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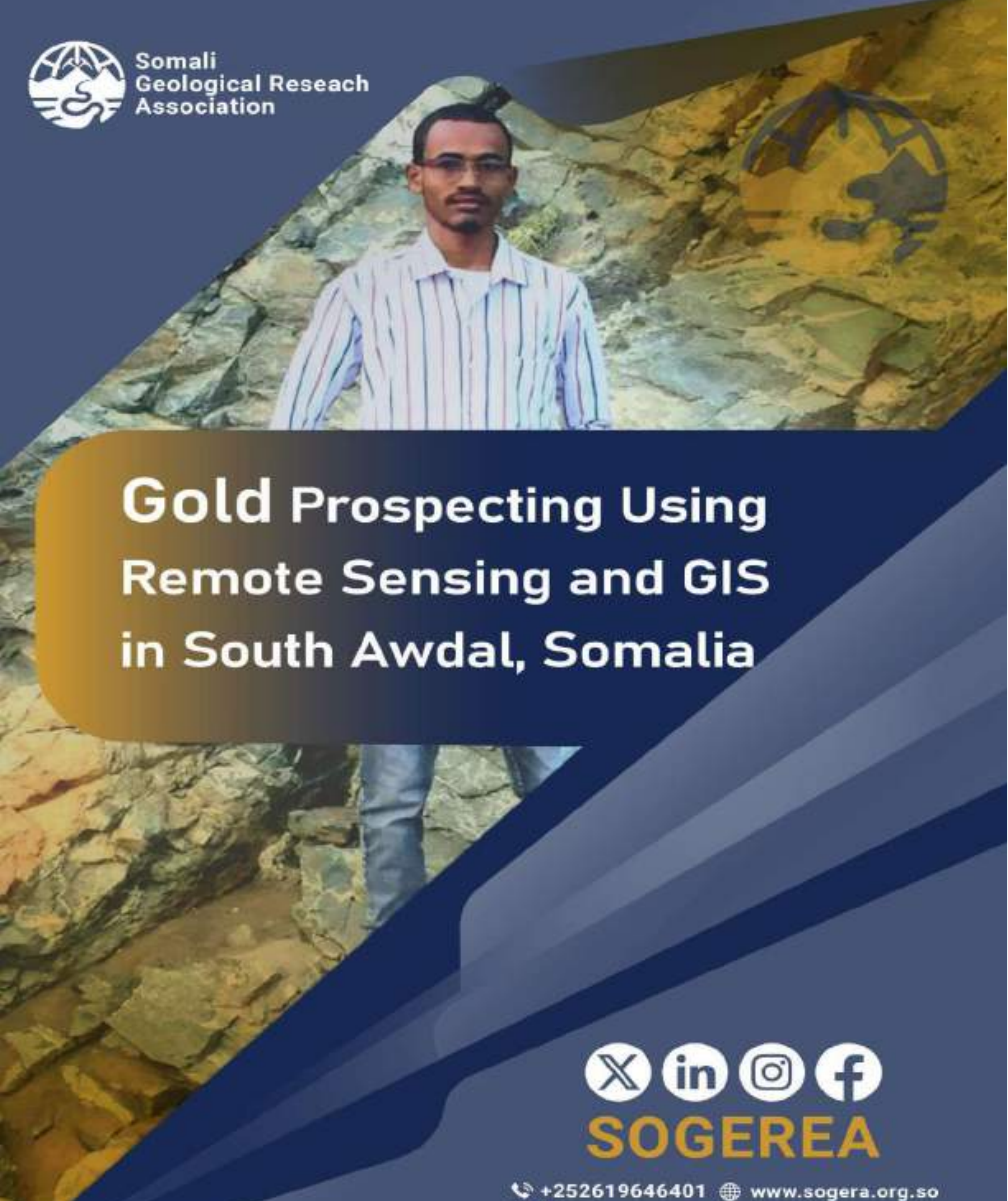

Gold Prospecting Using Remote Sensing and GIS in South Awdal, Somalia

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+252619646401 www.sogera.org.so
info@sogera.org Mogadishu, somalia

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Gold Prospecting using Remote sensing and GIS in South Awdal, northern Somalia

Author: Abubakar Abdinasir

"1. Somali Geological Research Journal Association of Geology, Mogadishu, Somalia, info@sogera.org

2. Department of Geology, Faculty of Science, Somali National University, Mogadishu, Somalia
snu@edu.so & science@edu.so

Abstract

South Awdal is a fully-fledged area of naturally viable gold mineralization and other gemstones. Prior studies bore by Greenwood (1960, 1961); Gellatly (1961, 1963, 1964); Daniels et al. (1965); Greenwood and Bleackley (1967); Greenwood et al. (1967) were related and, more importantly, subsequent studies by Ibrahim and Kafia (2020), Abubakar and Abdinasir (2022), and Mursal and Dr. Abdisalam (2023) have corroborated geological features and substantial mineral resources such as gold, iron ore, actinolite, and emeralds in the mountain of Borama. Despite these findings, ample geological potential is still waiting for exploration in Somalia, chiefly due to historic and logistic constraints. The 24 surface samples shown in Tables 1 revealed low gold content, suggesting the need for future exploratory work using trenches and core drills. Currently, gold mining in northeast Borama is done in open pits and quarries, avoiding high capital investment in conventional mining methods.

Advent in industrial technology through remote sensing and Geographical Information System (GIS) has facilitated, in recent years, exploration strategies for mineral deposits. This study adopts remote sensing and GIS technologies to discover and map the economic potential for gold mineralization in the South Awdal region. The interpretation of multispectral images and geospatial analysis suggested by the reconnaissance of geological formations, structural controls, and alteration zones is directed towards signs of gold deposits. This forms an inexpensive and efficient means to conduct a preliminary survey for finding minerals, hence reducing the number of extensive ground surveys. The evidence suggests remote sensing and GIS technologies have their efficacy when augmenting mineral exploration in arid and semi-arid regions such as South Awdal.

Corresponding author: abukar.nasir100@gmail.com

1. Introduction

This survey adopts Remote Sensing and GIS to build on previous research where updated geological data for the mountainous regions around Borama will be advanced in the first time of research in the northwest Somalia. The survey thus addresses knowledge gaps and addresses the need for a more comprehensive understanding of the geology of this region, which, in turn, is crucial for effective resource management and environmental conservation.

The ability to discriminate between hydrothermally altered and unaltered rocks are considerable in mineral exploration studies. In the region of solar reflected light, many minerals demonstrate diagnostic absorption features due to vibrational overtones, electronic transition, charge transfer and conduction processes. Hydrothermally altered rocks are frequently indicated by iron oxide, clay, carbonate, and sulfate minerals, which produce diagnostic absorption signatures throughout the visible and near infrared (VNIR) and shortwave infrared (SWIR) regions. (Khalid A. Elsayed. 2020)

Landsat TM/ETM+ image has been used for detecting alteration mineral assemblages associated with epithermal gold and porphyry copper mineralization and lithological mapping applications. Shortwave infrared bands (bands 5 and 7) of TM/ETM+ have been used as a tool to identify hydroxyl bearing minerals in the reconnaissance stages of copper/gold exploration (F.F. Sabins. 1999).

This technology, indeed, was developed in the 70s and has remained a great help not only for geological mapping but also for mineral exploration, but perhaps most especially in the identification of geological features that are known to host ore deposits, including fractures and faults, in mapping hydrothermal alteration minerals.

Multispectral remote sensing data is generally very useful for geological mapping, mainly in arid regions. This technology has meaningfully complemented the exploration of several ore deposits. Moreso, epithermal gold, porphyry copper, and uranium, using Landsat images and their blue and red bands, are particularly expressive for differentiating iron oxide/hydroxide minerals like hematite, goethite, and jarosite. (J.C. Velosky. 2003)

The SWIR region is of particular importance for the detection of hydrothermal alteration zones because hydroxyl-bearing minerals display diagnostic spectral absorption features in this part of the spectrum. This capacity for remote sensing has led to the development of the standard procedure in exploration geology, whereby the spatial patterns of formation minerals can be recognized, as there are spectrae of alteration minerals that provide the basis for their remote detection and identification associated with hydrothermal processes (Khalid A. Elsayed. 2020).

1.1 Background

Although it is fist research that consenting the Somalia specially Awdal Region to establishing the use of remote sensing and GIS in guiding gold exploration, the study also identifies some limitations.

The fall of the Somali government inflicted a huge setback on geological research and foiled attempts to publish literature and reference materials on Somalia's geology. In addition to, the lack of more up-to-date data, aerial photographs, topographic maps, or geophysical surveys mean that a thorough generalization on the geology of the area is impossible. Moreover, the small number of geoscience institutions and nongovernment organization are exploring and developing the mineral potential of the country.

(Gatto et al., 1981) The northern basement of Somalia is mostly composed of high-grade metamorphic rocks which host at least two remarkable greenstone belts; these greenstone belts bear evidence for volcanogenic gold-rich base metal deposits and hold high promise for gold exploration and discovery. Also (1972-1974) the UNDP project have done in northern Somalia.

Gold mineralization has been widely studied owing to both its economic importance and geological interest. The South Awdal area in British Somaliland, Somalia, has complex geology with favorable prospects for various mineral deposits, including gold. The traditional methods for mining exploration, such as geological mapping and geochemical analyzes, are labor-intensive and are also cost-consuming. With advancements, remote sensing and GIS have become one of the most productive means for mineral exploration; they afford a large-scale detailed analysis of surface mineralogy, structural geology, and lithological variances, all of which are important for pinpointing prospective gold-rich areas.

1.2 Objectives

The primary aim of this investigation is about the gold mineralization of the South Awdal region through the use of remote sensing and GIS techniques. The specific objectives shall include:

1. Identification of the geological formations and structures associated with gold mineralization.
2. Mapping alteration zones that indicate hydrothermal activity.
3. Creation of a mineral prospect networking model by using data from remote sensing and GIS.

2. Study Area

Borama is a city located in an upland area about 117 km west of Hargeisa-the capital city of Somaliland-and about 10 km north of the international border with Ethiopia. The city is the capital of the Awdal region and is in a mountainous area to the west of Somaliland. The total population of the town is assumed to be greater than 544,000 inhabitants. Borama may be approached through Hargeisa, Ethiopia, and Djibouti. The routes from Djibouti and Ethiopia are rather horrible-again, that is, they have horrendous conditions-while the road from Hargeisa is a bit of favor: it has been done by an upgrade process for the previous three years. The town covers a total area of about 25 km2, lying at a latitude of approximately 10°N and a longitude of 43°E, at an altitude level of about 1,400 m above sea level.

The geology of the region is characterized mainly by the Precambrian crystalline basement complex, granites, gneisses, schists, and younger sedimentary formations. The dry climate and scattered vegetation provide for an excellent setting of remote sensing applications because it minimizes data interference from dense vegetation covers. The study area is in the East Borama district, approximately 8 km from the Borama district; it is bounded between longitudes 43°12′30″ and 43°17′30″ E and latitudes 9°56′00″ and 9°53′30″ N (Fig. 1a). The area has good potential for mineral exploration in gold deposits, so many companies are working there and obtaining good results.

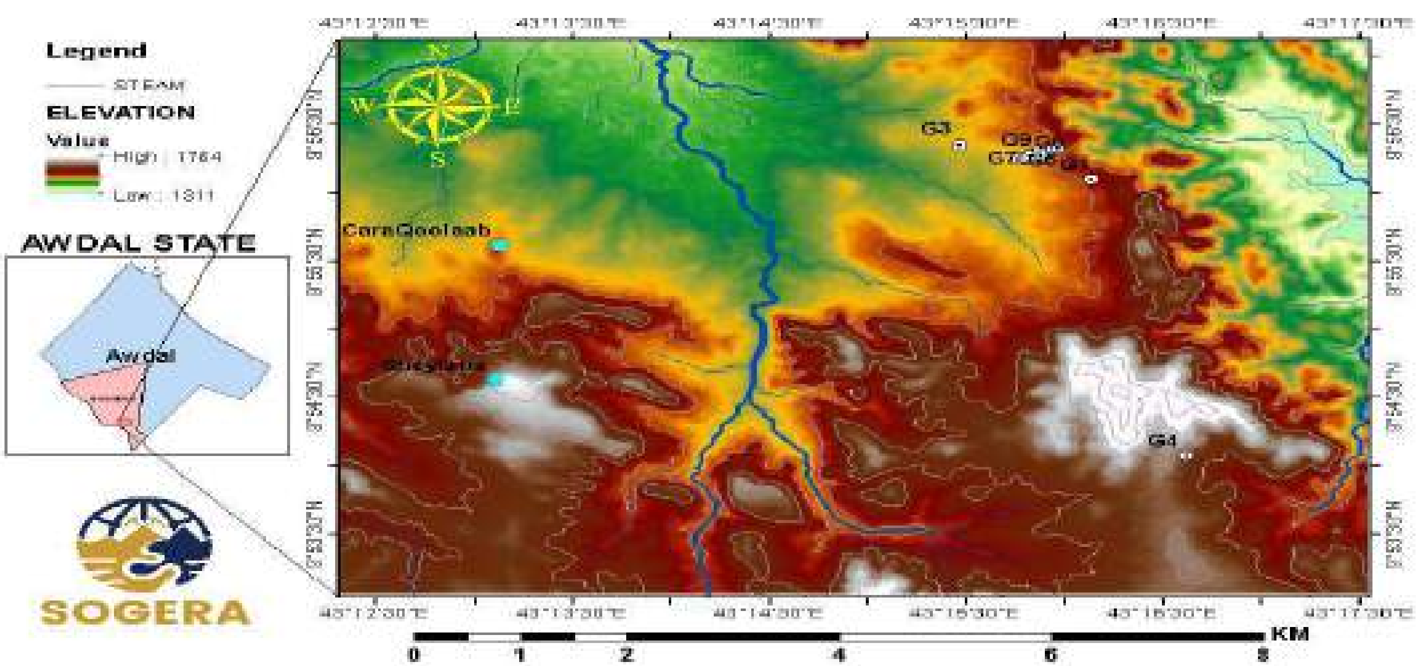

Figure 1. location map and digital elevation model of Study area

The geology of Somaliland mainly comprises high-grade metamorphic rocks embedded within the greenstone belts, known to contain gold-rich base metals. Greenstone belts are variously metamorphosed mafic to ultramafic volcanic sequences interspersed with sedimentary rocks and are found within Archaean and Proterozoic cratons formed between granite and gneiss bodies.

Nubian Gold Corp. is the first and, so far, only international company to go into Somaliland and begin its exploration for gold. This Canadian entity has three gold exploration licenses for the regions of Moro, Abdul Qadir, and Qahar complex. (Dal Piaz et al., 1987).

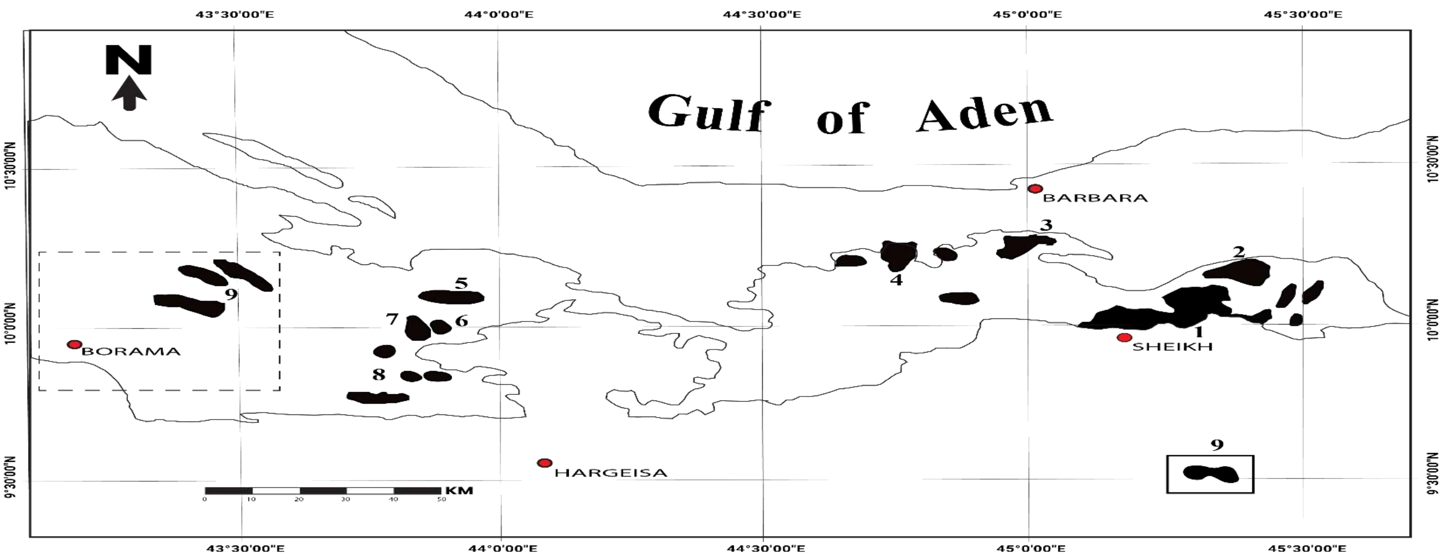

Fig. 2- Regional distribution of the main bodies making up the Gabbro-Syenite Belt in the notheast Borama and the Northern Somali Basement (taken from DANIELS et al. 1965)

Table 1. Chemical data concerning the Borama metarhyolites (Abdulkadir Complex) taken from (E. ABBETE, 1993).

SAMPLE	280	286	286/1	287	288	83-66	83-71	83-72	83-73	83-74	81-319
SIO2	71.3	76.98	78.63	76.67	76.93	74.78	74.78	73.4	71.36	78.03	76.83
TIO2	0.3	0.08	0.08	0.06	0.06	0.26	0.26	0.33	0.6	0.11	0.14
Al2O3	13.35	12.25	12.4	12.38	12.5	12.61	12.08	12.93	13.28	11.92	13.25
FE2O3	2.5	0.79	0.41	0.81	0.82	1.15	0.55	1.98	2.04	0.73	1.13
FEO	0.59	0.25	0.28	0.22	0.22	1.34	0.61	1.15	1.94	0.36	0.65
MNO	0.05	0.01	0.01	0.01	0.01	0.04	0.01	0.05	0.07	0.02	0.07
MGO	0.37	0.3	0.27	0.25	0.22	4.1	0.11	0.14	0.52	0.13	0.06
CAO	1.24	0.39	0.58	0.32	0.54	0.93	0.48	0.83	1.07	0.27	0.57
NA2O	4.08	4.01	6.05	4.25	4.96	2.67	4.35	3.6	3.76	3.22	4.71
K2O	1.82	3.65	0.39	3.31	2.15	5.63	2.56	5.16	4.02	4.44	3.94
P2O5	0.08	_	_	_	0.02	0.02	0.01	0.03	0.13	0.01	0.01
LOI	1.84	0.91	0.49	1.03	0.83	0.31	0.43	0.1	0.39	0.39	0.69
TOTAL	95.68	98.72	99.1	98.28	98.43	99.51	99.3	99.6	99.39	99.24	99.36
RB	50	90	17	84	51	119	78	164	126	175	_
SR	100	92	149	70	101	80	58	69	147	44	_

3. Methodology

This survey marks the first Remote Sensing and GIS study focused on the mountainous regions around Borama, building on previous research by providing updated geological data. This work aims to fill existing knowledge gaps and offer a more comprehensive understanding of the region's geology, which is essential for effective resource management and environmental conservation.

3.1 Data Acquisition

The data used in this study is based mainly on Sentinel-2 imagery. The Remote sensing and GIS software used for processing and mapping the data during the analysis. Arc Map is used mainly for the GIS interpretation (e. g. the statistical analyses of lineaments). The interpretation of images from satellites, of course, is done depending on the spectral reflectance of earth materials on the surface. However, such reflectance depends on the electromagnetic spectrum within which data have been collected by the satellite, (USGS, 2022). With this in mind, the next few paragraphs describe each kind of data. These datasets provide information across a range of wavelengths, from visible to infrared, which is crucial in detecting mineral signatures and alteration zones.

3.2 GIS and Remote Sensing Data Processing

The GIS technology has been used to integrate a variety of remote sensing data with other geospatial datasets, such as geological maps, structural lineaments, and digital elevation models (DEMs). The remote sensing data are processed based on standard methodologies involving radiometric and atmospheric corrections to improve data quality. Band combinations and ratios were used to highlight certain geological features:

1. False color composites (FCCs) were generated to differentiate between rock types as well as alteration zones.
2. Band ratios including band 5/7 (to detect iron oxides) and band 4/2 (for clay minerals) were conducted to improve the spectral signatures of minerals associated with hydrothermal alteration.
3. Principal Component Analysis was performed to reduce the dimensionality of the data and highlight image features indicative of mineralizational opportunities, as shown in Table 2.

4. Results and Discussion

The 24 surface samples shown in Tables 2 revealed low gold content, suggesting the need for future exploratory work using trenches and core drills. Currently, gold mining in northeast Borama is done in open pits and quarries, avoiding high capital investment in conventional mining methods. Remote sensing techniques of alteration mapping help identify several hydrothermally altered zones characterized by widespread occurrences of iron oxides, clay minerals, and silica. deeply associated with ore occurrences, these alteration zones were generally situated around major structural features. The band ratio of ASTER is useful for identifying those alteration minerals.

Geological interpretation of the remote sensing data had highlighted considerable lithological variation, with granitic intrusion and metamorphic rocks that could be possible hosts for gold mineralization. Regions of hydrothermal alteration are highlighted on false colour composite 7,3,1 and band ratio images, especially in those areas with elevated concentrations of iron oxides and clay minerals.

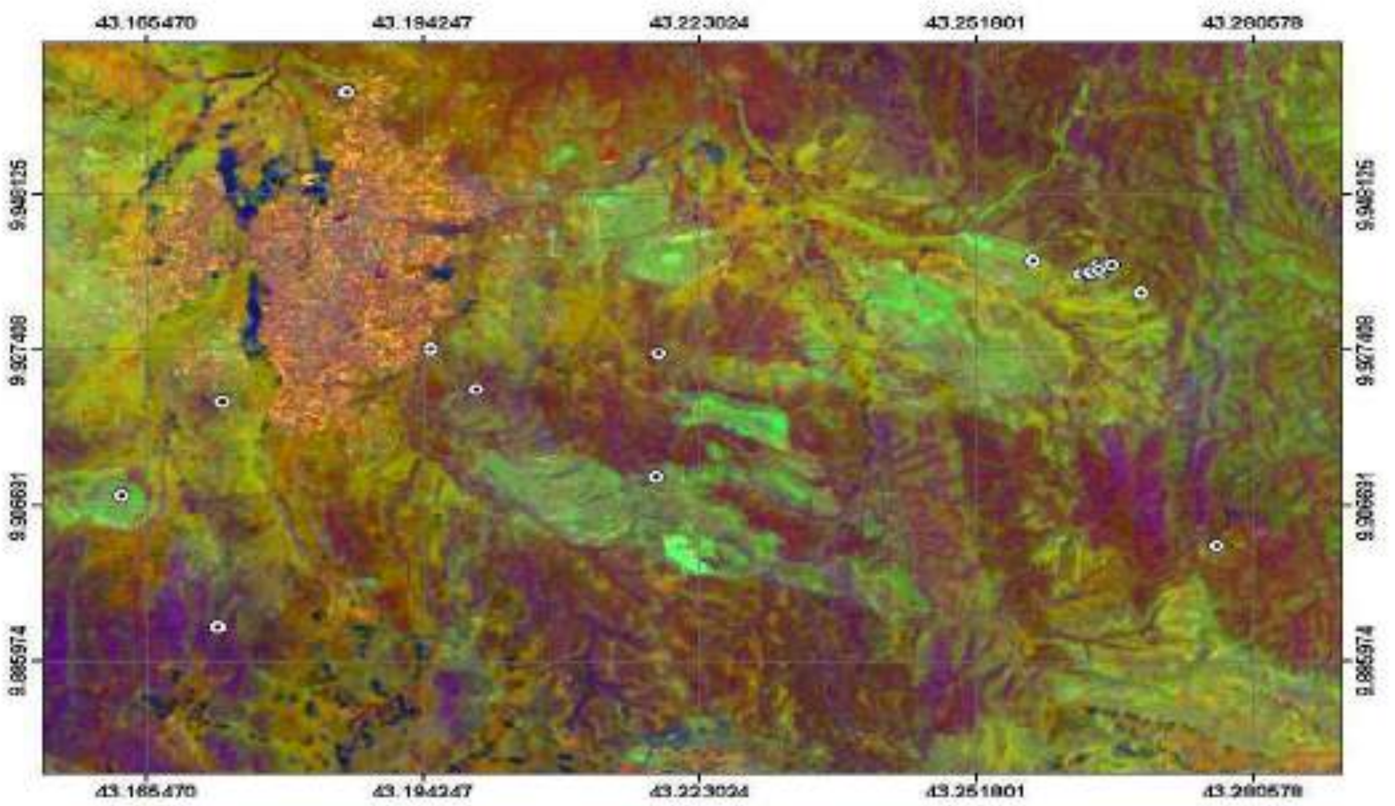

Fig. 3. Color composite of bands 7, 3, 1 in RGB, respectively.

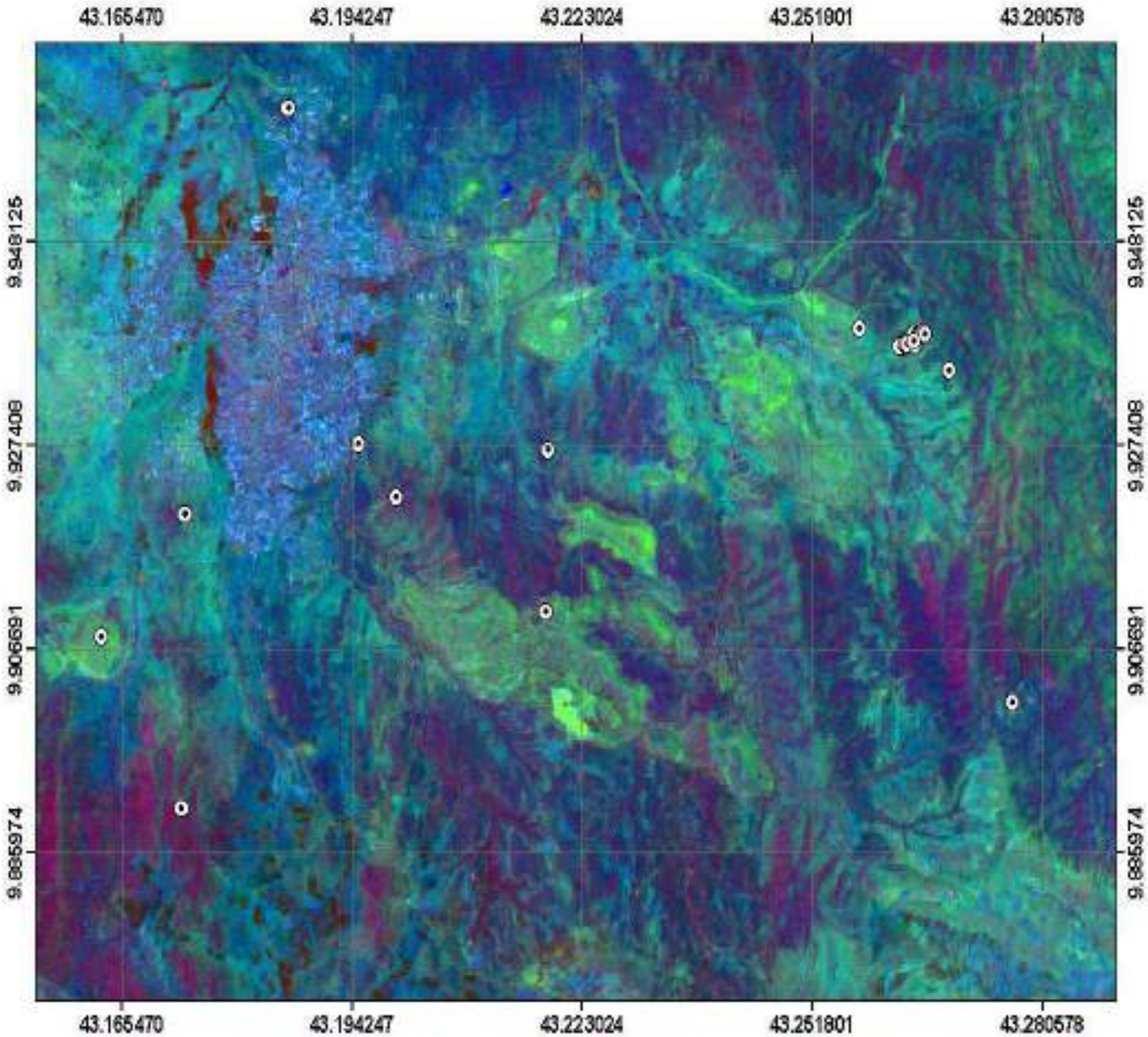

Fig 4. color composite of bands 7, 5, 4 in RGB, respectively.

In the Fif 4. The color composite image, created from bands 7, 5, and 4 of satellite imagery, enhances the identification of geological units by assigning specific colors to different rock types. Gneisses appear in brown, metasediments in olive green and dark blue, metavolcanics in light brown, and intrusive rocks in green. This method allows for clear differentiation of lithological features, aiding in geological mapping and analysis, and provides a valuable tool for remote sensing applications such as mineral exploration and land-use planning.

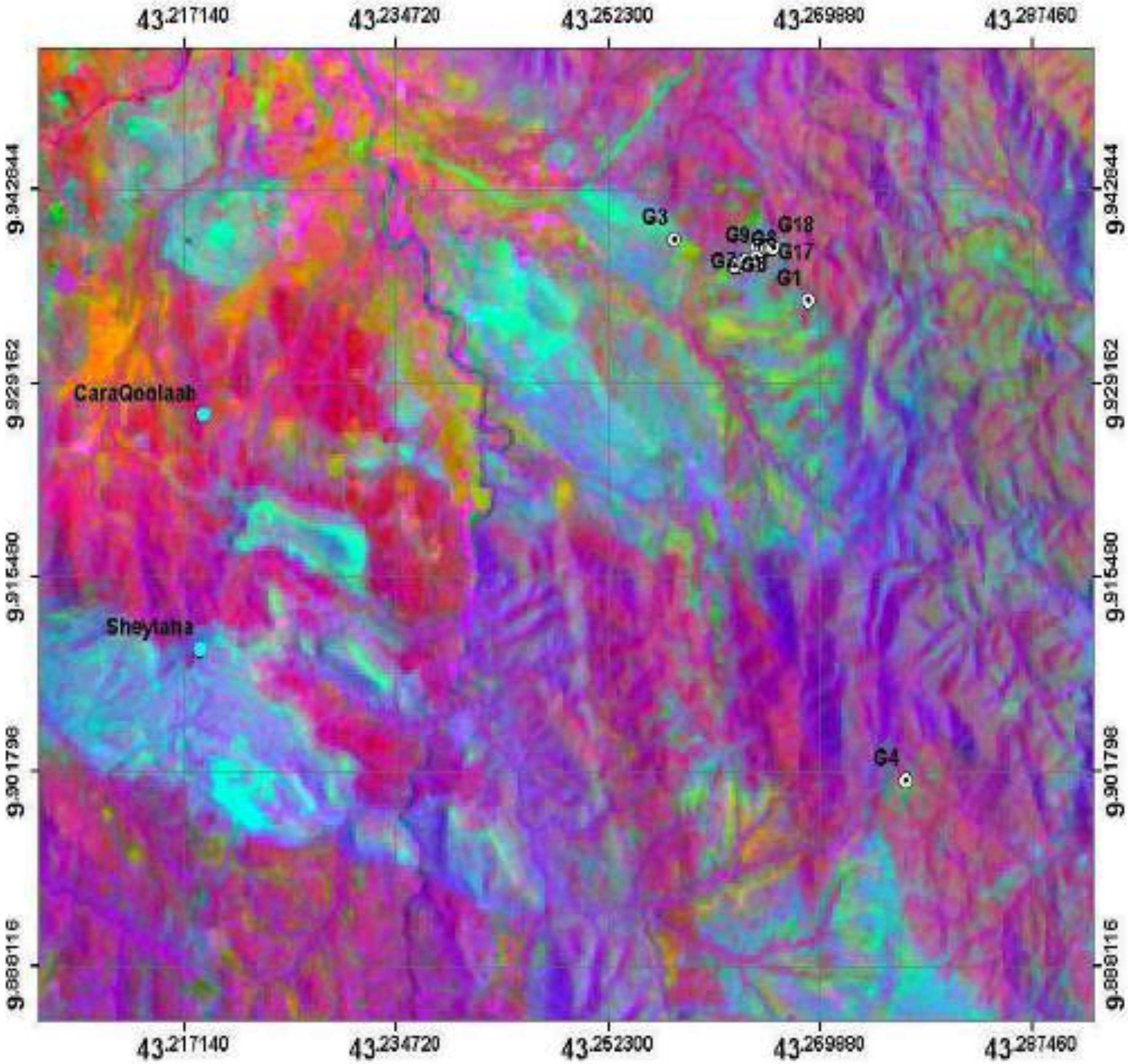

Fig 5. Principal component color composite of PC1, PC2, PC3 in RGB, respectively.

In the PC color composite of PC1, PC2, PC3 in RGB, respectively (Fig.5) the gneisses are shown in cyan, metasediments in bright blue, metavolcanics in violet, and intrusive rocks in bright blue. The composite image captures the spectral response variance among different rock types, highlighting the contrasting features that allow for the identification of geological features. Thus, the principle of color mapping with principal components increases interpretability. Moreover, it is a powerful tool in geoscience mapping and interpretation where remote sensing data is concerned.

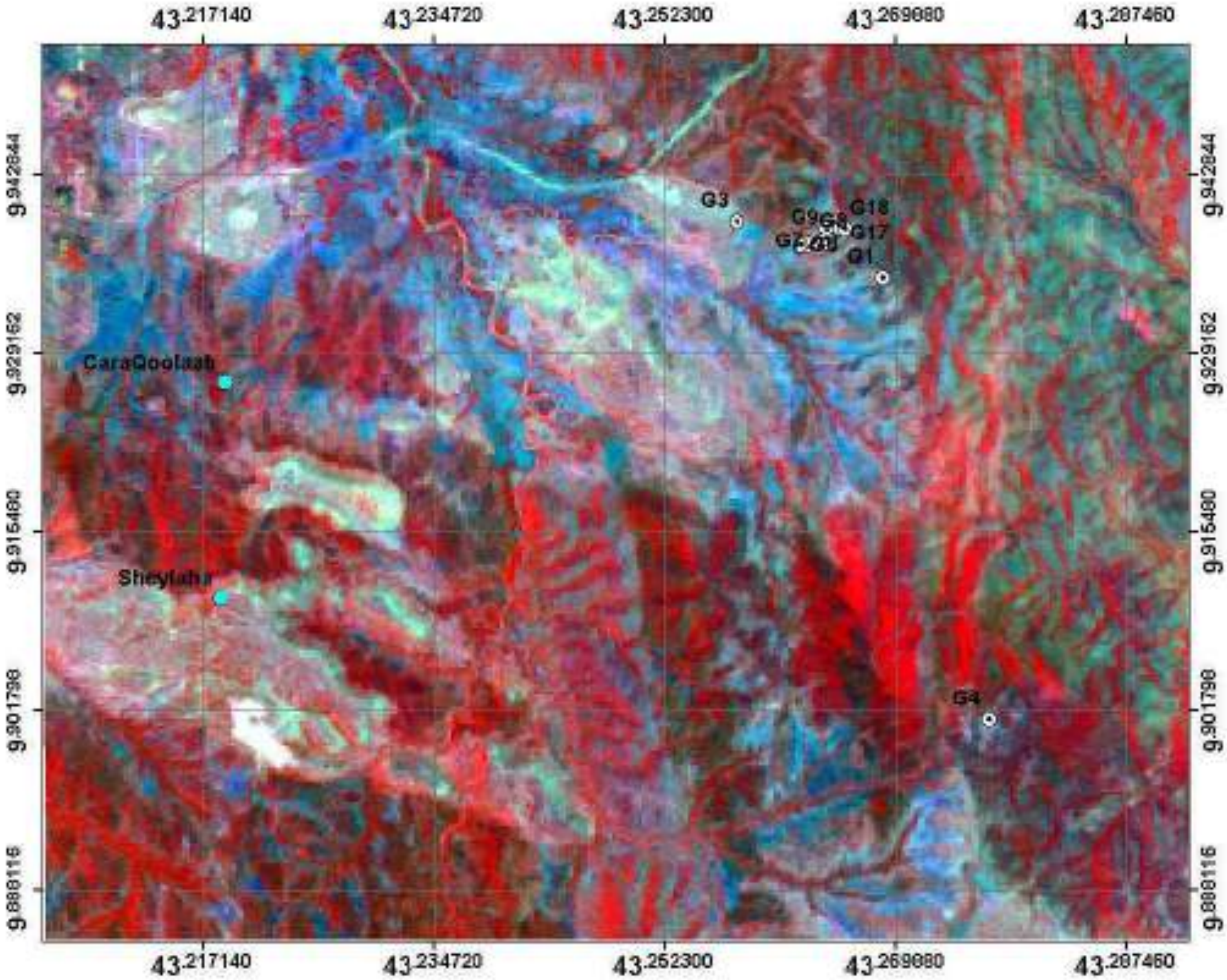

Fig 6. Hydrothermal composite of band ratios: 5/7, 3/1, 4/3 to RGB, respectively

(In the Fig 6.) The hydrothermal composite image generated with band ratios of bands 5/7, 3/1, and 4/3 assigned to RGB channels effectively highlights distinct hydrothermal alteration zones. Of the ratios employed, individuality of alteration of clay minerals and altered volcanic rocks, relative to adjacent altered areas, is enhanced on other unaltered ground, allowing for greater understanding of hydrothermal distribution spatial relationships and geologic attributes.

The structural analysis of the remote sensing and GIS records revealed various NE-SW and NW-SE-oriented lineaments and fault systems. Such structures are linked with regional tectonic events and could, by extension, provide channels for mineralizing fluids. Correlated spatial relationships between the above structural features and the zones of alteration strongly suggest structural control for the gold mineralization within the mineral zone.

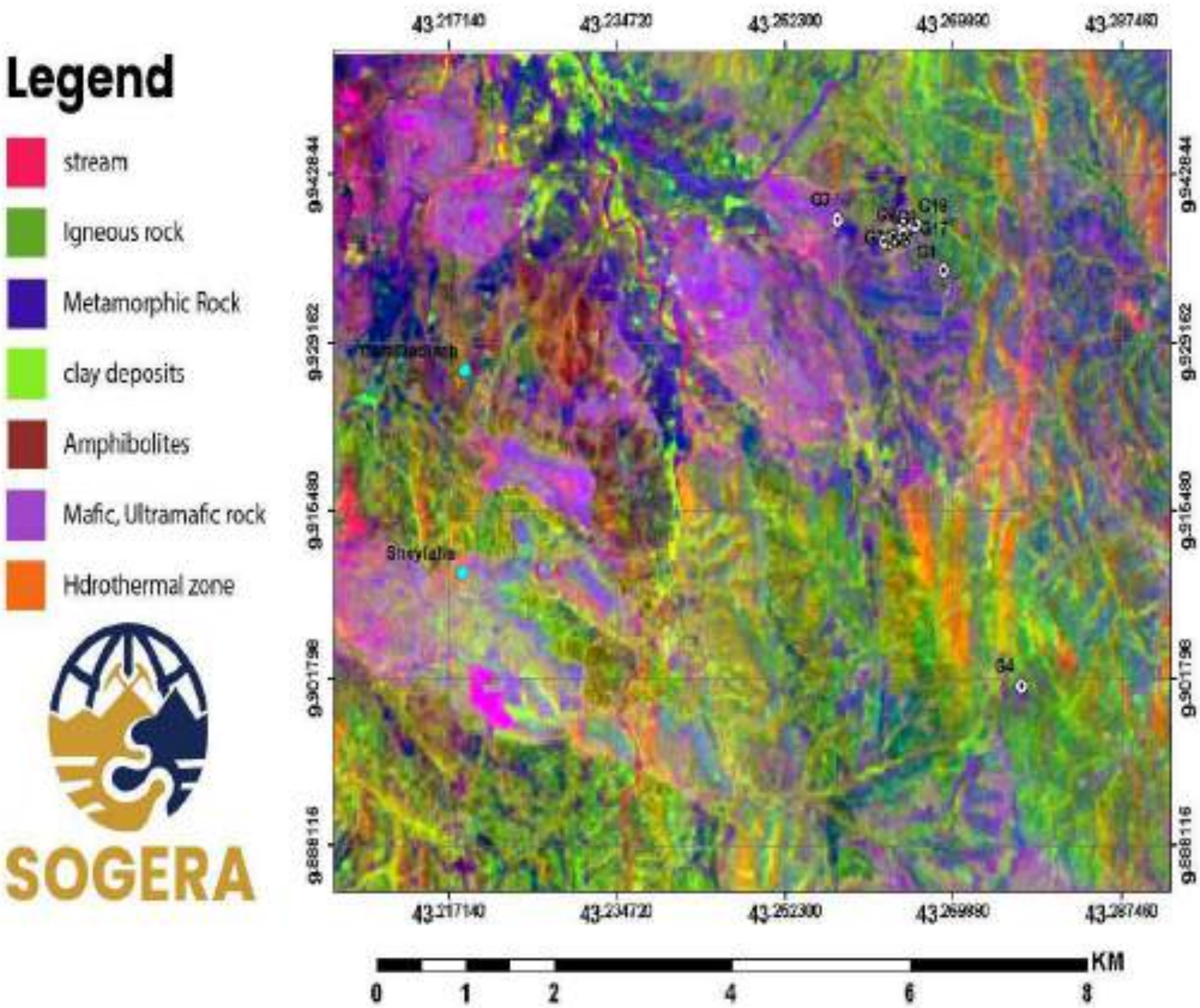

Fig 7. Mineral composite of band ratios: 5/7, 5/4, 3/1 in RGB, respectively.

In fig 7. The mineral composite image obtained through the band ratios of 5/7, 5/4, and 3/1 and distributed among the RGB channels has given a good depiction of geological features in the study area. In this composite, dark green areas depict igneous rocks distinguished by their own spectral signatures. Dark blue regions indicate metamorphic rocks, while light green tints reflect clay deposits, which are typically the result of weathered or altered terrains. The bright red colors symbolize amphibolite rock formations, generally rich in iron and magnesium. These color-coded differences clearly define the different rock types and provide insight into identifying and classifying geological features using satellite data.

Besides the primary rock types, the composite also shows important mineralized zones. Thus, purple areas are indicators of mafic and ultramafic rocks rich in magnesium and iron and are often related to specific mineral deposits. The orange areas may signify hydrothermal zones, thus possibly indicating mineral alteration or possible locations of ore bodies. The bright light colors in the composite form a clear track for gold-rich zones; this is valuable information for mineral exploration. The technique clearly enhances the prospect for a geologist to pick up and map different aspects and features, making it a fine instrument for basic geological and environmental studies.

5. Discussion

5.1 Implications for gold exploration

The present study bears significance mainly for gold exploration in the South Awdal region. Remote sensing integrated with GIS provide rapid evaluation of wide areas to define sites that should be investigated more closely using ground-based exploration. This entails lowering exploration costs along with reduced environmental impact, as fewer ground disturbances are required in order to define prospective sites.

5.2 Limitations and Future Studies

Although it is fist research that consenting the Somalia specially Awdal Region to establishing the use of remote sensing and GIS in guiding gold exploration, the study also identifies some limitations. Since the work has been carried out mostly on surface data, subsurface mineralization could remain undetected. Future research could aim to integrate remote sensing to other geophysical methods such as magnetic and radiometric surveys to better evaluating subsurface properties. Furthermore, the high-priority targets by comprehensive geological mapping and geochemical sampling in order to validate the findings reported throughout this study.

5. Conclusion

Remote sensing in conjunction with GIS technology represents a powerful weapon for mineral exploration in areas of difficult terrain and limited ground access, as in South Awdal, British Somaliland. The present study identified the potential zones for gold mineralization following satellite image analysis and geospatial data analysis, thus demonstrating that remote sensing and GIS are effective tools for first-order explorations, permitting even large areas to be scouted in searches for gold mineralization with limited fieldwork. The future perspective is to ground-truth these findings and extend the investigations to elaborate geochemical and geophysical surveying to ascertain the presence of gold mineralization.

6. Recommendation

The research gives the following recommendations based on its findings:

1. Conduct detailed geological mapping and geochemical sampling along the high-priority areas as outlined in the prospectivity map.
2. Geophysical Surveys- Geophysical surveys such as magnetic and radiometry could be used to complement underground investigations.
3. Advance remote sensing techniques- Hyperspectral images and drone-based remote sensing is to be considered to facilitate the identification of ore deposit minerals.
4. Engagement with Local Stakeholders: Engage local communities and stakeholders in exploration activities, to sustain development along eco-friendly lines.

7. Acknowledgements

We would like to thank the geologists Abdisalam, currently is gold miner in Awdal Region and former teacher form Almas, Ely, Banadir Universities. The author which expresses his deepest thanks to the Somali Geological Research Association for the incalculable support and cooperation rendered throughout this study. The local communities in the South Awdal region who assisted and cooperated throughout the fieldwork phase deserve special mentions. Also I would like thank Mr. Mursal, Senior Geologist in SOGERA.

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SOGERA

www.sogera.org.so
info@sogera.org
+252619646401
Km4 street,
Mogadishu, somalia