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Geospatial Mapping and Detection of Ferrous, Iron Oxides, and Clay Minerals in District Mohmand, Pakistan

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Abstract The study focuses on the utilization of remote sensing techniques to effectively identify and detect ferrous, iron oxides, and clay minerals in Mohmand district, Pakistan, using LANDSAT 8 multispectral images. This study focuses on the increasing demand and importance of these minerals in mining and commercial activities. Mineral exploration in Mohmand district, utilizing remote sensing technology to identify mineral compositions using the band ratio is done. This technique allows for a more focused and precise approach to exploration and extraction techniques. Cloud-free LANDSAT 8 images with minimal vegetation cover were utilized for the analysis. The band ratio approach was utilized to identify areas exhibiting diverse mineral compositions. The study highlights the effectiveness of the suggested methodology in mapping and detecting ferrous, iron oxides, and clay minerals, indicating the significant potential of remote sensing for mineral exploration. The results highlight the importance of developing distribution maps to support more efficient methods for mining and mineral exploration. The study contributes to a more focused and efficient assessment of mineral resources and extraction techniques in the Mohmand district and similar geological terrains, offering stakeholders a valuable tool for informed decision-making in mineral exploration and exploitation efforts.

Keywords: GIS, remote sensing, geology, landsat 8, band ratio.

Introduction

Mineral resources have the potential to make a substantial global contribution to socioeconomic development (Fadhili et al., 2002). The sustainable availability of mineral resources is essential for advanced economic development, urbanization, communication networks, and transportation (Akhtar, 2005). However, significant research and technological investment are needed for the sustainable exploitation of minerals and their discovery (Ahmad, 2019). At the regional level, the exploration and sustainable use of mineral resources is supported by the effective and efficient application of modern remote sensing and geographic information system (GIS) technologies (Krishna et al., 2019). To map and identify ferrous, iron oxide, and clay minerals in different locations, a variety of remote sensing techniques have been used. In the Hana district of Iran, ((Shirazi et al., 2018) discovered that the most accurate approach for mapping iron minerals was the Spectral Angle Mapper (SAM) method .

The Mohmand district is experiencing notable degradation of its land and ecosystem, which is a result of increasing human demand for its natural resources. The abundant natural resources of Mohmand have been vital to the region's economy and population (Ahmad, 2019). Unfortunately, numerous areas in the district have seen severe environmental and soil degradation as a result of their excessive utilization. This research aims to employ remote sensing techniques, specifically the analysis of LANDSAT 8 multispectral images, for mapping and identifying ferrous, iron oxides, and clay minerals in Mohmand district, Pakistan. The objective of the present study is to utilize the band ratio method to detect regions with different mineral compositions, specifically targeting areas with less vegetation and images that are free from clouds. The paper aims to showcase the significant capabilities of remote sensing in detecting minerals and offer stakeholders, a valuable tool for more efficient and focused mineral exploration and mining strategies in the Mohmand district and similar geological terrains.

Materials and Methods

Study Area

Mohmand district lies in Khyber Pakhtunkhwa province which covers an area of 2,296 sq km. It is located between Latitude: 34° 29' 59.99" N and Longitude: 71° 19' 60.00" E. It borders Afghanistan in the west, Bajur , Dir and Peshawar districts in north, east, and southeast, respectively (Fig. 1). Mohmand district is a region across the banks of the Kabul River that consists of rugged mountains with barren slopes.

Data Acquisition and Processing

The datasets used in this study included a variety of mineral-related data, including identification, potential zones, production rates, and topographic and geological characteristics of the study region. A thorough review of topographic, stratigraphic, and geological maps was conducted to guarantee maximum precision and best outcomes in the analysis of the designated area. Two multispectral remote sensing data types were employed, including Landsat-8 imagery and the Digital Elevation Model (DEM).

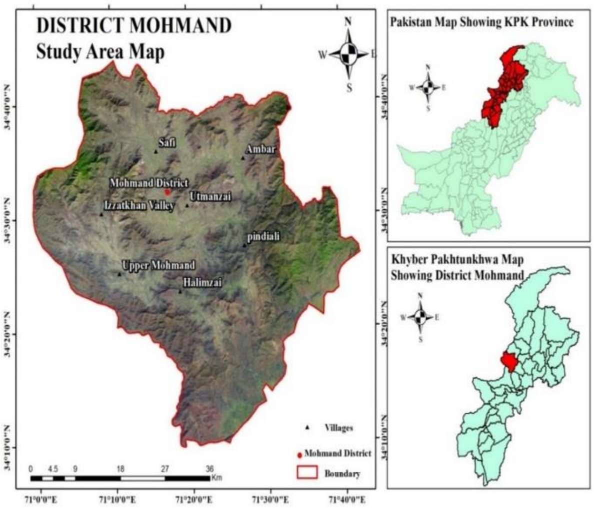

Fig 1. Location map of the study area.

Digital Elevation Model (DEM)

Digital elevation models are very helpful tools for determining many aspects of the terrain, such as aspect details, slope characteristics, and elevation profiles at certain locations (Pieczonka et al., 2011). DEMs are also essential for distinguishing specific features on the ground, like peaks, pits, drainage networks, drainage basins, watersheds, and other important landforms (Deilami & Hashim, 2011).

Band ratio is an information extraction method highlighting specific spectral differences by dividing one spectral band by another. This technique Band Ratio identifies the highest and lowest points in a reflectance curve, enhancing the visibility of elements or materials that might be invisible in raw bands (Tariq et al., 2019; Sabins, 1999).

Landsat-8

Landsat-8 images were utilized for digital image processing and interpretation since their spectral range is better suited for geological applications than those of other missions' output. This is because the spectral ranges of a particular band must encompass significant absorption mineral characteristics in the near-infrared (NIR) and short-wave infrared (SWIR).

RGB Combination

To enhance hydrothermally altered rocks and lithological units, RGB combinations of multispectral or thermal bands are used ((Pour and Hashim, 2015). Selected bands reflect mineral characteristics: silicates (10.30-11.70 μm), iron oxides and sulfates (strong red, low blue), and clays and carbonates (2.1-2.4 μm absorption, 1.55-1.75 μm reflectance).

Results and Discussion

Band Ratio

Band ratio analysis was used for the detection of ferrous, iron oxides, and clay minerals. The respective band ratio and their results are given below in Table 1.

Table 1. Tested band ratio for Landsat 8.

Band Ratio	Feature	Reference
Band 6/5	Ferrous Minerals	(Ullah et al., 2018)
Band 4/2	Iron Oxides	(Ullah et al., 2018); (Sabins, 1999)
Band 5/4	Clay Minerals	(Ullah et al., 2018)

Ferrous Minerals

Landsat-8 images were processed using a band ratio of 6/5 to cartographically represent ferrous minerals. Band 6 was simply divided by band 5 as part of the analytical process, which was carried out by using the raster calculator tool in the ArcGIS software. The zones that indicate the presence of ferrous minerals are shown in Figure 2.

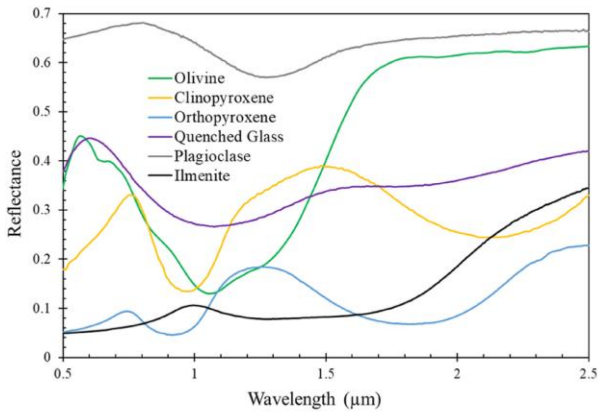

Fig. 2 Reflectance spectra of ferrous minerals illustrate the variation in spectral signatures across different wavelengths (Pour and Hashim, 2015).

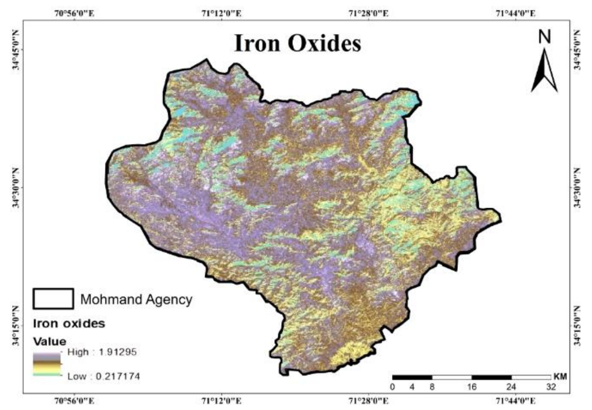

Fig. 3 Iron oxide-bearing zones are delineated on a geographic map, highlighting regions with elevated concentrations of Iron oxides.

Iron oxides

Iron oxides are chemical compounds made up of iron and oxygen, and were mapped using a band ratio technique, utilizing Landsat 8 imagery in particular. The process comprised using the raster calculator function to divide Band 4 by Band 2, which made it easier to map the iron oxides in the depicted geographical area as shown in Figure 3.

Clay Minerals

Clay minerals are layer silicates that typically form when other silicate minerals near the earth's surface weather chemically. Clay minerals are among the most significant and practical industrial minerals in the world. The study area's clay minerals are mapped using a band ratio of 5 to 4. To do this, Band 5 was divided over Band 4 using a raster calculator tool of the ArcGIS as shown in Figure 4.

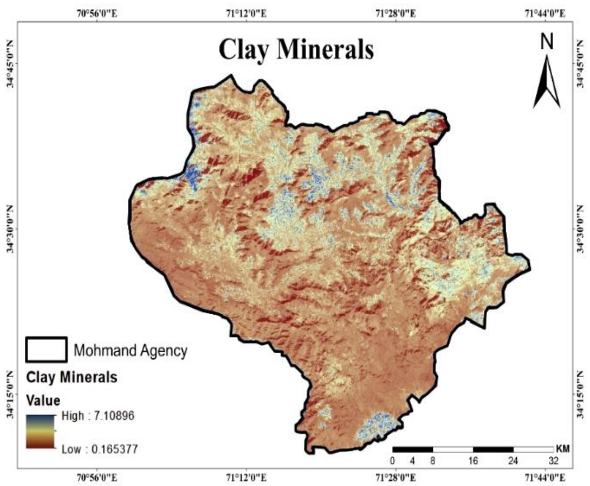

Fig. 4 Geographic distribution of clay mineral-bearing zones, highlighting areas characterized by significant concentrations of clay minerals.

RGB Combinations

Various RGB combinations were examined to identify unique lithological units using Landsat-8 data. Key combinations included: 2,5,7 and 6,5,7 for iron oxides and clay minerals (Tariq et al., 2019), 10,11,7 for silicate minerals (Pour & Hashim, 2015) and 6,7, 4 for lithological contrasts. As shown in Table 2 and Figures 5,6,7, and 8.

Table 2. Tested RGB combinations for Landsat 8.

RGB combinations	Features
RGB 6,7,4	Lithological Contrast
RGB 10,11,7	Silicate Minerals
RGB 2,5,7	Iron oxides
RGB 6,5,7	Clay Minerals

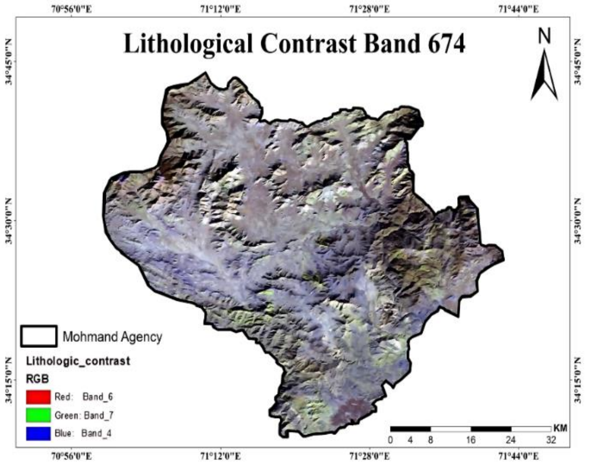

Fig. 5 RGB composite image for enhanced lithological contrast, utilizing Red, Green, and Blue bands to highlight geological variations and features. Band 6,7,4

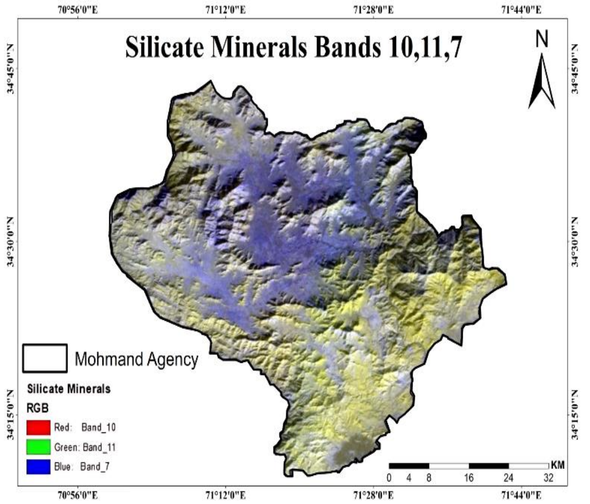

Fig. 6. RGB composite image highlighting silicate mineral occurrences, generated from Red, Green, and Blue spectral bands.

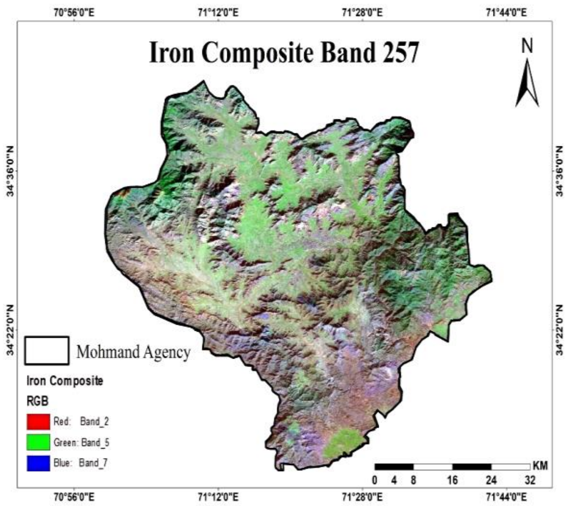

Fig. 7 RGB composite image illustrating ferrous mineral distributions, generated through the integration of Red, Green, and Blue spectral bands band 2, 5, 7.

Digital Elevation Model (DEM)

A digital elevation model (DEM) is a digital description of the topography of the Earth that emphasizes the bare ground aspect by eliminating objects like buildings, trees, and other surface objects. DEMs are derived by using a variety of data sources. DEM has proved helpful in this study's examination of several topographic features, including the creation of maps that depict the following elements:

Slope Map

The slope map shows the differences in the terrain's steepness or slope and provides information about the topographical relief as shown in Figure 9.

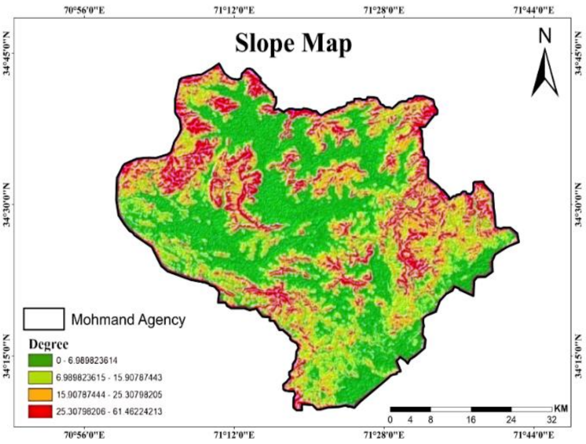

Fig. 9 Slope map showing the terrain characteristics of the study area.

Land Use/Land Cover Map

The LULC map offers a thorough overview of the distribution of various land use and land cover classes in the research region and provides insight into patterns of environmental features and human activities as shown in Figure 10.

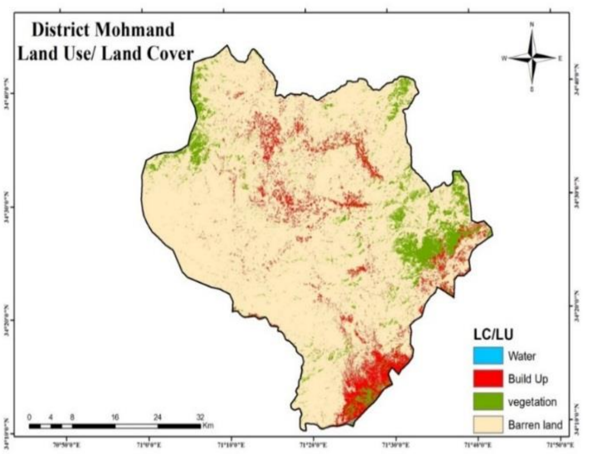

Fig. 10 Land use and land cover map displaying the spatial distribution of different land cover types within the study area.

Geology

The geological map, which was created using satellite imagery, shows the distribution of different rock types and geological formations, which simplifies the study area's geological context as shown Figure 11.

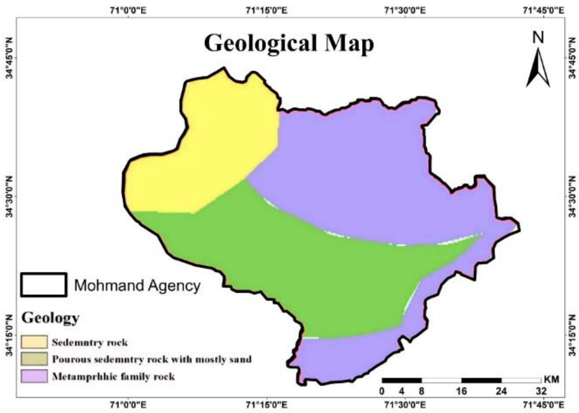

Fig. 11 Geological map presenting the distribution of geological formations and rock types within the study area.

Conclusion

The application of Geographic Information Systems (GIS) and Remote Sensing (RS) techniques has proven to be an effective approach for the assessment and management of natural resources, specifically mineral resources in the Mohmand district of Pakistan. This study successfully demonstrated the potential of these technologies in identifying and mapping ferrous iron oxides and clay minerals using cloud-free LANDSAT 8 multispectral images. The use of the band ratio technique allowed for the precise detection of mineral compositions in areas with minimal vegetation cover. The key findings of the study include the creation of distribution maps highlighting the spatial locations of significant mineral deposits. These maps are crucial for more efficient and targeted mineral exploration and extraction strategies. The results underscore the utility of remote sensing in providing a strategic framework for stakeholders involved in mineral exploration, enabling them to focus efforts on areas with high mineral potential. Moreover, the study offers a valuable methodology that can be applied in similar geological settings, thereby broadening the scope of mineral resource management and exploration. Integration of GIS and RS not only enhances the efficiency of mineral detection but also supports sustainable resource management practices by providing detailed and accurate geological information.

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