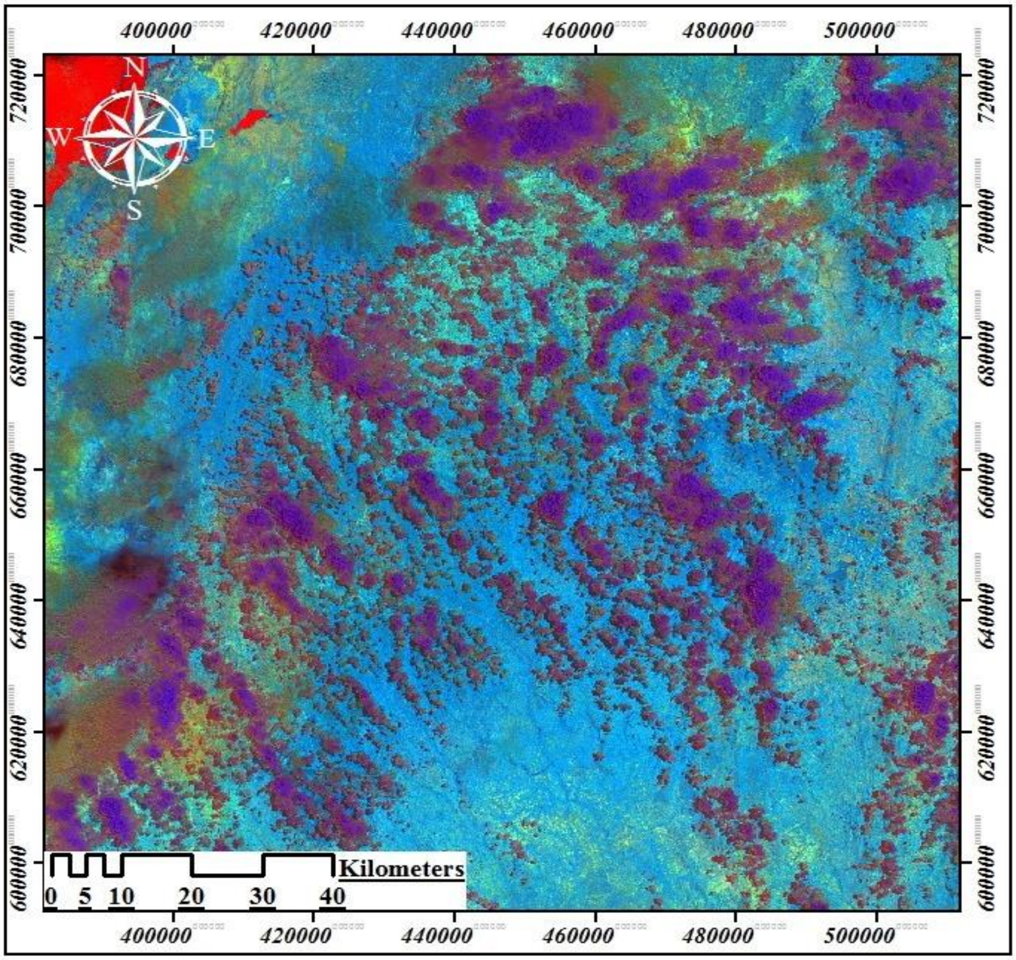

Figure.6. Sultan's Color composite of band ratios in RGB, respectively

The obtained image (Fig. 7) shows biotite quartz gneiss in reddish, while the actinolite tremolite schist is in light green color and easily noticeable from other rock units. The alteration zone is mapped in reddish-yellow.

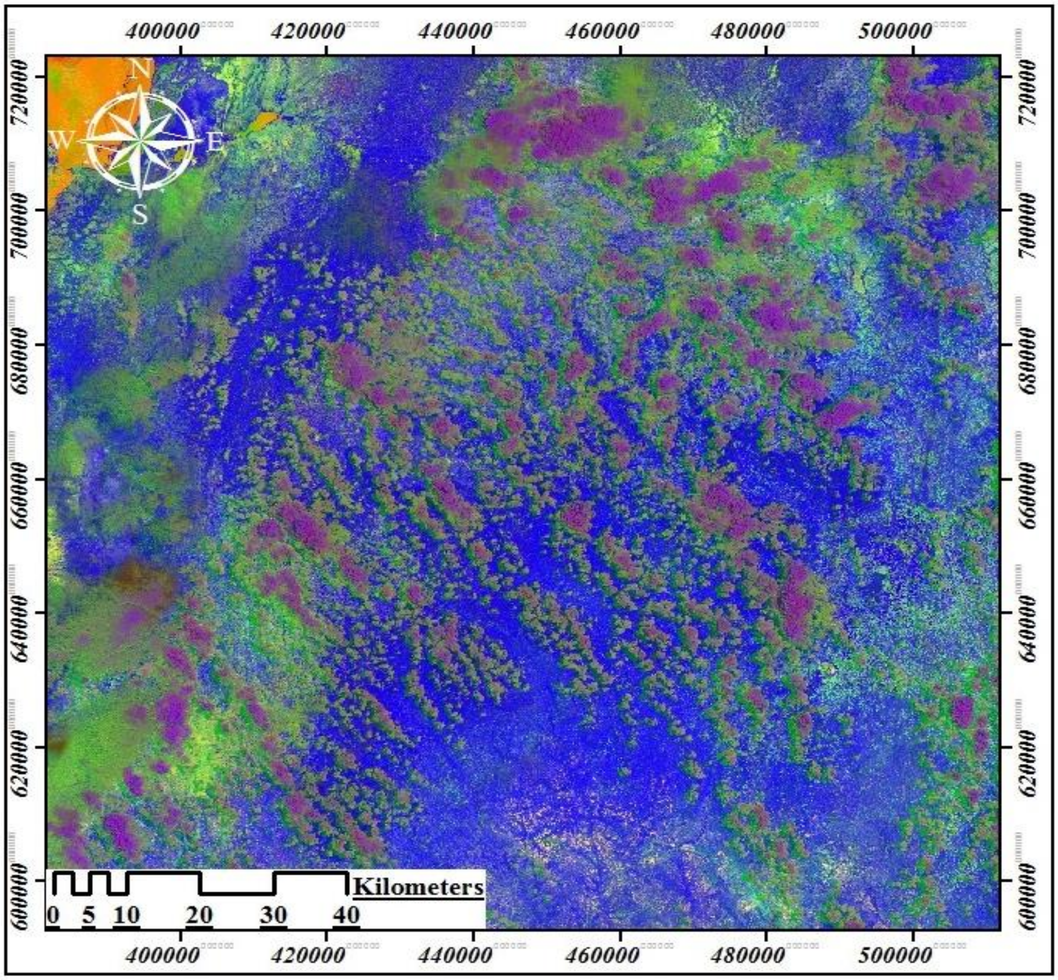

Figure 7. Mineral composite image obtained using the combination in RGB, respectively

GEOLOGY

Regionally the study area is mainly covered by the stratified high-grade rocks and associated meta-intrusive, which are later covered by tertiary basalts and quaternary alluvium covers. The gneisses are bounded to the east and west by NNE-SSW trending dextral shear zones that are parallel to the trend of the southeastern Bulbul belt. The stratified high-grade rocks comprise extensive strongly mylonitized augen biotite-quartz-feldspar gneiss and patches of meta-quartzite in the eastern part and strongly mylonitized biotite-quartz-feldspar which have shear zone contact with the former gneisses.

Various economic mineral resources were found in the study area. They include pyrite, tourmaline, limonite, Zircon, epidote, garnet, magnetite, spinel, rutile, ilmenite, and native gold. From this pyrite, magnetite, limonite, ilmenite, tourmaline and native gold are more abundant while the others are in trace amount.

Detailed geological mapping was conducted at the scale of 1:50,000 (Fig.8) and the major lithologic units observed in the area are summarized as follows in Table 2.

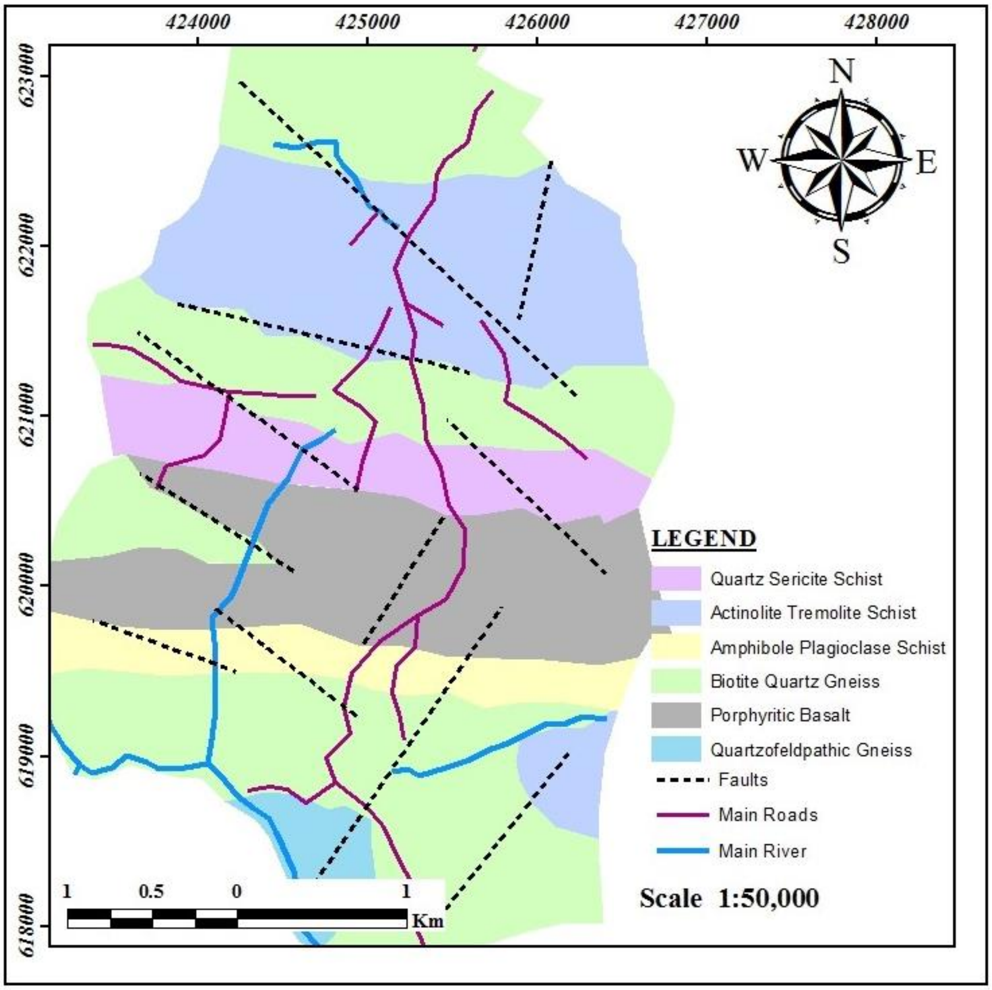

Figure 8. Geological map of the study area

Table 2. Rocks in the study area and their characteristics

Lithology Units	Remarks	Texture/Mineralogy
Biotite Quartz Gneiss	It covers most of the southern part of the area and ridge forming rocks in the area along the valley. It is overlain by basaltic rocks on the top.	It is leucocratic and mostly fine grained, and subordinate coarse grained variety. It have different grain size of the feldspar such as augen shape or porphyry feldspar. It is often schistose, but also exhibits large scale compositional layering.
Quartzofeldsphatic Gneiss	It is dominated at the central part of Kape valley trending NNW-SSE direction.	It is leucocratic, coarse grained, banded. Mainly composed of quartz and alkali feldspars with subordinate amounts of biotite and sericite. Banding is represented by thin mafic layers of biotite and thick felsic layers of quartz and alkali feldspars.
Quartz Sericite Schist	Formed in the north-central part of the area trending NNW-SSE direction.	It is pinkish-brown, fine grained, weathered, kaolinized, ferruginized. Mainly composed of quartz, muscovite, sericite and minor alkali feldspars.
Actinolite Tremolite Schist	Dominated in the north-central part of the area.	It is light green and medium to coarse grained and highly schistosed.
Amphibole Plagioclase Schist	Dominated in the north-central part of the area trending NNW-SSE direction.	It is dark grey, medium grained, and composed of plagioclase and amphibole with subordinate amounts of quartz and biotite.
Porphyritic Basalt	Dominated in the north-central part of the area.	It occurs as thin sheets and fragments. Represented by a dark grey to greenish grey porphyritic basalt in which phenocrysts of plagioclase and olivine are enclosed within a fine grained matrix.

STRUCTURE

The most pronounced geological structure in the study area is foliation planes, lineations, faults, pegmatite, veins, and joints. The majority of the faults observed were trends of the northeast-southwest (NE–SW), and northwest-southeast (NW–SE) (Fig. 9). Most of these faults are strike-slip where the dominant displacement is horizontal and parallel to the strike of the fault. During geological field mapping, it was ascertained that majority of the streams in the area flow through fracture zones and fault lines. This confirmed the observations from satellite imagery that drainage patterns in the area are guided by lineaments.

Lineaments can also be extracted from satellite images using both manual visualization and automatic lineament extraction through software such as PCI Geo-Analyst, Geomatica, and Matlab. GeoAnalyst-PCI package to extract structural lineaments in the study area.

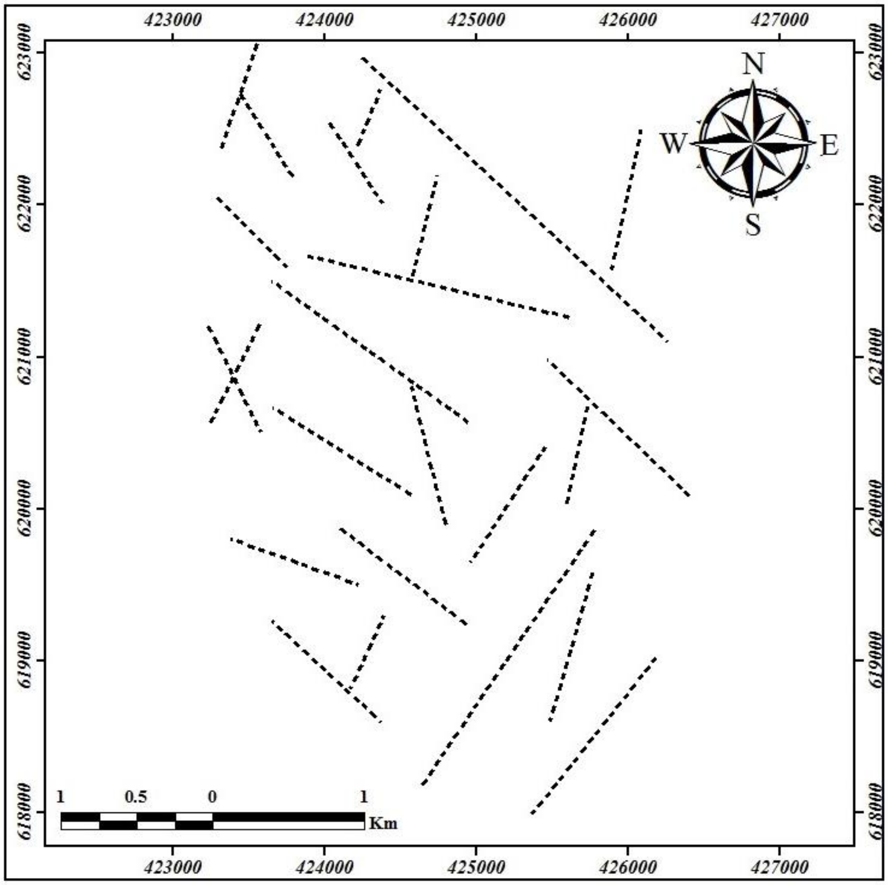

Figure 9.Lineament map of the study area

Mapping alteration zones using band ratio combination

Extensive hydrothermal alteration zones and weathering of the sulfide mineralization within biotite quartz gneiss and actinolite tremolite schist represent a significant mineral province in the study area. The false-color composite image called the hydrothermal composite because of its ability to enhance hydrothermal wall rock alteration was produced using a combination of bands 6/7, 4/2, 5/4 in R, G, B, respectively (Fig. 10).

In this image, the altered rocks appear in reddish-pink colors. These alteration zones are observed along linear structures trending NW–SE in the biotite quartz gneiss and actinolite tremolite schist rocks.

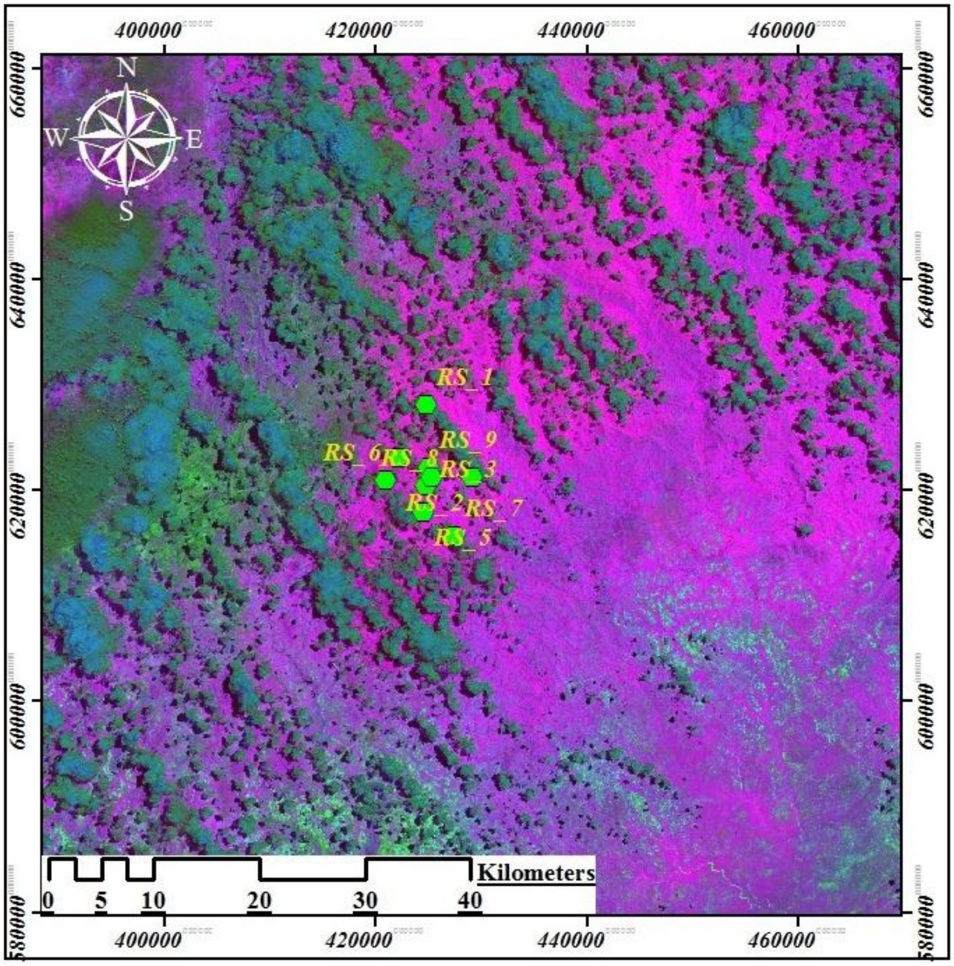

Figure 10.Band ratio color composite produced using the following ratios 6/7, 4/2, 5/4 in R, G, B, respectively. Green circles are samples collected for geochemical analysis

GEOCHEMICAL ANALYSIS

Ground truthing and field check-up were made to validate the results obtained by the alteration zone mapping through satellite image interpretation. Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) method was used to analyze major and trace elements of the rock samples collected from the study area. The major elements are given in weight percent. Pearson correction coefficients were used to test the dependence between the ten major geochemical elements. The Pearson correlation matrix results were plotted using MS Excel (Table 3).

Table 3. Pearson Correlation matrix for major elements in Kape Area

	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	TiO2	MnO	P2O5
SiO2	1									
Al2O3	.589	1								
	.073									
Fe2O3	-.112	.189	1							
	.758	.600								
CaO	.054	.683*	.184	1						
	.883	.030	.612							
MgO	-.743*	-.871**	-.352	-.424	1					
	.014	.001	.318	.222						
Na2O	.545	.610	.365	.155	-.712*	1				
	.103	.061	.300	.670	.021					
K2O	.330	.372	-.240	-.180	-.320	.243	1			
	.352	.290	.504	.619	.367	.498				
TiO2	-.365	.017	.739*	-.123	-.111	.330	.228	1		
	.300	.962	.015	.736	.760	.352	.526			
MnO	.667*	.265	.477	-.158	-.629	.513	.052	.182	1	
	.035	.459	.163	.663	.051	.130	.886	.615		
P2O5	.114	.401	-.297	.023	-.283	.175	.836**	.153	-.293	1
	.754	.251	.404	.949	.428	.629	.003	.672	.412	

From these analyses, it is noted that SiO2 correlates negatively with Fe2O3, MgO, and TiO2. This means that their delivery model in the study area is not similar. A strong correlation was noted between Fe_2O_3, TiO_2, Na_2O, and MnO indicating that their mode of delivery in the area could be similar, with a likely source from hydrothermal fluids whose source is magmatic intrusions in the area. Through geochemical analysis and Pearson correlation of major elements, showed that iron ore and gold in the Keleltu area came from hydrothermal/magmatic sources due to different alterations like ferruginization and sericitization which are an indication of iron and gold potential with materials of the host rock. In this study, it has therefore been illustrated that remote sensing techniques can be used to supplement geological field mapping in delineating zones of economic mineralization. Therefore, this area is extremely encouraging for further ground survey and exploration work.

CONCLUSION

Satellite remote sensing is one of the best techniques for mapping geological structures and mineralized zones. This is because of its ability to capture data at different bands using the reflectance energy from objects on the ground based on their unique spectral signatures. A major challenge exists in interpretation because it requires human intervention. Since different people could interpret different features differently, ground-truthing is, therefore, a critical stage.

However, care must be taken in the usage of satellite images as base maps for geological mapping as different rock types have similar reflectance properties. The use of remote sensing in such study areas must be considered as a major and efficient tool as these areas are characterized by hilly topography and harsh environment.

The study concludes that the use of Landsat 8/OLI was an effective method of mapping economic mineralized zones and geological structures in the study area. Alteration zones that are normally rich in mineral deposits were successfully mapped using different techniques such as band ratio combination, hydrothermal composite, and geochemical analysis. The result of these shows that the area has potential for mineral exploration and exploitation. This process revealed the existence of alteration zones within the study area. Geochemical analysis proves the altered rocks to be iron ore and gold (Au) bearing. This is in general, an encouraging result for further exploration in the outlined area.

For future studies, more detailed fieldwork should be conducted especially in the outlined alteration zones to verify the remote sensing results and to collect good amounts of field measurements to enhance the geologic understanding of the area and to re-correct the final geological maps. Also, a detailed structural analysis of the lineaments of the study area should be carried out. Future research could incorporate high (spectral and spatial) resolution satellite data to map certain windows of geologic and/or target localities of economic significance in the area. This will support the production of more detailed geological maps of suitable scales.

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