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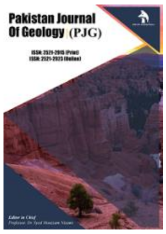

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RESEARCH ARTICLE

EFFECTIVE USE AND INTERPRETATION OF GEOGRAPHICAL DATA IN REGIONAL MINERAL EXPLORATION IN HUNZA VALLEY PAKISTAN

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ABSTRACT

Because of limited accessibility and the phantom nature of mineral occurrences, northern regions of Pakistan have no or very little understanding of the area's mineral potential. Still, these regions are known to be rich in mineral resources. This research aimed to apply Geographic Information Systems (GIS) and Remote Sensing technology for the identification and examination of different mineral deposits in the northern areas of Pakistan. The subject study area was analyzed for its mineral potential through ArcMap 10.5 and the ENVI software. ENVI software also includes satellite image processing capabilities, so it was used to apply the band ratio methods which contained relevant mineralogical information. The study area selection done previously was based on known deposits with unexplored extension region. The processing of the satellite images was done in the hopes of discovering certain minerals that signify the presence of valuable deposits. To achieve this, the band ratio technique was used separately for each spectral signature of various minerals. The b2/b1 ratio was used for detecting ferric iron, while the b1/b3 ratio was used in connection with clay mineral identification. Detection of sulphates was accomplished with the use of b1/b2, and identification of quartz was done with b13/b10 ratios. The b1/b14 ratio determined carbonates, while kaolinite was identified with b11/b12. Together, these data enabled the differentiation of various mineral compositions of the study area. This research demonstrates that eastern Hunza Valley contain major zones enriched in carbonated minerals and ferric iron, especially in Region A and Region B, which both showed high values for concentration of these resources. Furthermore, significant amount of clay minerals was also found to exist in these regions. These areas with rich mineral content can further investigated for mining purposes and developmental projects to boost the economy of the region while aiding future mineral exploration work.

KEYWORDS

Mineral Exploration, Remote Sensing, Hunza Valley, ENVI Software, Geosptial Analysis, Spectral Band Ratios, ArcMap

1. INTRODUCTION

MINERAL exploration is the search for the mineral resources that can be extracted profitably (Okada, 2022). It is an important aspect of the mining sector because it helps companies find and utilise precious assets, such as metals, nonmetals, and fossil fuels needed to satisfy the participating needs of society (Smith and Wentworth, 2022). This typically involves combining geological, geochemical, and geophysical surveys with drilling, sampling, and evaluating economic and environmental considerations (Yousefi et al., 2019). The purpose of mineral exploration is to locate and assess the resources of minerals that can be developed into mines. Such minerals can be categorised as precious metals, blende and cuprite, operational minerals like limestone and gypsum, or even fuel-forming minerals such as coal and oil.

According to the study, all types of vessels can carry out mineral exploration because it can be performed by independent prospectors, small exploration companies, and even large mining firms (Bougrain et al., 2003). Most of the time, mining exploration begins with a preliminary examination of a given region. This involves assembling geological, geochemical, and geophysical information (Ochola, 2021). Regions with the best chances of housing mineral deposits are established from this information. By and large, the conventional techniques of mapping and prospecting together with modern techniques such as the use of remote sensing and geophysical surveying can be used (Ruban et al., 2007). A typical example is satellite imagery, which can be used to study the likely areas for the location of mineral deposits. On the other hand, remote sensing is the use of instruments to locate mineral deposits by measuring the magnetic or gravitational fields of the earth (Zuo et al., 2021; Aitaand Omar, 2021).

After selecting a potential location, companies will conduct further research that involves geological mapping, sampling, and drilling (Barak et al., 2023). The gathered information is used to predict the quantitative and qualitative parameters of the mineral's body and its possibility of being economically extracted (Akbar et al., 2024). There are numerous arguments that justify the exploration of minerals. One of the principal aims is to determine other minerals that can be profitably extracted. Minerals constitute an essential element that is incorporated into a vast number of products such as construction, industries, electronics, and energy (Gielen, 2021). The demand for a specific sample tends to increase, and in the same manner, the need to discover the sources of these minerals also escalates. The search for minerals is a method of identifying and locating new deposits that can be economically worked and developed into mines (Bougrain et al., 2003). The search for minerals is a very important activity and very complicated since success depends on various factors such as resource combination, funds, skilled personnel, and

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environmental considerations (Nwaila et al., 2022). In the future, as attention to resources continues to develop, the need to search for minerals becomes more significant. The developments in technology are offering newer means of locating and harvesting mineral deposits, all while lessening the damage to the environment.

2. Study Area

The provincial study region lies in the eastern fringes of the Hunza Valley, located within the Gilgit-Baltistan province of northern Pakistan (Khan et al., 2022). Its altitude of about 2,500 metres (8,200 feet) places it within the Himalayan, Karakoram and Hindu Kush mountain ranges. The Hunza River valley supports agriculture, facilitated by the river's waters (Miandad et al., 2014). This area has excellent scenery, rich cultural values, and an agricultural and tourism-based economy. In this area, academic studies tend to concentrate on global warming, modifications in anthropogenic land use, and folklore (Marwat and Faryal, 2022).

According to the study, the rocks of Hunza Valley are classified into metamorphic, sedimentary, and igneous types (Khan et al., 2022). While still a type of sedimentary rock, sandstone and limestone were created by sedimentary compaction. After some time, schist, gneiss, and amphibolite metamorphic rocks transformed into sedimentary types due to the pressure and heat applied to them (Laurs et al., 1998). Granite and diorite, for example, and other forms of igneous rocks are produced when magma cools and crystallises (Zeitlerand Chamberlain, 1991). Intense collision between Indian and Eurasian plates gave rise to the boundary forming the Indus Suture Zone and Hunza Fault. These faults make the valley deep and also possess folding features, the latter of which has been extensively described by (Hanson, 1989). The different forms of rocks give rise to the unparalleled splendour of the valley, making it an extraordinary site for geo-scientific studies.

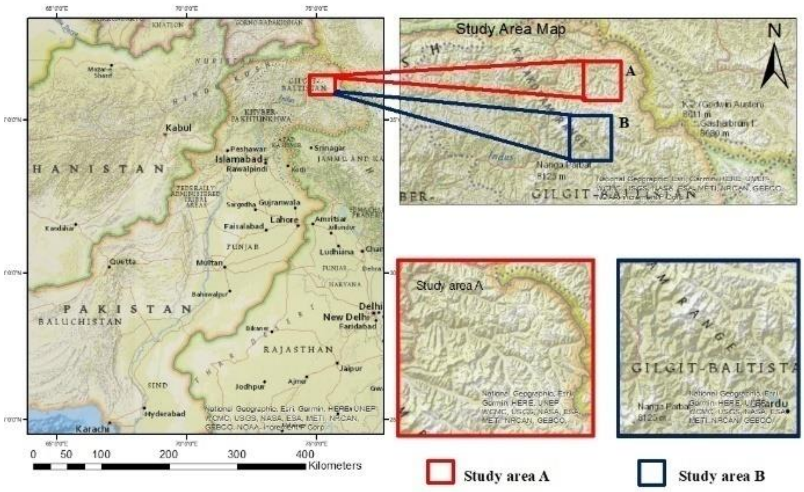

Figure 1: Map Showings the locations of Study Area A and B in the Eastern Hunza valley

2.1 Objectives of Our Study

- To analyses the prospect of mining minerals in the eastern part of Hunza, Pakistan, through the application of band ratios for locating different minerals.
- To plot the detected minerals on the map for further geographic assessment.

2.2 Geological Setting OfHunza Valley

The Hunza Valley is a geographically beautiful area of Pakistan located in Gilgit-Baltistan (Qasim et al., 2024). Based on its name, one would assume that the Hunza region is also stunning, and indeed it is, with beautiful features such as the sparkly Hunza River, together with the famous Hunza valley peaks like Rakaposhi and Ultar (Khan et al., 2022). From a geological perspective as shown in figure 2, the Hunza valley is situated in a complex tectonic setting, shaped by the collision of the Indian and Eurasian plates (Su et al., 2022). The clash of these two plates has led to the building of the youngest mountain range in the world, the Himalayas together with the Karakoram mountains, which form the highest mountain range on earth (Ali et al., 2021). Furthermore, the valley is under the influence of the motion of the Indus-Tsangpo Suture zone, which is the mark of the boundary of Indian and Eurasian plates (Yaseen et al., 2024). Geological map of Hunza is shown in figure 2.

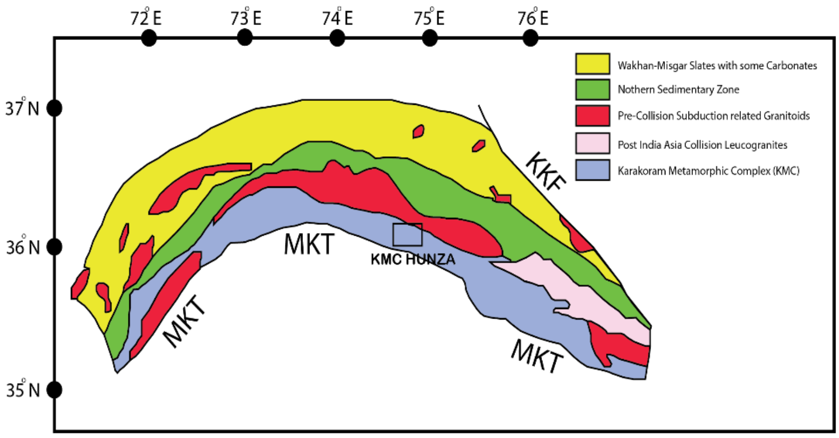

Figure 2: Showing the Geological map of Hunza (modified after Frazer et al., 2001)

Granite and diorite, which are some kinds of igneous and metamorphic rocks, can be observed within the valley. Schist, slate, and gneiss formations within the region developed as a result of extreme heat and pressure arising from tectonic plate collisions (Jan and Gohar, 2013). The activity in the Earth's crust produced by the violent collision of the plates is what shaped the valley. The valley's principal fissures and faults, The Main Thrust Boundary and Central Thrust, also cut across and created a variety of rock units within the valley. To sum up, a valley is a complexly built and, geologically, a distinctive region formed of the collision of Indian and Eurasian Plates (Kaukab et al., 2021). The area is comprised of various metamorphic, igneous and gneisses rocks as well (Liang et al., 2021). These dominant great faults have contained the valley and greatly define the tectonic framework of the area (Hussain et al., 2021).

2.3 Data And Methodology

With respect to the region of Gilgit Baltistan, this study utilises the nogo ratio approach for the processing of ASTER images, as well as mapping of Eastern Hunza Valley for coal, sulphide, pegmatite, garnet, quartz, and gneiss. All these zones have been mapped with the corresponding mineralised areas and field samples. The findings show that the various region structures are the primary control for the distribution of minerals within the regions. This study further assessed the utility of ASTER data together with other image processing techniques and GIS, as well as spectra from different sources like laboratories and field- JPL measurements, for mineral areal mapping. (Abrams, and Yamaguchi, 2019).

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a remote sensing device onboard NASA's Terra satellite (Rajendran and Nasir, 2019). Because different minerals have their own unique spectral signatures, ASTER simply utilises such features to identify and map different ASTER target minerals on the Earth's surface (Hunt, 1977). At the initial stage of mineral extraction, high-resolution ASTER images of the proposed area of study were first obtained.Standard ASTER band ratios are shown in Table 1.

Table 1: Standard Aster Band Ratios (USGS)

Spectral Range	ASTER Band	Wavelength (um)	Spatial Resolution (m)
VNIR	1 2 3n 3b	0.520-0.600 0.630-0.690 0.760-0.860 0.760-0.860	15
SWIR	4 5 6 7 8 9	1.600-1.700 2.145-2.185 2.185-2.225 2.235-2.285 2.295-2.365 2.360-2.430	30
TIR	10 11 12 13 14	8.125-8.475 8.475-8.825 8.925-9.275 10.250-10.950 10.950-11.650	90

After adding the coordinates of the study area to the images, the images were forwarded to GIS. The data was analysed with specialised software that uses spectral signatures of certain minerals for detection (Pournamdari et al., 2014). Subsequently, the data were merged with the maps showing mineral distribution and abundance to facilitate exploration and extraction activities in the region. There are several works done in the country and in the world using ASTER images and band ratios for mineral search and processing (Abrams and Yamaguchi, 2019).

2.4 Data Sources

Our research on minerals located in the eastern Hunza of Pakistan obtained the relevant data from two sources: the United States Geological Survey (USGS), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite images (Davies et al, 202). The primary source of information the USGS possesses is a variety of geosciences data and information resources. These datasets were found to enhance comprehension of the study area's geology and mineral resources.

Also, USGS data, mining environmental and land use features that could limit the eastern Hunza region's mineral exploration and extraction were analysed using ASTER imagery. The Advanced Spaceborne Thermal Emission and Reflection Radiometer is a high-resolution imaging system that photographs Earth and aids in identifying mineral deposits and assessing land use patterns of the area (Bishop et al., 2011). The combination of the USGS and ASTER datasets facilitated a thorough understanding of the mineral resources and the possible impacts of mineral exploration in the eastern Hunza of Pakistan. This helped in outlining the focus regions for mineral exploration and supported planning for mineral extraction activities (Abrams and Yamaguchi, 2019).

2.5 MetadataOf Study Area "A"

ASTER images include a combination of three near-infrared bands, each with a spatial resolution of 15 metres, six short wave infrared bands with a resolution of 30 metres, and five infrared bands, each with a spatial resolution of 90 metres. The dataset was taken during the day which had cloud coverage of 49. The sun's elevation was measured at 31.8244 and the sun's azimuth was 159.023 (Davies et al., 2020).Values regarding the study area's metadata can be found in table 2.

Table 2: Meta data of study area A

Data Set Attribute	Attribute Value
Local granule ID	AST_LIT_003012720220545 40_202201281
Entity ID	AST_LIT_003012720220545 40_202201281
Central latitude	36°16' 17.40°N
Central longitude	75°22' 55.92°E
Acquisition date	1/27/2022
Band 1	Y
Band 2	Y
Band 3	Y
Band 4	N
Band 5	N
Band 6	N
Band 7	N
Band 8	N
Band 9	N
Band 10	Y
Band 11	Y

Table 2 (cont): Meta data of study area A	
Band 12	Y
Band 13	Y
Band 14	Y

2.6 Study Area B Meta Data

All the steps in the preprocessing are exactly the same that were applied previously in the study area A. After all the steps were applied. The minerals were easy to extract from the preprocessed images. Values regarding the metadata of study area are given table 3.

Table 3: Showing meta data of study area B

Data Set Attribute	Attribute Value
Local granule ID	AST_LIT_003012720220540 407_202201281
Entity ID	AST_LIT_00301272022054607_202201281
Central latitude	35°44’ 15.87°N
Central longitude	75°13’ 25.48°E
Acquisition date	1/27/2022
Band 1	Y
Band 2	Y
Band 3	Y
Band 4	N
Band 5	N
Band 6	N
Band 7	N
Band 8	N
Band 9	N
Band 10	Y
Band 11	Y
Band 12	Y
Band 13	Y
Band 14	Y

2.7 Band Ratios

Satellite images are processed using ASTER band ratios, with SWIR and VNIR ratios aiding in the detection of certain minerals, while specific reflectance values help other minerals get identified. For instance, clay, iron oxide, and carbonates can be detected using the SWIR ratio (Band 3/Band 4), with quartz, feldspar, and mica being identified with the VNIR ratio (Band 1/Band 2). Likewise, minerals like hematite and limonite, which have notable absorption features, are detected through the NIR ratio (Band 6/Band 7). These ratios have been proportionately adopted by professionals to construct mineral maps that can be used for exploration, mining, or monitoring ecological damage. Table 4 shows the band ratios associated with the different types of minerals.

Table 4: Shows band ratios of minerals (Sheikhrahimi et al., 2019)

Name of Minerals	Band Ratios
Iron oxide minerals:	Band 3 (0.62 um) / Band 4 (0.56 um)
Carbonate:	Band 5 (2.13 um) / Band 7 (2.29 um)
Silicates:	Band 5 (2.13 um) / Band 7 (2.29 um)
Phyllosilicates (clays):	Band 1 (0.52 um) / Band 3 (0.62 um)
Sulfates:	Band 1 (0.52 um) / Band 2 (0.45 um)
Sulfides:	Band 3 (0.62 um) / Band 4 (0.56 um)
Feldspars:	Band 1 (0.52 um) / Band 3 (0.62 um)
Quartz:	Band 1 (0.52 um) / Band 3 (0.62 um)
Mafic minerals:	Band 3 (0.62 um) / Band 4 (0.56 um)
Olivine:	Band 3 (0.62 um) / Band 4 (0.56 um)
Pyroxenes:	Band 3 (0.62 um) / Band 4 (0.56 um)
Amphiboles:	Band 3 (0.62 um) / Band 4 (0.56 um)
Micas:	Band 1 (0.52 um) / Band 3 (0.62 um)
Talc:	Band 1 (0.52 um) / Band 3 (0.62 um)
Kaolinite	Band 1 (0.52 um) / Band 3 (0.62 um)
Halloysite	Band 1 (0.52 um) / Band 3 (0.62 um)
Hematite:	Band 3 (0.62 um) / Band 4 (0.56 um)
Goethite	Band 3 (0.62 um) / Band 4 (0.56 um)
Limonite:	Band 3 (0.62 um) / Band 4 (0.56 um)

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) employs 14 bands that cover both visible and infrared light. The visible component can detect some minerals like iron oxide, kaolinite, and alunite (Gabr et al., 2010). The approach known as the band ratio defines specific pairs of bands that are responsive to certain minerals, and it calculates the ratio of their reflectance. A band ratio image is constructed, where regions of high reflectance values are indicative of minerals. However, the ground truth identification does not achieve optimal accuracy until ground truth validation is completed, as well as other preprocessing operations like atmospheric corrections to improve accuracy (Ourhzif et al., 2019). The ASTER images have been in the public domain since 1999, with the first Landsat satellite launched in 1972, which initiated the era of geological surveillance by remote sensing. ASTER has been recognised as exceeding other sensors in multichannel mineral mapping due to higher resolution and radiometric accuracy, which makes it the primary satellite imagery for geological study. For more than two decades, ASTER has proven efficient in the recognition of new mineral resources by characterising hydrothermally altered mineral assemblages and delineating mineralised zones (Sheikhrahimi et al., 2019).The band ratios used in this study are presented in Table 5.

Table 5: Showing standard band ratio used in study

Mineral Name	Standard Band Ratio	Source
Ferric Iron	b2/b1	Rowan, CSIRO
Clay/Phyllosilicates	b1/b3	Bierwith
Sulphates	b1/b2	Rowan, USGS
Granite	b12/b13	Rowan, CSIRO
Quartz	b13/b10	Rowan, USGS
Carbonates	b1/b14	Rowan, USGS
Gypsum	(b11*b11)/(b10*b12)	Hewson, CSIRO
Kaolinite	b11/b12	Volesky

2.8 Data Analysis

The analysis of the data is only one step of many included in the process of mineral sifting using ASTER images in ENVI (Environment for Visualising Images). Putting the work plans with ASTER images begins with importing them into ENVI. The next task involves applying radiometric corrections and atmospheric calibrations that aim to eliminate errors linked to the atmosphere and the sensor's quality attribution. The band ratios were later calculated for designated wavelength bands of the ASTER sensor.

Reflectance values divided by each other are the basis of these ratios. These ratios enable the determination of specific minerals by examining their spectral characteristics and distinctive absorption features. For example, the SWIR ratio is useful for detecting clay, iron oxide and carbonate minerals. The ASTER 3/4 ratio has the same purpose. On the other hand, R 6/7 allows the detection of Hematite and Limonite. (Ourhzif et al., 2019). As illustrated in Figure 3, the steps taken to execute the ASTER images method of mineral extraction in ENVI are presented.

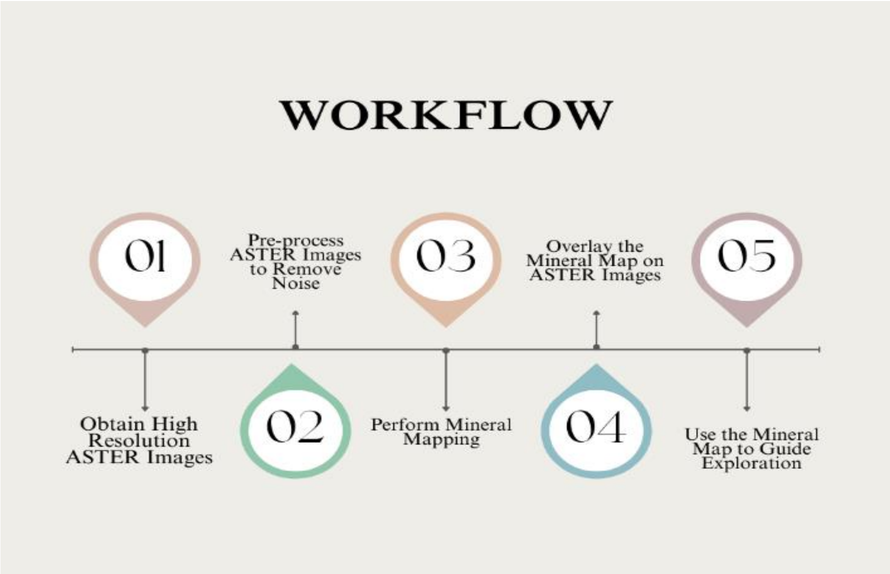

Figure 3: Shows methodology workflow.

- First obtain high resolution images from the ASTER database. The data can be acquired from NASA LP DAAC or other sources.
- Post-process these ASTER images by removing noise, correcting atmospheric effects, and enhancing the spatial resolution. The Atmospheric Correction Module or Image Quality Module in SPA software can be utilised for this purpose.
- Conduct mineral mapping using the ASTER images with a PCA or MNF transformation technique to ascertain the spectral signatures of the different minerals.
- Integrate the results of the mineral mapping into the ASTER images. The map produced will display the location and concentration of various mineral types in the area of interest.
- Utilise the created mineral map for planning exploration and extraction activities. This may involve field sample collection or planning drill hole locations based on the derived map.
- Supervise the region over extended periods by employing additional ASTER images to assess changes in concentration and distribution of minerals and analyse the effects of mining activities on those minerals.

3. Methodology

Firstwe imported the images into the ENVI software. To import the images, the file format needs to be selected first. Aster images consist of three visible near infrared bands with 15 m spatial resolution, six short wave infrared bands with a spatial resolution of 30 m, and five infrared bands with a spatial resolution of 90 metres. Radiometric and atmospheric corrections are applied to all bands. Radiometric correction is applied first. After that it's the turn of the short-wave infrared bands. Layer stacking command is used to merge the two bands together in the form of a single band. After that we convert the spatial resolution to 30 m. Now we move towards the atmospheric correction of the bands after the conversion. Narrow down the numbers between the ranges zero to one.

Now it is time for the thermal band to perform atmospheric and radiometric correction operations. Radiometric correction is applied first. After that the atmospheric correction is applied. Now we need to layer stack all the bands. The resolution is converted to 30m so that the all the thermal bands, near infrared bands, short wave infrared bands become

30m. Once the preprocessing of the minerals is completed, the minerals can be identified by using the formula for mineral identification. The band ratio method is a technique used in remote sensing to analyze satellite imagery to identify the presence of certain minerals. The technique involves comparing the reflectance of different spectral bands in an image to identify patterns that are characteristic of specific minerals. After this we used to apply many attributes and complex workflow used which is shown in figure 4.

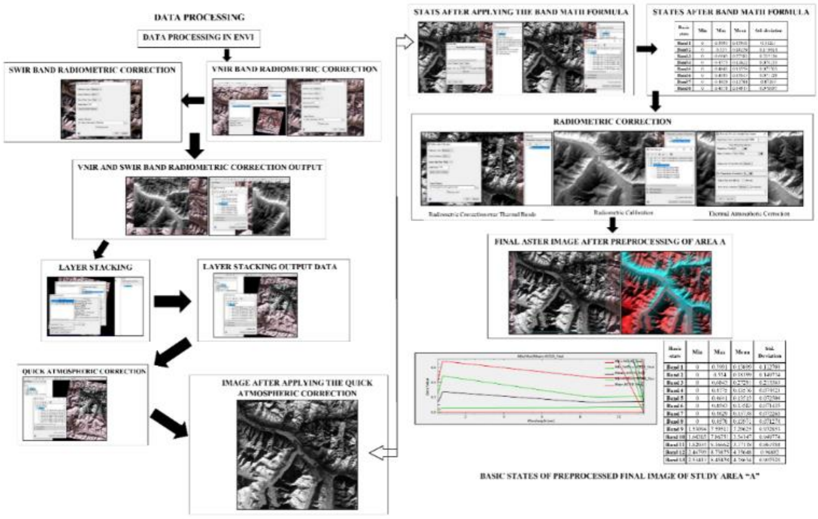

Figure 4: Showing the detailed Methodology used in this study.

4. Results and Discussion

The research on mineral extraction in the east of Hunza in Pakistan using band ratios for ASTER images in the software and integration with GIS has yielded several important findings. A total of eight minerals were identified using band ratios, including ferric iron, kaolinite, gypsum, quartz, granite, carbonates, clay, and sulfates. Integration of the GIS system with scanned ASTER data files was performed successfully and the global position of the area of interest was acquired. Using band multiplication, the software was also able to classify the minerals and the classification results were found to be reasonably accurate.

This study aims to evaluate the mineral exploitation potential in the eastern parts of Hunza, Pakistan. The study was remotely analysed using remote sensing methods and employing the ratio of bands to ascertain the presence of several minerals. The area of concern was assessed utilising satellite photographs. Ratios of bands were done on the photographs for the purpose of visualising the assorted minerals. Using Geographic Information System (GIS), the minerals were annotated and their spatial distribution analysed. The study also proved that some minerals were located in the region by using remote sensing techniques and band calculations. Areas with red colour superimposed due to high values of some band ratios indicate a few of the minerals that are situated within the research area. The mineral map processed with red areas denotes those portions where iron III was located using the ratios of the bands b2/b1. Another area marked with red where clay was located by using the ratio of the bands b1/b3.

B1/b2 is the band ratio that identifies the presence of sulphates while b12/b13 was used for identifying granite within the study area. In the same way, quartz was identified and marked red on the mineral map using the band ratio b13/b10. Both dolomite and limestone are carbonates and are marked red on ENVI generated mineral maps with band ratio b1/b14. The red marks the presence of gypsum which was found from the band ratio ((b11*b11)/(b10*b12)). The red regions in all images correspond to the presence of kaolinite which has been found from the band ratio b11/b12.

All of these minerals were found to have a particular region of concentration, which varied throughout the study area. Concentrations of ferric iron were found to be the highest in the northern region along with kaolinite and gypsum, while quartz, granite, carbonates, clay, and sulphates were found in greater concentration in the southern region. Minerals flourished areas in study area A are shown in figure 5.

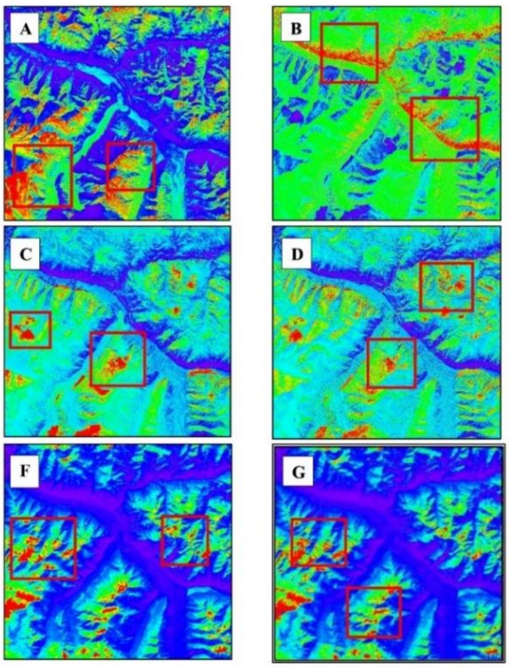

Figure 5: Minerals flourished areas in study area "A": (A) Carbonates (B) Ferric Iron (C) Phyllosilicates (D) Sulphates (E) GraniteF) Kaolinite

The same techniques that were applied for the study area A were applied on the study area B located eastwards of the Hunza Valley. The results of this study suggest that the east of Hunza Pakistan has potential for mineral extraction. The identified minerals, particularly ferric iron, kaolinite, and gypsum could be extracted and utilized for various industrial purposes. The ratio values calculated for each mineral using the software assisted in determining the position of the minerals on the GIS coordinated map. The regions with red colour, which result from very high values of a particular band ratio, denote the occurrence of certain minerals within the area of study.

However, these minerals are not homogeneously distributed within the specified area, which means that further exploration and mapping will be required to identify the best places for extraction. The study provides valuable insight on mineral extraction in the eastern region of Hunza in Pakistan. As a result of the exploration, the industrial grade minerals were also located; therefore, further mapping and exploration needs to be done in order to find the best sites for extraction. The use of GIS technology facilitated the precise mapping and analysis of the mineral distribution which is essential to mineral extraction and mining operations. The analysis further confirmed that a number of minerals such as ferric iron, kaolinite, gypsum, quartz, granite, carbonates, clay, and sulphate constituents with varying physical and chemical attributes have enormous potential for development and commercialisation in the eastern part of Hunza, Pakistan.Moreover, the established patterns of mineral distribution corroborated with the available geological maps of the region, which can be useful for conducting explorative and mining works in the region in the future. The patterns and trends in the distribution of the minerals revealed from the data spatial analysis of the minerals provided more helpful information for the extraction and mining of the minerals. Minerals flourished areas identified in study area B are shwon in figure 6.

The study adds useful knowledge to the eastern Hunza area of Pakistan regarding its mineral assets and has illustrated the band ratios within the ASTER images in the software as an effective tool for mineral identification. The findings of the study are beneficial for the region's extraction and mining operations, while also providing guidance for possible future exploratory and mining endeavours.

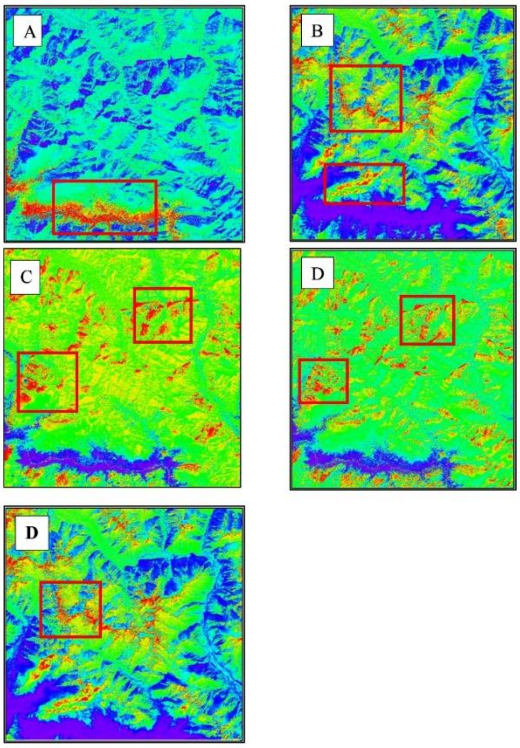

Figure 6: Minerals flourished areas in study area B; (A) Ferric iron (B) Carbonates (C) Phyllosilicates (D) Sulphates (E) Quartz

The analysis of remote sensing data facilitated the mapping of minerals in eastern Hunza, Pakistan by using satellite imagery, even though some inaccuracies were present in the method employed. The scope of this research was limited to surface minerals, foreclosing any other possibilities. Its results are also not valid for a wider area. The analysis of the satellite data helped establish the first-order estimate, but validation through further sampling and chemical analysis is pending. Later studies should focus on revising the mineral maps and determining how the extraction processes have altered the local ecological and social conditions. Future studies may be improved with the inclusion of geological, geomorphological, and geochemical data along with band ratio analysis.

5. Implications for Future Research

The outcomes of this research have particular relevance in regard to their potential applications in the area of mineral extraction and resource management in the eastern region of Hunza, Pakistan. The discovery of ferric iron, kaolinite, gypsum, quartz, granite, carbonates, clay, and sulfates suggests the possibility of mining in the region and hence, there are eight different minerals in the study area. The extraction of these minerals would economically benefit the region's industrial development.

Results indicate that the minerals are not evenly distributed throughout the study region. This implies that further exploration and mapping will be required in order to determine the most economically viable extraction locations. This will aid in proper resource management and planning. This research serves as a reference in formulating policies and regulations concerning the management and exploitation of minerals in the eastern parts of Hunza, Pakistan. Moreover, this research could serve as a cornerstone for further research, for instance, on the impacts of mineral extraction on the surrounding environment. The study also tells something to those companies that, having the needed technology, wish to prospect and mine the region; it can assist them in knowing the amount of minerals and their concentrations in different places which may facilitate the planning of mineral production. To sum up, the research undertaken contributes to the mineral potential of the eastern parts of Hunza, Pakistan, and the region's resource future use and management.

References

Abrams, M., and Yamaguchi, Y., 2019. Twenty years of ASTER contributions to lithologic mapping and mineral exploration. Remote Sensing, 11(11), 1394.

Aita, S. K., and Omar, A. E., 2021. Exploration of uranium and mineral deposits using remote sensing data and GIS applications, Serbal area, Southwestern Sinai, Egypt. Arabian Journal of Geosciences, 14(21), Pp. 1-17.

Akbar, S., Abdolmaleki, M., Ghadernejad, S., and Esmaeili, K., 2024. Applying Knowledge-Based and Data-Driven Methods to Improve Ore Grade Control of Blast Hole Drill Cuttings Using Hyperspectral Imaging. Remote Sensing, 16(15), 2823.

Ali, A., Ahmad, S., Ahmad, S., AsifKhan, M., Khan, M. I., and Rehman, G., 2021. Tectonic framework of Northern Pakistan from Himalaya to Karakoram. Structural Geology and Tectonics Field Guidebook—Volume 1, Pp. 367-412.

Baig, S. S., Xue, C., Qureshi, J. A., Hussain, A., Alam, M., Khan, G., and Hussain, S. A., 2021. Fluid Inclusion Study Of Karakoram Metamorphic Complex Hunza Valley, Pakistan. Bahria University Research Journal of Earth Sciences, 6, Pp. 40-45.

Barak, S., Imamalipour, A., and Abedi, M., 2023. Application of fuzzy gamma operator for mineral prospectivity mapping, case study: Sonajil area. Journal of Mining and Environment, 14(3), Pp. 981-997.

Bishop, C. A., Liu, J. G., and Mason, P. J., 2011. Hyperspectral remote sensing for mineral exploration in Pulang, Yunnan Province, China. International Journal of Remote Sensing, 32(9), Pp. 2409-2426.

Bougrain, L., Gonzalez, M., Bouchot, V., Cassard, D., Lips, A. L., Alexandre, F., and Stein, G., 2003. Knowledge recovery for continental-scale mineral exploration by neural networks. Natural Resources Research, 12, Pp. 173-181.

Davies, R. S., Groves, D. I., Trench, A., Dentith, M., and Sykes, J. P., 2020. Appraisal of the USGS Three-Part Mineral Resource Assessment through estimation of the orogenic gold endowment of the Sandstone Greenstone Belt, Yilgarn Craton, Western Australia. Mineralium Deposita, 55(5), Pp. 1009-1028.

Gabr, S., Ghulam, A., and Kusky, T., 2010. Detecting areas of high-potential gold mineralization using ASTER data. Ore Geology Reviews, 38(1-2), Pp. 59-69.

Gielen, D., 2021. Critical minerals for the energy transition. International Renewable Energy Agency, Abu Dhabi.

Hanson CR, 1989. The northern suture in the Shigar Valley, Baltistan, northern Pakistan. In: Malinconico LLJ, Lillie RJ (eds) Tectonics of the Western Himalayas

Hassan, S., Arif, H., Batool, S., Amer, A., Aslam, M. R. M. S., and Talib, B., 2021. Novel Technique to Investig Hypsometry in Hunza Using Spatial Autocorrelation.

Hunt GR., 1977. Spectral signatures of particulate minerals, in the visible and near-infrared.

Hussain, A., Shah, M. T., Arif, M., Agheem, M. H., Mughal, M. S., Ullah, S., and Sadiq, I., 2021. Chemical composition of gemstones and characterization of their host pegmatites and country rocks from ChumarBakhoor, Gilgit-Baltistan, Pakistan: implications for the source of gem-forming fluids. Arabian Journal of Geosciences, 14(13), Pp. 1-15.

Jan, M.Q. and Gauhar, S.H., 2013. Earth Sciences and Mineral Exploration History of Pakistan with Reference to Khyber Pakhtunkhwa and Its Adjacent Tribal Areas. Abstract Volume, Sustainable Utilization of Natural Resources of the Khyber Pakhtunkhwa and FATA, February 11, Peshawar, Pakistan

Kaukab, I. S., Batool, S., and Mahmood, S. A., 2021. Trend Analysis of Polynomial Surfaces and Surface Dynamics (TAPS–SDs): A Paradigm from (MMT–NPHMZ) in the Northwestern Himalayas, Pakistan. Geotectonics, 55, Pp. 273-292.

Khan, A., Shitao, Z., and Khan, G., 2022. Comparative analysis and landslide susceptibility mapping of Hunza and Nagar Districts, Pakistan. Arabian Journal of Geosciences, 15(21), Pp. 1-21.

Laurs BM, Dilles JH, Wairrach Y, Kausar AB, Snee LW., 1998. Geological setting and petrogenesis of symmetrically zoned, miarolitic granitic pegmatites at StakNala, Nanga Parbat Haramosh Massif, Northern Pakistan

Liang, W., Garzanti, E., Andò, S., Gentile, P., and Resentini, A., 2021. minerals MDPI. Heavy Minerals, 153.

Marwat, S. U. K., and Faryal, A., 2022. Ecotourism and its socio-economic impact on Hunza Valley in Pakistan. Pakistan Languages and Humanities Review, 6(2), Pp. 1195-1204.

Miandad S, Shah MT, Khan SD, Ahmad L., 2014. Investigation for gold and base metals mineralization and petrochemical characteristics of the rocks of upper parts of Bagrot valley, Gilgit-Baltistan, Pakistan. J Himal Earth Sci 47(2): Pp. 29–48

Nwaila, G. T., Frimmel, H. E., Zhang, S. E., Bourdeau, J. E., Tolmay, L. C., Durrheim, R. J., and Ghorbani, Y., 2022. The minerals industry in the era of digital transition: An energy-efficient and environmentally conscious approach. Resources Policy, 78, 102851.

Ochola, K., 2021. Application of Geophysical Exploration Methods in Mapping Gold Mineralisation Zones. Case Study: Makina Prospect in the Busia-kakamega Greenstone Belt, Se Uganda (Doctoral dissertation, University of Nairobi).

Okada, K., 2022. Breakthrough technologies for mineral exploration. Mineral Economics, 35(3), Pp. 429-454.

Ourhzif, Z., Algouti, A., and Hadach, F., 2019. Lithological mapping using Landsat 8 OLI and ASTER multispectral data in Imini-Ounilla district south High Atlas of Marrakech. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42, Pp. 1255-1262.

Petterson, M. G., 2019. The plutonic crust of Kohistan and volcanic crust of Kohistan–Ladakh, north Pakistan/India: lessons learned for deep and shallow arc processes. Geological Society, London, Special Publications, 483(1), Pp. 123-164.

Pournamdari, M., Hashim, M., and Pour, A. B., 2014. Application of ASTER and Landsat TM Data for Geological Mapping of Esfandagheh Ophiolite Complex, Southern I ran. Resource Geology, 64(3), Pp. 233-246.

Qasim, M., Ali, S., and Aqeel, M., 2024. Geographic Diversity and Landscape in Transition: Analyzing the Physical Features of Gilgit Baltistan Region. Journal of Social Sciences Development, 3(2), Pp. 154-169.

Rajendran, S., and Nasir, S., 2019. ASTER capability in mapping of mineral resources of arid region: A review on mapping of mineral resources of the Sultanate of Oman. Ore Geology Reviews, 108, Pp. 33-53.

Ruban, D. A., Al-Husseini, M. I., and Iwasaki, Y., 2007. Review of Middle east Paleozoic plate tectonics. GeoArabia, 12(3), Pp. 35-56.

Sheikhrahimi, A., Pour, A. B., Pradhan, B., and Zoheir, B., 2019. Mapping hydrothermal alteration zones and lineaments associated with orogenic gold mineralization using ASTER data: A case study from the Sanandaj-Sirjan Zone, Iran. Advances in Space Research, 63(10), Pp. 3315-3332.

Smith, D. J., and Wentworth, J., 2022. Mining and the Sustainability of Metals. Parliamentar y Office of Science and Technology, UK Parliament, London.

Su, X., Zhang, Y., Meng, X., Rehman, M. U., Khalid, Z., and Yue, D., 2022. Updating inventory, deformation, and development characteristics of landslides in Hunza Valley, NW Karakoram, Pakistan by SBAS-InSAR. Remote Sensing, 14(19), 4907.

Yaseen, M., Ahmad, J., Anjum, M. N., Naseem, A. A., and Shah, S. T., 2024. Characterization and Quantification of Outcrops Exposed Along the Karakoram Highway (KKH) and Part of Central Karakoram National Park (CKNP), North Pakistan; Implications for Geoheritage Assessments and Geosite Recognition. Geoheritage, 16(4), Pp. 1-26.

Yousefi, M., Kreuzer, O. P., Nykänen, V., andHronsky, J. M., 2019. Exploration information systems–A proposal for the future use of GIS in mineral exploration targeting. Ore Geology Reviews, 111, 103005.

Zeitler PK, Chamberlain CP., 1991. Petrologic and tectonic significance of young leucogranites from the northwestern Himalaya, Pakistan

Zuo, R., Wang, J., and Yin, B., 2021. Visualization and interpretation of geochemical exploration data using GIS and machine learning methods. Applied Geochemistry, 134, 105111.