Copper-associated Mineral Mapping in Khetri Region using Sentinel-2A Data

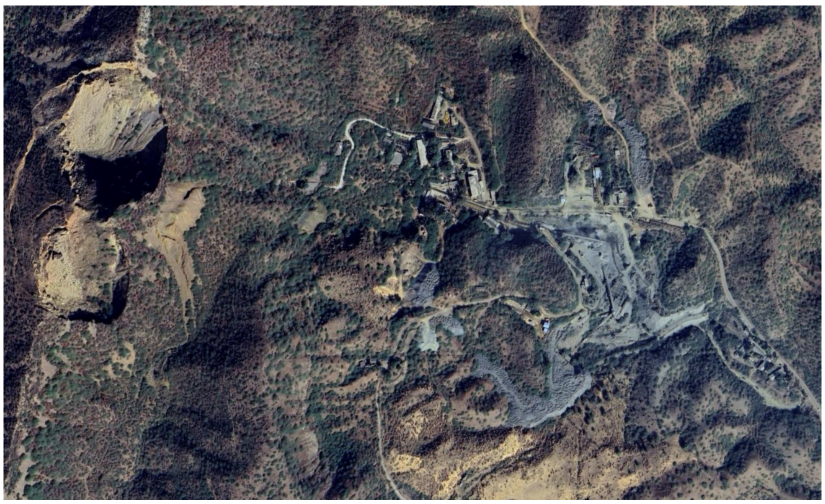
Introduction

Copper is one of the most economically significant metals, widely used in industrial applications and infrastructure development. The identification of copper-bearing minerals and associated alteration zones is crucial for exploration and sustainable resource management. The Khetri region in Rajasthan, India, is a well-known copper belt that hosts a number of active and historic copper mines, including the Kolihan mine. This study utilizes Sentinel-2A satellite imagery to conduct mineral abundance mapping and spectral analysis for copper exploration in the region. Sentinel-2A's multispectral capabilities, combined with efficient image processing tools such as QGIS, offer a cost-effective and accurate solution for remote mineral exploration.

The approach involves selective band utilization, spectral resampling of medium-resolution bands to high resolution, and computation of band ratios and spectral indices to highlight mineral signatures indicative of hydrothermal alteration. Specific indices were derived to identify clays, carbonates, and iron oxides, all of which serve as pathfinders for copper mineralization. The integration of these indices into a false color composite enhances the visualization and interpretation of mineral distribution across the study area.

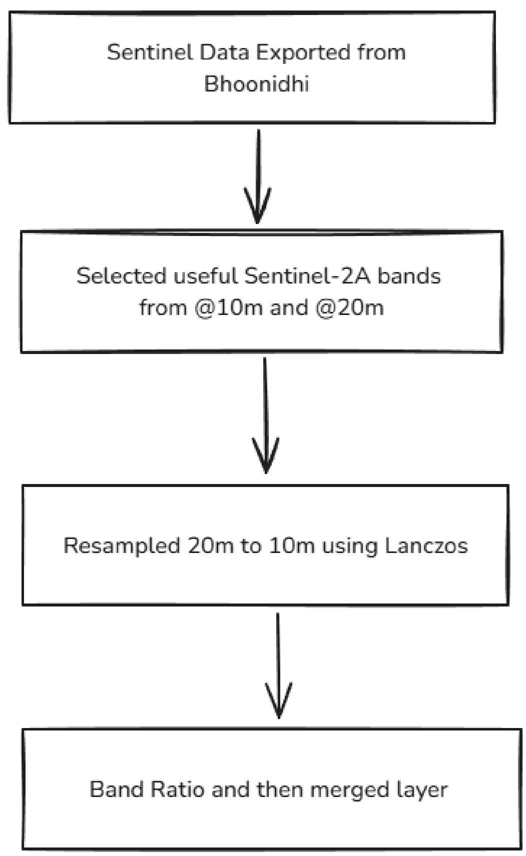
Study Area

The study was conducted in the Khetri region, located in the Jhunjhunu district of Rajasthan, India, renowned for its substantial copper deposits. This area forms a critical part of India's copper belt, characterized by significant mineralization predominantly within the Proterozoic Delhi Supergroup. The primary site chosen for mineral identification and mapping is the Kolihan mine, an active underground copper mining operation notable for its substantial production and geological complexity. Additionally, the area around the Copper Dam, situated adjacent to the Kolihan mine, was included to investigate mineral distribution in water-influenced terrains.



The Kolihan mine is particularly known for its mineralization of chalcopyrite, pyrite, bornite, and associated alteration minerals such as chlorite, epidote, sericite, kaolinite, illite, and carbonate minerals including calcite and dolomite. Surrounding areas host other significant mining sites, contributing to the region's reputation as a major copper-mining hub. These combined sites present a diversified geological environment, ideal for remote sensing-based mineral identification and abundance mapping utilizing Sentinel-2A satellite data.

Research Methodology

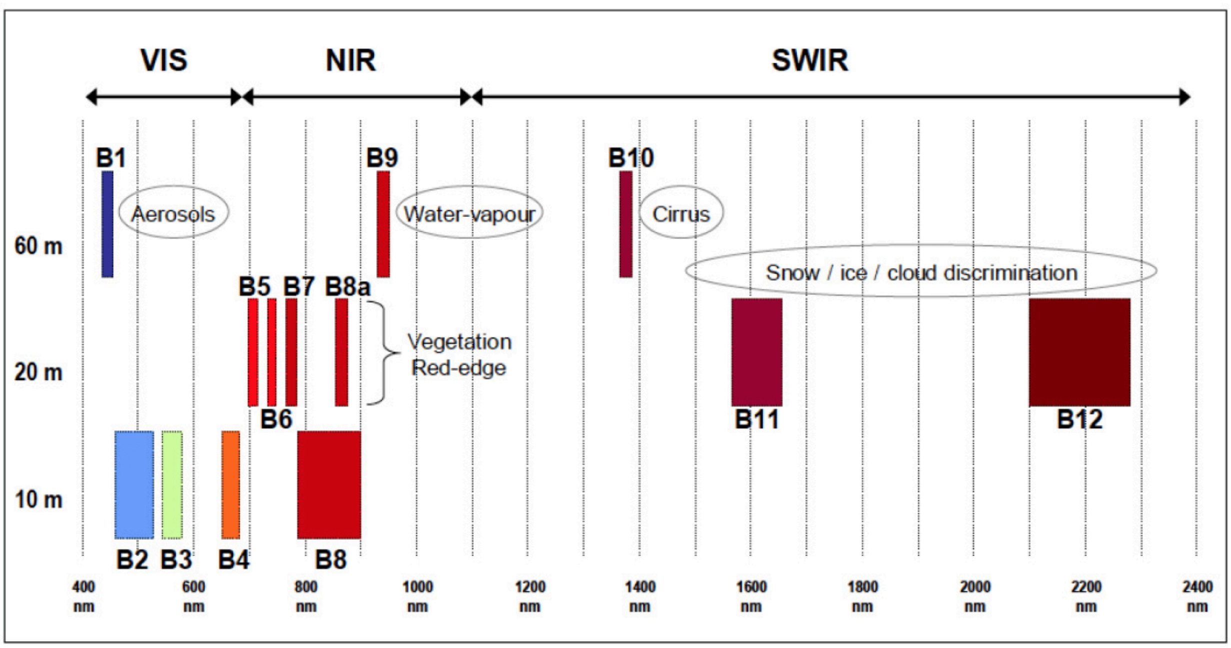


Data Used

The dataset utilized in this study was acquired from the open-source Bhuvan Bhoonidhi portal. Specifically, we employed the Sentinel-2A Multispectral Instrument (MSI) dataset, which comprises 13 spectral bands encompassing the visible spectrum, near-infrared (NIR), and shortwave infrared (SWIR) regions. Sentinel-2A MSI data are available in varying spatial resolutions of 10 meters, 20 meters, and 60 meters, facilitating detailed analyses across different spectral characteristics.

We selected the Sentinel-2A MSI Level-2A data due to its comprehensive preprocessing capabilities, including atmospheric corrections such as haze removal, water vapor compensation, and effective cloud masking. This preprocessing ensures reduced data preparation requirements, making the dataset immediately suitable for accurate and efficient mineral identification and mapping analyses.

Band Selection



For this study, we excluded bands B1 and B9 as they primarily serve for coastal aerosol and water vapor detection, respectively. Additionally, band B10 is not available at any spatial resolution in the dataset. Consequently, the analysis was conducted using bands B2, B3, B4, and B8 at 10-meter resolution and bands B5, B6, B7, B8a, B11, and B12 at 20-meter resolution. The 60-meter resolution bands were omitted since their primary function pertains to atmospheric corrections, which were already accounted for in the Level-2A preprocessing.

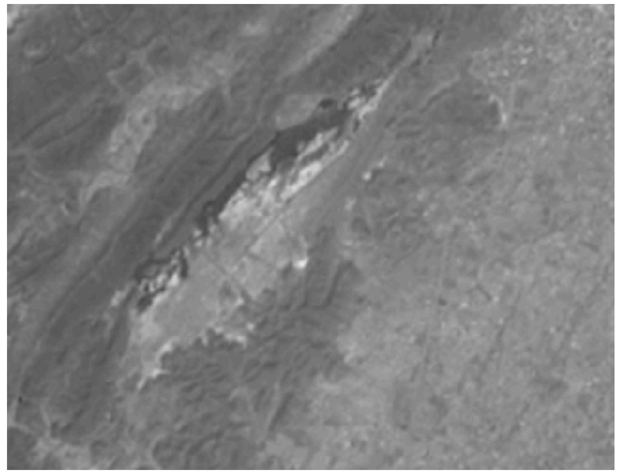
Band number	Function	Central wavelength	Bandwidth (nm)	Spatial resolution (m)
B1	Coastal aerosol	443	27	60
B2	Blue	490	98	10
B3	Green	560	45	10
B4	Red	665	38	10
B5	Red-edge	705	19	20
B6	Red-edge	740	18	20
B7	Red-edge	783	28	20
B8	NIR	842	145	10
B8a	Red-edge	865	33	20
B9	Water vapour	945	26	60
B10	SWIR	1380	75	60
B11	SWIR	1610	143	20
B12	SWIR	2190	242	20

Spectral Resampling

Bands B5, B6, B7, B8a, B11, and B12, originally available at 20-meter resolution, were resampled to 10-meter resolution to ensure uniformity across all selected bands for multispectral analysis. The Lanczos resampling algorithm was employed for this purpose due to its superior interpolation capabilities. Lanczos is a sinc function–based method that performs convolution over a windowed kernel, allowing for smoother transitions and improved edge preservation compared to traditional methods like nearest-neighbor, bilinear, or bicubic interpolation.

$$L(x) = \begin{cases} 1 & \text{if } \ x = 0 \\ \dfrac{a\sin(\pi x)\sin(\pi x/a)}{\pi^2 x^2} & \text{if } \ 0 < |x| < a \\ 0 & \text{otherwise} \end{cases}$$

Lanczos effectively minimizes aliasing and ringing artifacts, thereby maintaining spectral integrity and spatial precision—essential for accurate mineral mapping and classification. Post-resampling, a visibly smoother profile was observed across all enhanced bands, significantly improving image quality and consistency for subsequent processing and analysis steps.



B05 at 20m resolution **B05 after applying Lanczos converting to 10m**

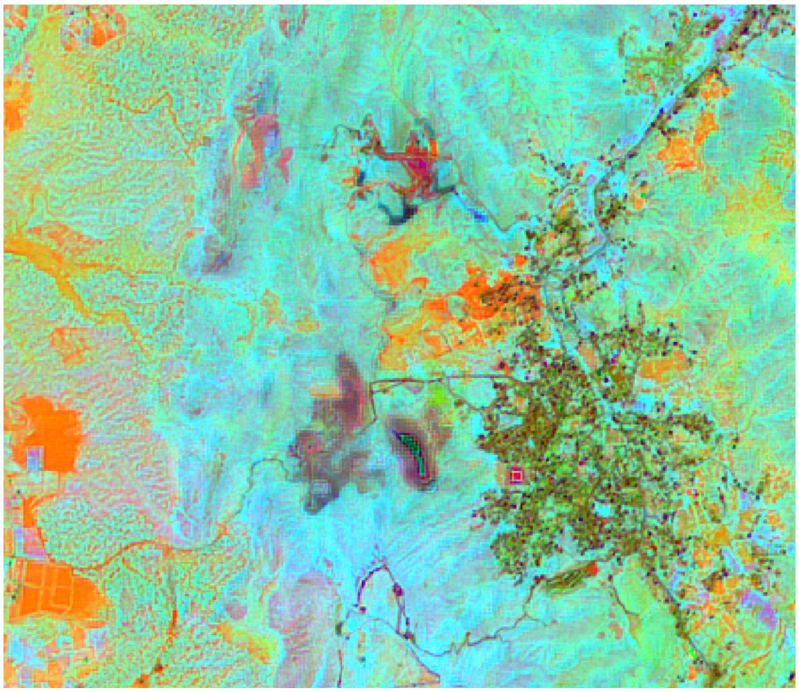
Band Ratio and Spectral Indices Analysis

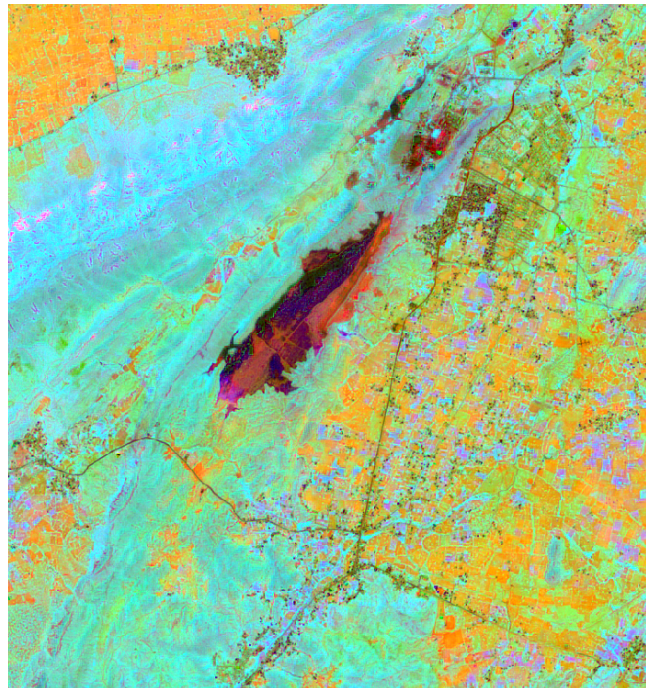
Based on insights from previous research and established spectral characteristics of alteration minerals, various band ratios and spectral indices were computed using the Raster Calculator in QGIS to enhance mineral discrimination.

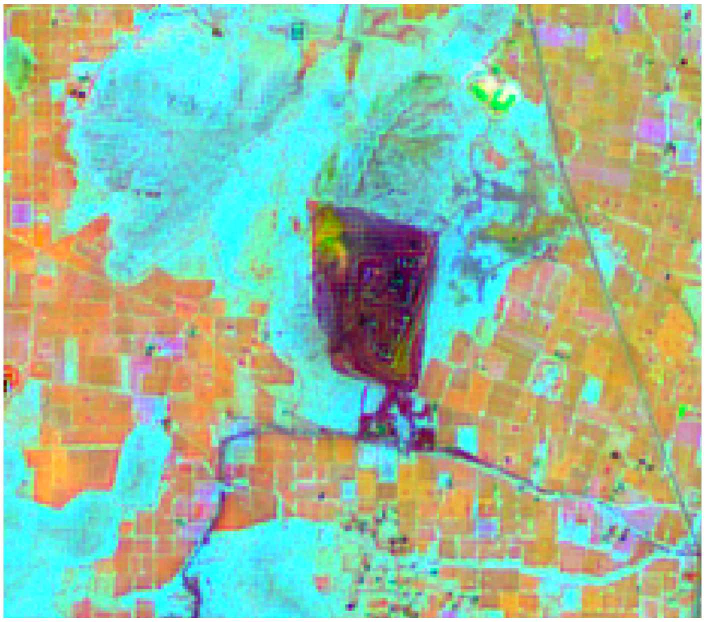
1. **Clay mineral (general)**
   a. $B11\ (SWIR1)\ /\ B12\ (\ SWIR2)$
   b. $(\ B11\ -\ B12\ )\ /\ (\ B11\ +\ B12\ )$ Clay Index
2. **Kaolnite and Al Rich Clays**
   a. $B12\ (SWIR2)\ /\ B8\ (NIR)$
3. **Carbonates(Calcite, Dolomite , Siderite)**
   a. $B11\ (SWIR1)\ /\ B4\ (red)$
   b. $(\ B11\ -\ B4\ )\ /\ (\ B11\ +\ B4\ )$ Normalized Difference Clay Index
4. **Iron Oxide (Hematite)**
   a. $B4\ /\ B2$
   b. $(\ B4\ -\ B2)\ /\ (\ B4\ +\ B2)$ Normalized Difference Iron Index

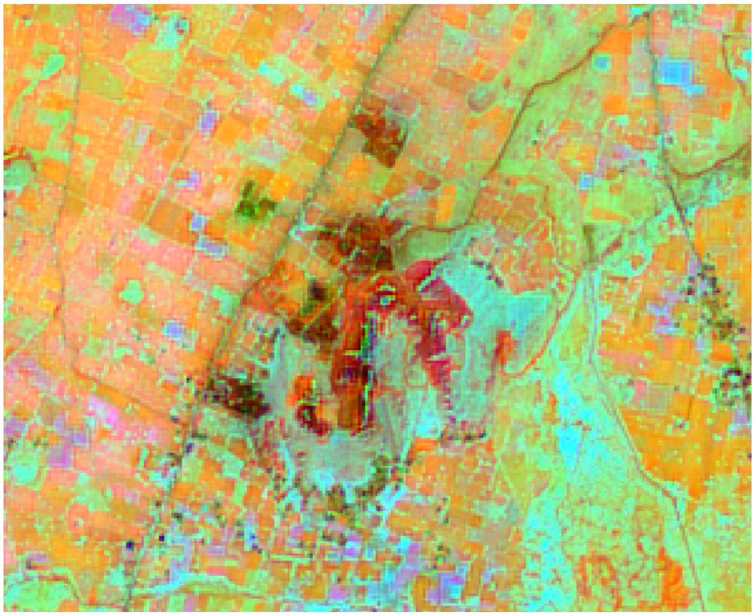
These indices helped differentiate zones enriched in clay, carbonate, and iron oxide minerals, which are crucial in identifying hydrothermal alteration and copper mineralization.

Visual inspection of the generated ratio layers revealed significant spatial variations corresponding to the above indices. To facilitate integrated interpretation, the key indices were merged into a single false color composite image using RGB band assignment: **Red for the Normalized Difference Iron Index (NDII), Green for the Carbonate Index (CI), and Blue for the Normalized Difference Clay Index (NDCI)**. This composite visualization enhances the identification of lithological variations and alteration zones, providing a comprehensive mineralogical perspective for copper exploration in the study area.









Conclusion

This study demonstrates the effectiveness of Sentinel-2A multispectral data for mineral mapping and copper exploration in the Khetri region of Rajasthan. By leveraging band ratio techniques and spectral indices within the QGIS platform, we successfully identified key mineral groups—clays, carbonates, and iron oxides—associated with hydrothermal alteration. The application of Lanczos resampling further ensured spatial consistency and spectral fidelity across all utilized bands.

The integration of various mineral indices into a composite visualization enabled clear differentiation of alteration zones, offering valuable insights into potential copper-bearing areas. This approach provides a replicable and cost-efficient methodology for remote mineral exploration, particularly in metallogenic provinces like Khetri where traditional field-based mapping is limited by scale and accessibility.