Lithological discrimination using ASTER and Hyperion data in Salem District, Tamil Nadu

Linda Theres B¹, Selvakumar R², Saranaathan S.E³

School of Civil Engineering, SASTRA Deemed to be University, Thanjavur, India
¹lindatheres@civil.sastra.ac.in, ²selvakumar@civil.sastra.edu, ³esaranathan@yahoo.co.in

Abstract— Lithological mapping is a crucial factor in identifying and mapping the spatial distribution of minerals. It aids in accurately defining the most promising primary prospects for local exploration. The differentiation of rock units across a wider region is likely to be attributed to remotely sensed satellite data. Therefore, the research focuses on utilizing remote sensing methods to create a geological map for a specific area in Salem district, Tamil Nadu, by employing HYPERION and ASTER satellite images. Various techniques, such as Band Ratio (BR), Spectral Angle Mapper (SAM), Minimum Noise Fraction (MNF), Mixture Tuned Mapped Filtering (MTMF), Spectral Feature Fitting (SFF), and Support Vector Machines (SVMs), are utilized to classify lithological units, which are crucial for data analysis. The outcomes of these methods will be compared to field-mapped geological boundaries to assess accuracy. In the final phase, a highly precise geological map is produced by combining remote sensing data with on-site investigations. The application of these approaches holds significant potential for enhancing geological mapping and mineral exploration in hard-to-reach areas.

Keywords— Remote Sensing, Hyperspectral, Multispectral, Lithology, ASTER, Hyperion

1 Introduction

Lithology mapping, or the mapping of different rock types in an area, is an important aspect of various fields such as geology, mineral exploration, and engineering. A better understanding of the distribution and properties of rock types can lead to improved resource management, more effective exploration and extraction of minerals, and improved engineering design [1]. For decades, Lithology mapping was done by collecting field observations and samples, analyzing the rock properties, and mapping the distribution of different rock types. This method has been used for centuries and has provided valuable information about the geological history and evolution of many areas. However, conventional field mapping is time-consuming, labor-intensive, and often limited to small
areas. In addition, access to some remote and difficult-to-reach areas may be limited, leading to incomplete data. The use of satellite data for lithology mapping, on the other hand, provides a more efficient and comprehensive way to map large areas [2]. This makes it possible to map remote and difficult-to-reach areas that would be challenging or impossible to access using conventional field mapping methods [3]. In addition, satellite data provides a synoptic view of the area, allowing for the detection of patterns and relationships that may not be apparent from field observations alone. Another advantage of using satellite data is that it can be combined with other data sources, such as topographic information, to provide a more complete understanding of the area [4]. Remote sensing data has been widely employed for identifying rock formations, mapping geological structures, and conducting mineral exploration. Several studies have utilized satellite data to study rock formations and mineral resources in an area [5-9]. The use of ASTER and Hyperion data for lithology mapping has been extensively studied in recent years [10-14].

The interpretation of satellite data to map geological features is typically based on observable surface characteristics [15]. The utilization of ASTER images has proven highly advantageous for enhancing geological maps due to ASTER's distinct spectral bands across the electromagnetic spectrum and the availability of diverse algorithms for image processing. Consequently, recent research has extensively employed ASTER data for geological mapping and distinguishing rock units [16]. In contrast, hyperspectral imaging has found application in various geological contexts since its inception in the 1970s. In recent times, geologists have developed multiple approaches to analyze hyperspectral data and extract valuable geological insights, such as lithological information, from remote sensing images [17]. The exceptional spectral resolution of hyperspectral remote sensing positions it as a valuable instrument for accurately recognizing and mapping surface materials. The numerous contiguous spectral bands within hyperspectral images can be leveraged to capture pixel spectra, facilitating the differentiation of minerals and rocks [18].

Salem, located in Tamil Nadu, presents an excellent setting for geological exploration due to its encompassing hills and scattered hillocks [19,20]. The objective of this investigation is to chart the various lithological components within Salem. To achieve this, the study employs ASTER and Hyperion remote sensing datasets along with a range of image processing methods, including band ratio and spectral angle mapping, to discern different lithological units. These techniques are deployed across both ASTER and Hyperion bands, using satellite images to map and differentiate rock formations in the designated study area. By amalgamating the outcomes from these image-processing approaches with on-site observations and existing geological maps, the research team effectively distinguishes between distinct rock units. The ultimate aim of this research is to extract the spatial arrangement of lithological units from the ASTER and Hyperion data, thereby facilitating fieldwork planning and the development of accurate geological maps.

2 Study Area

Salem District is located between latitudes 11° 14' and 12° 53' in the north and between longitudes 77° 44' and 78° 50' in the east. Salem, which is a part of Western Tamil Nadu, is situated at the foot of the Yercaud hills, a well-known tourist spot. Salem is surrounded by hills on all sides, including the Nagaramalai Hills to the north, the Shevaroy Hills to the northeast, the Jarugumalai Hills to the south, the Kanjamalai Hills to the west, and the Godumalai Hills to the east. The Kariyaperumal Hill is located towards the southwest of the city. The city is split into two sections by the Thirumanimuthar river. Salem is surrounded by hills and has hillocks scattered throughout the landscape, making it a geologist's heaven and hence the study aims to map lithology in Salem (Figure 1).
A significant portion of Tamil Nadu's mineral richness, according to the Department of Geology and Mining, is restricted to the Salem District, where a number of significant minerals, including Magnesite, Dunite, Bauxite, Limestone, Iron ore, Quartz, Feldspar and Soapstone, Granites, etc., are discovered. Salem District has 108 Black & Color granite quarries, 83 Major Mineral mines, and 35 Roughstone quarries. The greatest magnesite
deposits in India are in Salem. Here are mines owned by organizations like Dalmia and TANMAG. Rich mineral and bauxite reserves are also present. Implementation of conventional methods to map the lithology in such a mineral-rich area is time-consuming. Hence the study implements remote sensing methods to map the lithology of the Salem region using the available tiles of ASTER and Hyperion datasets. Figure 2 and 3 shows the footpath image of ASTER and Hyperion data respectively, where the red polygon feature is the Salem district region.

3 Data and Software

The research employs a pair of satellite datasets: ASTER and Hyperion. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), one of the five imaging instruments aboard the Terra satellite, which was launched in 1999 under NASA’s Earth Observing System, serves as a key component. ASTER is tasked with gathering comprehensive details at a relatively fine spatial resolution concerning elevation, surface temperature, emissivity, and reflectance. It acquires data across 14 distinct spectral bands, encompassing 3 bands in the visible spectrum and 11 in the infrared spectrum. Hyperion is a hyperspectral imager and has 220 bands with wavelengths between 400 and 2500 nm. The length of each scene is 42 km or 185 km. EO-1 Hyperion data of path 143 and row 51 was downloaded from the USGS Earth explorer website. The complete process flow from pre-processing of data to the final interpretation of lithology was performed in ENVI software.

4 Methodology

![Methodology Flowchart](image)

Fig. 4. Methodology Flowchart
The study aims to map the lithology of the Salem region under study using ASTER and Hyperion datasets and finally evaluate the interpreted results. The ASTER data is pre-processed followed by performing band ratio, Minimum noise fraction (MNF), Principal Component Analysis (PCA), and finally Classification using Spectral Angle Mapper (SAM) method. Hyperion dataset is also processed in a similar approach: Atmospheric and geometric correction, MNF, Pixel Purity Index (PPI), N-D visualizer, and finally SAM for classification. As the final step, the results from both datasets are compared with the existing geological map (Figure 4).

Mapping lithology using Hyperion dataset

The Hyperion dataset offers enhanced spatial resolution, enabling more precise mineral mapping. However, these datasets commonly encounter challenges due to atmospheric effects, which necessitates atmospheric correction for accurate analysis. This correction process is executed using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) module within the ENVI software [21]. Subsequently, the minimum noise fraction (MNF) transformation is employed to assess the intrinsic dimensionality of the image data, diminish noise within the data, and reduce computational demands for subsequent processing stages. Seven lower noise fraction images are derived, maximizing information content across various bands. These seven bands are subjected to further scrutiny to isolate the data's pure pixels. The pixel purity index is employed as a means to identify the most spectrally pure pixels within an image. To establish the region of interest (ROI) for the pixel purity index image, a minimum threshold of 5 is set, achieved through a comparison with a calibrated image, enhancing comprehension of the pure pixel positions. These identified pure pixels are subsequently utilized to select end members.

The n-Dimensional Visualizer offers an interactive approach to select end members within an n-dimensional space [18]. This method generates clusters of points in an n-dimensional coordinate system corresponding to the pixels identified through MNF components. It facilitates dynamic rotation of the data clusters, enabling users to observe spectral information from diverse viewpoints across various dimensions. This visualization presents distinct spectra (displayed in different colors) resembling end members, viewed from multiple orientations. The chosen classes are then extracted and applied to the designated region of interest (ROI) for subsequent spectral analysis as the final output.

The designated classes are assigned specific lithology units through the utilization of the Spectral Angle Mapper Classification (SAM) technique. SAM serves as an automated tool for direct comparison between object spectra and reference or end members, typically determined in a laboratory or field using a spectrometer. This method treats all spectra, both known and unknown, as vectors, measuring the angular difference between their spectra. This quantifies the spectral resemblance between the reference reflection's spectrum (ASD spectrum) and the image's spectrum (test spectrum). SAM yields an angular discrepancy measured in radians, ranging from zero to π/2, which offers a qualitative estimation of similarity between the image's spectrum and the ASD spectrum [22]. Lower values indicate higher spectral similarities between image and ASD spectra, while larger angles signify diminished comparability. The outcome of the SAM classification is an image indicating the optimal match at each pixel.

Lithology mapping with ASTER dataset

The initial processing steps for ASTER data involve several actions, including the elimination of crosstalk effects, re-sampling, stacking, radiometric standardization, and atmospheric correction [23]. Crosstalk correction was executed on ASTER's SWIR bands to eliminate the impact of energy spillage from band four into bands five and nine. Atmospheric correction was carried out using the FLASH module within ENVI. The study employed Level 2 ASTER Data, which constitutes radiometrically corrected data. For effective lithological mapping, the Band Ratio (BR) technique is a key and suitable
The selection of specific bands depends on their spectral reflectance and the locations of absorption bands of the minerals being mapped. The ASTER image's band ratios (4/7, 3/4, 2/1 as RGB) were chosen to map lithological units such as metasediments, volcaniclastics, and granitoids. In order to distinguish alkali granites, BRs (8/5, 5/4, 7/8 as RGB) were employed. Similarly, for the mapping of gneiss domes and granites, BRs (7/6, 6/5, 6/4 as RGB) were utilized. The resultant data was then stacked in layers using the ENVI software.

The ASTER data underwent further processing through MNF to extract data free from noise. An inverted MNF transformation was applied using a selective spectrum subset, which retained only the relevant bands while smoothing out the noisy bands. Subsequently, Principal Component Analysis (PCA) was employed to eliminate redundant spectral data from the multiband datasets. PCA is utilized in remote sensing to condense a larger dataset of multiple bands while preserving the majority of the original spectral information. This produces a set of uncorrelated image bands referred to as PC bands. The PCA-transformed PC bands were subjected to the SAM classification algorithm. Ultimately, the outputs of SAM classification and the band ratio technique were combined to generate a comprehensive mapping of the final lithological units.

Validation of classification results

Conventional field mapping provides detailed information about rock properties and is useful for studying small areas or specific features. However, the use of satellite data provides a more efficient and comprehensive way to map large areas and can be combined with other data sources to provide a more complete understanding of the area. Both methods can complement each other and provide valuable information for understanding the lithological units. Hence the prime approach is to check the classified results through a field visit. This is merely a qualitative assessment of the output. In order to evaluate the classified outputs quantitatively image-to-image comparison is performed with the existing maps.

5 Results and Discussion

Mapping Charnockite and Gneiss from Hyperion data

From the SAM output image of Hyperion data, the spectral plot is obtained. Each spectra line shown in the plot graph with different colours shows spectra of different materials. We referred a lithological map of Salem to see the different kind of lithological forms found there. The major rock types found in these regions were gneiss rock and charnockite rock. The laboratory spectra of gneiss and charnockite were obtained from reference [24] and [25] respectively. The spectral plots of both rock types were shown in figures 5 and 6. Then the laboratory/experimental spectra were compared with the SAM plot of Hyperion data. The spectra of the study area obtained from the SAM plot is shown in figure 7. Not all the lines in the SAM plot are related to rock types. Some represent rock types others represent urban areas, water bodies, and other solid forms. We related only the spectral lines which look closer to the laboratory spectra we have collected and identify the rock types.

From observing the above spectral plots, it is found that the spectra of charnockite and spectra of gneiss rock types are found in the SAM plot approximately. The lack of accuracy may be due to the minor improper atmospheric correction. However, the spectra almost match the respective rock types. Hence while observing the SAM output image the colors corresponding to the spectra similar to the spectra of charnockite and gneiss rock types can be classified. The interpreted rocks are mapped as shown in figure 8 and it was observed that gneiss units are predominant in the area under study.
Fig. 5. Laboratory spectra of gneiss rock type

Fig. 6. Laboratory spectra of charnockite rock

Fig. 7. SAM plot of the processed satellite data
The results of SAM classification in ASTER data gave us the following spectral profiles showing different rock materials. By referring to the lithological map of Salem, different kinds of lithological forms were determined. Some of them include Laterite, Siderite-Ankerite gneiss, Magnetite Quartzite, Charnockite, Biotite gneiss, Amphibolite, Pdp, and so on. But on a wide scale of classification, the study area consists mainly of charnockite and gneiss-type lithological forms. This observation also conforms with the classified output from the Hyperion dataset. The procedure was like mapping from Hyperion. The available spectra is compared with the spectral profile from ASTER data (figures 9 and 10) to map the resultant lithology features as shown in figure 11. The map shows that the spatial distribution of charnockite and gneiss matches almost perfectly as seen in the map from the Hyperion dataset.
Evaluation of results

The classified outputs were tested for their correctness using two approaches. The first approach was a field visit. This provided a vague picture of how accurate the classified outputs are. The second approach was to compare the resultant maps with the existing geological map. The image-to-image comparison was performed in the python environment. Relating to the geologic map taken for reference, rocks cannot be extracted with 100 percent accuracy from both ASTER and Hyperion satellites. The classification results of this
Hyperion dataset accept an average 73 percent matching accuracy and ASTER has 69 percent accuracy. The comparative results between the Hyperion and ASTER-generated maps gave a 9.4 percentage difference in their accuracy with the existing map. In conclusion, both Hyperion data and ASTER data are suitable for lithological mapping and accurate maps can be generated by applying the best available techniques.

6 Conclusion

The ultimate objective of our project is to find the lithology of an area using remote sensing. The outcomes demonstrate that Hyperion and ASTER data provide mostly similar results. Due to the occurrence of more SWIR and thermal bands, the Hyperion and ASTER images can accomplish improved lithologic mapping compared to other satellites. While the classifications suggest the fact that Hyperion data provides improved precision than that of ASTER data, the lithological data derived from ASTER image is largely analogous to the data from Hyperion. On top of this, the ASTER radar takes much greater spatial coverage compared with hyperspectral instruments, while ASTER data's cost is almost nil. Typically, hyperspectral devices take a small range (e.g. 7.6 km for Hyperion), and only scarce areas on the Planet have been pictured by Hyperion. ASTER data is thus appropriate for using it in lithological and mineralogical mapping in wider and more assorted areas, especially where data on Hyperion or other hyperspectral airborne data are not available.

References


