

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2021; 3(2): 08-15
Received: 18-04-2021
Accepted: 05-06-2021

Ajay Kumar Sharma
Research Scholar, Department
of Earth Science, Barkatullah
University, Bhopal, Madhya
Pradesh, India

Dr. Jyoti Sarup
Professor, Department of Civil
Engineering, MANIT, Bhopal,
Madhya Pradesh, India

Dr. DC Gupta
HOD & Professor, Dept. of
Earth Science, Barkatullah
University, Bhopal, Madhya
Pradesh, India

Corresponding Author:
Ajay Kumar Sharma
Research Scholar, Department
of Earth Science, Barkatullah
University, Bhopal, Madhya
Pradesh, India

Hyperspectral image processing to evaluate the mineral resources in and around Kajali Dongri, Jhabua district Madhya Pradesh

Ajay Kumar Sharma, Dr. Jyoti Sarup and Dr. DC Gupta

Abstract

Mineral exploration and geological mapping through conventional geological techniques are tedious, expensive and time-consuming. Mapping and targeting an economic deposit through traditional techniques involves extensive fieldwork, structural mapping, study of landforms, petrography, mineralogy and geochemical analyses. These techniques need a strong laboratory database to discern slight variation in composition of ore grades. With the advent of multispectral sensors (e.g. ASTER, Landsat) having bands in the Shortwave Infrared (SWIR) and Thermal Infra-Red (TIR) regions, lithological discrimination and mineral potential mapping were possible from space/airborne platforms. However, detailed understanding on precise mineral composition and relative abundance of constituents within Field of View (FOV) was not possible with these data due to coarse bandwidth and poor spectral contiguity. However, when spectroscopy, radiometry and imaging techniques were bundled as imaging spectroscopy, limitations of multispectral remote sensing were overcome.

Keywords: Mineral exploration, hyperspectral image analysis, kajali dongri

Introduction

Remote Sensing has become an important and effective aiding tool in mineral exploration. Earliest use of Remote Sensing techniques (visual interpretation) for mineral exploration started with Aerial photography, and then came space photography followed by aerial and space multispectral scanning. Remote Sensing techniques, generally used now-days includes analysis of various types of air and space born photography and multispectral scanner imagery; Hyperspectral Imagery.

Hyperspectral Remote Sensing (HRS) is that the technology which will provide detailed spectral information from every pixel in a picture. Hyperspectral Remote Sensing technology provides spatial and spectral information simultaneously, improving understanding of the remote environment. It enables accurate identification of both targets and phenomena because the spectral information is presented on a spatial instead of point (pixel) basis

Hyperspectral Remote Sensing technology is well accepted in remote sensing as a tool for several applications, like in geology, ecology, geomorphology, atmospheric, etc. especially for cases during which other remote sensing means have failed or are incapable of obtaining additional information. The Hyperspectral sensors are capable of acquiring images in 100–200 contiguous spectral bands. This ability to acquire laboratory-like spectra from an air/space borne sensor is a major breakthrough in remote sensing. As a result, hyperspectral sensors provide a unique combination of both spatially and spectrally contiguous images that allow precise identification of minerals. Over the last two decades, mineral mapping and lithological discrimination using airborne hyperspectral sensors like AVIRIS, HYDICE, DAIS, Hy MAP have been extensively attempted.

Methodology and Results

Geological mapping methods have been undergoing continuous change along with technological and scientific advances in other relevant fields. Remote sensing techniques are now being increasingly used to prepare geological information on which further detailed work is based. The district Jhabua can be divided into two geological units' namely Archaean rock and Cretaceous Deccan Traps. Archaean rocks represented by Granite gneiss, Quartzite, Granite, Phyllite, Schist and Dolomite, limestone are overlain by Bagh sandstones and Basalt of cretaceous age. Geological succession of the study area is shown in Table 1.

Table 1: Geological Succession

| System | Litho Stratigraphic Unit | Lithology |
|----------------------|--------------------------|--|
| Recent | - | Alluvial soil & lateritic |
| Cretaceous To Eocene | Deccan traps | Basalt lava flows with intertrapean clay & calcareous beds |
| Cretaceous To Eocene | Lametas & Bagh beds | Limestone & Sandstone |
| - | Intrusives | Pegmatites, Quartz veins & basic dykes |
| Archaeans | Aravalli Super groups | Granite gneiss, Dolomitic limestone quartzite Quartzite & dolomite Chlorite schist & Phyllites |

The blue and violet amphiboles commonly labeled "Winchite" are heavily zoned and the following amphiboles have been identified from these crystals, Tremolite, Manganoan² Cumingtonite, Magnesio-Arfvedsonite, Manganoan Eckermannite and Magnisioriebeckite in addition to Winchite. In Jhabua district, manganese ores are associated with Quartzites traversing the Phyllites and Dolomitic Limestones of Aravalli system. The chief ore minerals are Braunite with some psilomelane, pyrolusite and hollandite. The major occurrences are at Tumdia, Mandli and Rampura. In Bilaspur district, low grade manganese ores comprising Pyrolusite, Psilomelane, manganite and wad.

The district offers a host of igneous rocks and minerals at the surface, many of which are difficult to identify visually. A strategy utilizing regional targeting with Hyperspectral data to optimize field mapping followed by collection of field spectra using Spectroradiometer with Hyperspectral imaging (HSI) data will be adopted. Hyperspectral maps show good correspondence with the results of field reconnaissance verification and spectral measurements acquired using an ASD field spectrometer. Analysis of Hyperion (satellite-based) Hyperspectral data indicates that good mapping results can be achieved from satellite altitudes. These examples illustrate the high potential of Hyperspectral remote sensing for geologic mapping and mineral exploration. Comprehensive mapping of the mineral composition of the Earth's surface, at village level is of value for a range of geosciences applications from mineral and petroleum exploration through to soil characterization. This paper will discuss the use of hyper spectral imagery for mapping mineral resources in and around Kajali Dongari village in Jhabua district of M.P. The accuracy of the methodology will be verified through ground truthing using Analytical Spectral Device (ASD) Field Spectroradiometer. Hyperspectral space borne imaging spectrometers have been developed to measure the solar reflected upwelling radiance spectrum from ~400 to ~2500 nm at 5 to 10 nm resolution. The objectives of these imaging spectrometers are to use the molecular absorptions and constituent scattering characteristics expressed in the spectrum (Pantazis *et al.*, 1998) to detect and identify the surface and atmospheric constituents present. Hyperspectral imageries are also used to assess and measure the expressed constituent concentrations, assign proportions to constituents in mixed spatial elements, delineate spatial distribution of the constituents, monitor changes in constituents through periodic data acquisitions and to validate, constrain and improve models.

High spectral resolution allows identification of materials in the scene, while high spatial resolution locates those materials (Gross and Schott, 1998). Hence, Hyperspectral data have enormous potential in target detection, high quality mapping, material mapping and identification. These

high spectral resolution sensors are useful for various applications as in mineralogy, agriculture, physics, and surveillance. Hyperspectral sensors look at objects using a vast portion of the electromagnetic spectrum. Certain objects leave unique 'fingerprints' across the electromagnetic spectrum. These 'fingerprints' are known as spectral signatures and enable identification of the materials that make up a scanned object. Hyperspectral imaging can also take advantage of the spatial relationships among the different spectra in a neighbourhood allowing more elaborate spectral-spatial models for a more accurate segmentation and classification of the image. Hyperspectral imaging sensors are not immune to the effects of the intervening atmosphere since the various atmospheric constituents attenuate the incident and upwelling reflectance and finally degrade the signal corresponding to the feature being sensed. The atmospheric correction refers to the removal of unwanted atmospheric components of the measured radiance and for which appropriate radiative transfer models should be used.

The Hyperspectral sensors provide information over a wide spectrum and hence can be effectively used for the various applications like mineralogy, agriculture, physics, surveillance etc. This study will demonstrate the use of spectral indices to target diagnostic reflectance absorption features associated with mineral abundances, composition and variations. This work is an attempt to use this technique of segmentation and classification of image in mineral mapping over Kajali Dongari village of Jhabua district in Madhya Pradesh and accuracy of the mapping will be verified by using ASD spectro Radiometer.

Following materials and instruments have been used in the research project;

- Survey of India Toposheet
- Hyperspectral image of Hyperion Sensor
- Garmin Etrex H handheld Global Positioning System(GPS) instrument
- ASD spectro-radiometer
- ENVI 5.x
- ArcGIS 9.x

The methodology of this study was divided into following steps

- Acquisition of Hyperspectral data, Toposheet, Hand held GPS
- Processing and Analysis of Hyperspectral data
- Mineral mapping of study area
- Reconnaissance survey and field varification
- Analysis of ASD spectra of field sample data with ENVI library
- Classification of Hyperspectral data
- Model generation

Acquisition of Toposheet, handheld GPS and Hyperspectral data

In this study, Survey of India (SOI) Toposheet number (45J/5) of Madhya Pradesh on 1:50,000 scale was used for base information, contours and field verification. This was acquired from SOI Bhopal as shown in Figure 1.

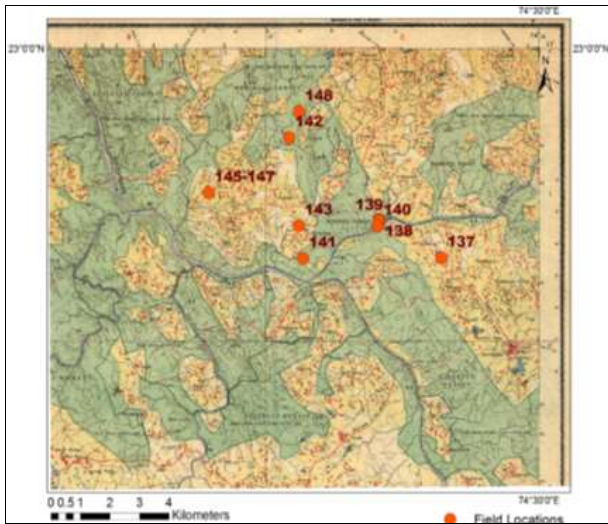


Fig 1: SOI Toposheet

The hand held GPS of Garmin was purchased for collecting the GPS locations in the field as shown in Figure 2.



Fig 2: Garmin etrex Hand held GPS Instrument

In this study Hyperion sensor data of EO-1 satellite was downloaded for Hyperspectral analysis. The National Aeronautics and Space Administration (NASA) EO-1 satellite was launched on November 21, 2000 as part of a one-year technology validation/demonstration mission. The EO-1 comprehensive Mission is chartered to accumulate and distribute ALI (Advanced Land Imager) multispectral and Hyperion hyperspectral products in response to Data Acquisition Requests (DARs) (source: EO-1 website). A DAR allows a customer to provide the information necessary to schedule an acquisition over his/her area of interest.

Hyperion data was used for analysis of Hyperspectral activity. Hyperion data downloaded from Glovis USGS web server by means of DAR. Hyperion data of 28 October 2015 was used in this study. Data was Level 1 processed and Geographic Tagged Image File Format (Geo TIFF), written as band sequential (BSQ) files stored in 16-bit signed with zero percent cloud. Hyperion data has characteristics as

spatial resolution is 30 meter, swath is 7.5, and spectral channels are 220 unique channels. VNIR (70 channels, 356 nm - 1058 nm), SWIR (172 channels, 852 nm - 2577 nm), spectral bandwidth is 10nm and digitization 12 bit. Geographical location of the data is 22° 56' 24"N and 74° 27' 36"E (centre location).

Exelis Visual information Solution (Exelis VIS) provides software for the study and visualization of scientific data and imagery. The company develops product such IDL, ENVI and IAS which are used in a variety of industries, including remote sensing, engineering, geology, aerospace, defense and intelligence, and medical imaging (source: wiki). ENVI 5.x was used in this research project for analysis of Hyperspectral image, resample of ASD spectra with ENVI libraries, matching of spectra and mapping.

ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analysing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database. In this project ArcGIS was used for import GPS coordinate on the toposheet, overlaying and creating maps.

The View Spec™ application was used for post-processing spectra files that were saved using an ASD instrument. Export the spectra in form American Standard Code for Information Interchange (ASCII) format and jpg format and convert it in user defined library in ENVI software.

Processing and Analysis of Hyperspectral Data

Following steps were adopted for analysis and computation of Hyperion data in this research. Steps which is taken to achieve the target is shown in Figure 3. Hyperion sensor data was taken as a Hyperspectral imager, Data was Level 1 processed and Geographic Tagged Image File Format (Geo TIFF). Level 1 Geo TIFF file format is radiometrically and geometrically corrected but not atmospherically corrected so it has to be pre-processes.

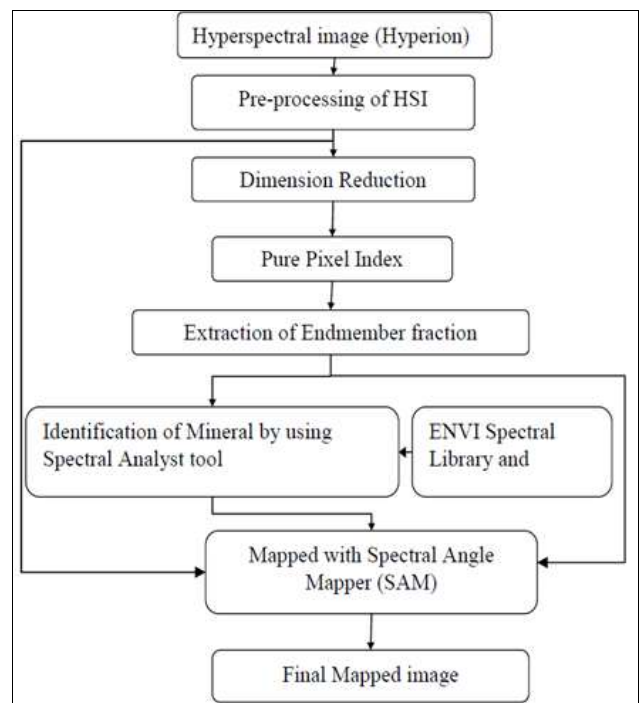


Fig 3: Process Flow

Pre-processing of Hyperion data

- Bad band removal
- Atmospheric correction

To remove bad bands, it only need deselect these bands in the header info of image. Numbers of bad bands are given by different-2 research references which are showing in the Table 2.

Table 2: Number of bad bands in Hyperion data

| References | Bad Band |
|--|--|
| Bisun Datt, Tim R. <i>et al.</i> 2003 ^[2] | 1-7, 58-76,22-242 |
| P. Jarecke, P. Barry, <i>et al.</i> 2001 | 121-126, 167-180, 222-242 |
| ENVI 5.X | 1-10, 50-93, 114-135, 163-194, 224-242 |

After analysis of above references, the total numbers of bad bands are 1-7, 58-76, 121- 126, 167-180, and 222-242.

These two basic steps consisting to atmospheric correction.

- Converting Hyperion level 1 data to radiance
- Atmospheric correcting or removing the envelope convert from radiance to reflectance

Converting Hyperion level 1 data to radiance

Hyperion level 1 data are in units of W/m² micron SR, for conversion from data to radiance it's multiply the scaling factor by 40 for the VNIR and 80 for the SWIR. But the Fast Line of sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) atmospheric correction tool uses units of micro W/cm² nm SR so the scaling factors used in FLAASH should be 400 for the VNIR and 800 for the SWIR because there is an extra factor of 10 when using FLAASH.

Atmospheric correcting or removing the envelope converts from radiance to reflectance

Atmospherically correct or remove envelope from Hyperion radiance data to create reflectance data using FLAASH. FLAASH is a MODTRAN-based "atmospheric correction" software package which is being developed by the Air Force Phillips Laboratory, Hans com AFB and Spectral Sciences, Inc. to support current and planned IR visible- UV hyperspectral and multispectral sensors.

The main objectives are to provide

- (1) Accurate, physics-based derivation of surface and atmospheric properties (such as surface albedo, surface altitude, water vapor column, aerosol and cloud optical depths, surface and atmospheric temperatures),
- (2) Minimal computation time requirements,
- (3) Interactive, user-friendly interface for running arbitrary MODTRAN calculations,

FLAASH is written in the Interactive Data Language (IDL) (Research Systems, Inc., Boulder, CO) for compatibility with a wide variety of computer platforms and to facilitate its use with IDL-based display/analysis software such as ENVI.

Input data should be a radiance data file because of FLAASH tool for conversion from radiance to reflectance. FLAASH is need following parameters should be known. All values can be getting from. Meta file and Hyperion data users file.

Dimension Reduction and PPI

HSI data have 242 bands, after removal of bad bands, only 196 bands have the information. The Minimum Noise Fraction (MNF) Transform takes linear combinations of the

input data to produce new, uncorrelated components ordered in terms of increasing signal-to-noise ratio. The MNF transform produces a set of principal component images ordered in terms of decreasing signal quality. This method was developed specially for analysis of multispectral and Hyperspectral remote sensing data. The MNF transform has the appealing property of sorting its components in descending order of SNR according to image quality, thus it might be possible to tune the amount of noise in the reconstructed data by setting an ad-hoc threshold. It can be used for noise filtering. 196 bands of data have information but after apply atmospheric correction for conversion from radiance value to reflectance, some bands have negative, zero and same standard deviation values, that bands should be remove because they does not carry any relevant information. So after removal those 155 bands remain, which have reflectance value. MNF transform technique was applied to 155 bands for image dimension reduction, and reduced it up to 13 bands out of 155 bands. MNF dimension reduction data were taken for PPI calculation.

Pure pixel index (PPI) is one of the most popular EFA, which is developed by Boardman *et al.* Pure pixel Index is used in multi bands image for analysis of End members extraction. By ENVI software, it can be easily calculated. PPI was designed to search for a set of vertices of a convex geometry in a given data set that are supposed to represent pure signatures present in the data. Figure 4 shows the PPI image with interested field locations. In the figure 5, the brightest location is purest pixel, which indicates that bright pixel location given to pure material spectra. Figure 5 shows an image with two ROIs, where red color is for Psilomelane and green color is for Muscovite. ROIs created by simulating Hyperspectral data and PPI data. 42 pixels and 6 pixels have been included in Psilomelane ROI and Muscovite ROI respectively.

Spectral library

ENVI offers predefined spectral library for identification of minerals and vegetation type. Researchers at the Spectroscopy Lab have measured the spectral reflectance of hundreds of materials in the lab, and have compiled a spectral library. The libraries are used as references for material identification in remote sensing images. All spectra are measure of reflectance but wavelengths are in units of micrometers, whereas our sample image bands are in nanometers. To properly query the spectra, it is required to specify the band limits in micrometers. Range of USGS spectral library 0.3951 to 2.56 Micrometers and sampled in 420 bands but in this study HSI data generate spectra of 373 band so it is required to resample the spectral library by resampling algorithm.

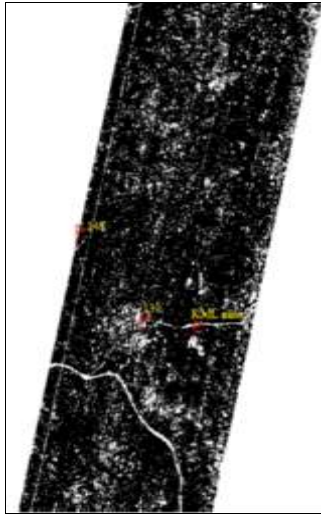


Fig 4: PPI of image

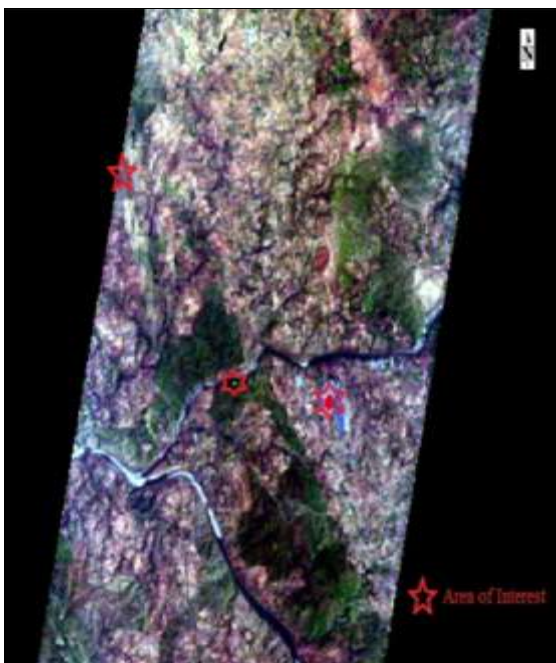


Fig 5: Regions of interest (ROIs)

Spectral analyst Tool/Spectral Analysis

The Spectral Analyst tool was used for the identification of materials based on their spectral characteristics. The Spectral Analyst uses ENVI techniques such as Binary Encoding, Spectral Angle Mapper and Spectral Feature Fitting to rank the match of an unknown spectrum to the materials in a spectral library. The output of the Spectral Analyst is a list of the materials in the input spectral library ranked in order of best to worst match. An overall comparison score is reported, along with individual 0 to 1 scores for each technique.

The output of the Spectral Analyst is a ranked or weighted score for each of the materials in the input spectral library. The highest score indicates the closest match and indicates higher confidence in the spectral similarity. Similar materials may have relatively high scores, but unrelated materials should have low scores. Spectral Feature Fitting is probably the best method in case of the materials which have good absorption feature pattern. Otherwise, Spectral Angle Mapper or Binary Encoding will yield better results.

Spectral Angle Mapper

Spectral Angle Mapper (SAM) is a physically-based spectral classification that uses an n-D angle to match pixels to reference spectra. The algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands. This technique, when used on calibrated reflectance data, is relatively insensitive to illumination and albedo effects.

End member spectra used by SAM can be in ASCII format, spectral libraries, can be extracted directly from an image (average spectra of ROI). SAM compares the angle between the End member spectrum vector and each pixel vector in n-D space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified. Mean spectra is taken as reference spectra for SAM classification. Threshold angle suitable of the image under analysis is found by various trials by altering the angle until suitable SAM classified image is generated.

Reconnaissance survey and field verification

The rock samples were collected from different locations for the petrographic analysis. The same samples were used for spectra generation of the material by ASD spectroradiometer. Thin layer section is paste the very small thin layer of data sample material on the glass strip. Purpose of thin layer section and polish layer was for petrographic or microscopic analysis of material. Over all ten samples were taken from study area. The Latitude and longitude of each sample point is shown in Table 3.

Table 3: Location of sample material

| Name of location | Lat. | Long. | Height (m) |
|---------------------------|----------|----------|------------|
| 137 near kajali doungeari | 22.941N | 74.470 E | 298 |
| 138 patt river | 22.951 N | 74.451 E | 268 |
| 139 patt river | 22.951 N | 74.451 E | 261 |
| 140 patt river | 22.950 N | 74.451 E | 249 |
| 141 | 22.940 N | 74.428 E | 276 |
| 142 Khatama mine | 22.975 N | 74.424 E | 304 |

Geological point of view Jhabua district is very important region of Madhya Pradesh because of its minerals rich region. There are many small and large mines working for extraction the minerals. Some rock sample is taken from near to these mines at the time of data material collection. Some pictures with their location name and GPS coordinate which are shown below in Figure 6, 7 & 8.



Fig 6: Location 138 and 22.951 N, 74.451 E at Patt



Fig 7: Location 140 and 22.950 N, 74.450 E



Fig 8: Location 141 and 22.940 N, 74.428 E

Analysis of ASD spectra of field sample data with ENVI library

Open ASD spectra in View spec pro software and spectra appear in form of 2D plot between wavelengths (nanometer) versus DN value. It converted in between wavelength versus reflectance. Figure 9 shown below the plot of location 137 in ASD software.

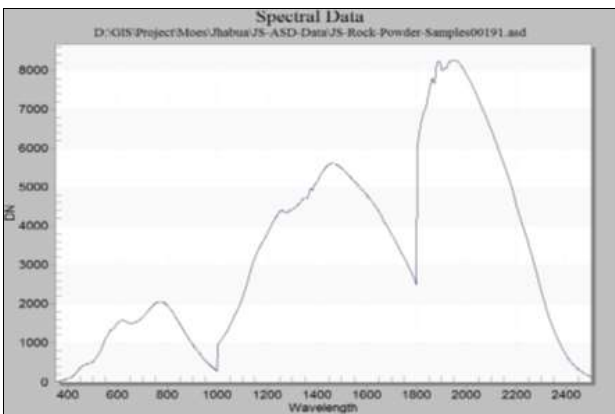


Fig 9: Spectral plots between wavelengths versus DN values

Export spectra in ASCII file format and import it in ENVI, Repeat these steps for all field sample data and build up a user define spectra library of field data sample. All spectra of field data material which are created by using ENVI

spectral library tool, shown below in figure 10.

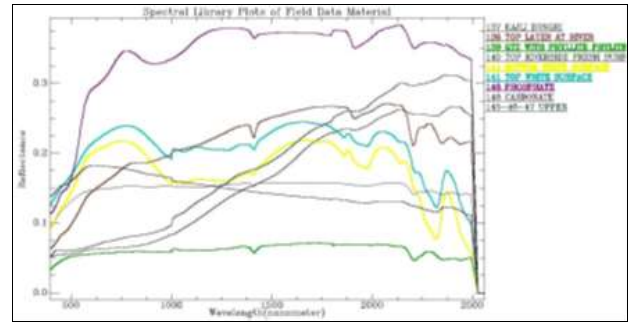


Fig 10: Spectral plots between wavelengths versus Reflectance values

Resampled the user define library according to USGS defined library which is available in ENVI.

Spectral analyst tool helps in identification of minerals based on their spectral characteristics. For identification of materials based on their spectral characteristics by using Spectral Analyst tool. The Spectral Analyst uses ENVI techniques such as Binary Encoding, Spectral Angle Mapper, and Spectral Feature Fitting to rank the match of an unknown spectrum to the materials in a spectral library. The output of the Spectral Analyst is a list of the materials in the input spectral library ranked in order of best to worst match.

Classification of Hyperspectral data

SAM classification mapped the study area into three mineral types Psilomelane, Muscovite and Pyrite in yellow, blue and red color respectively in Hyperion image, which is showing below in Figures. As per definition of spectra of pure pixel, Psilomelane, Muscovite and Pyrite minerals could be clearly identified and distinguished by means of SAM technique. Area (km²) and percentage (%) of total area (147.6 km²) are covered by Psilomelane, muscovite and Pyrite.

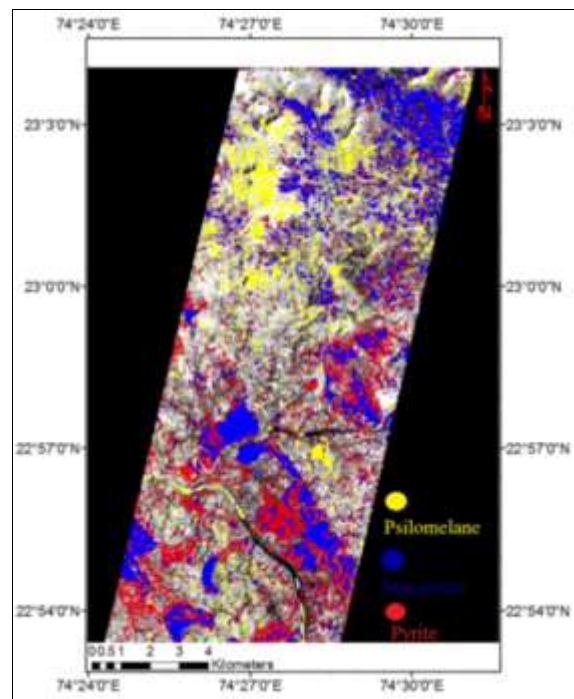


Fig 11: Mineral map of Psilomelane, Muscovite and

Discussion and Conclusion

The following results was found after the analysis of Hyperspectral image, spectra generated from field sample using ASD spectro radiometer and petrographic slice. The pure pixel at latitude (22.945 N) and longitude (74.467 E) near Kajali Dongari mine was selected. The spectra were generated as shown in Figure 12 and it was matched with spectra of known USGS mineral library as shown in Figure 13. Maximum absorption was found to be at point of wavelength 994 nm, between the range of visible and near infrared (400nm-1000nm) and in range of short wave infrared (2100-2500nm) having maximum matched of spectral pattern (circle in red color) as shown in Figure 14. Spectral Angle Mapper (SAM) was used for classification of hyperspectral image and created map on RGB and Grayscale image of mineral. Field where mineral found as shown below in yellow color in Figure 15

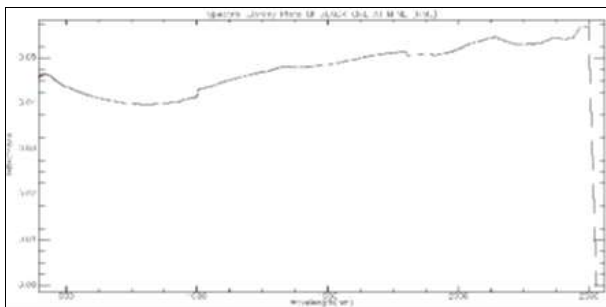


Fig 12: ASD spectra at Kajali Dongari (KML) mine

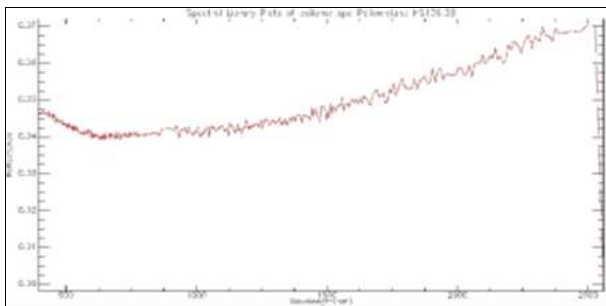


Fig 13: Spectra of Psilomelane mineral

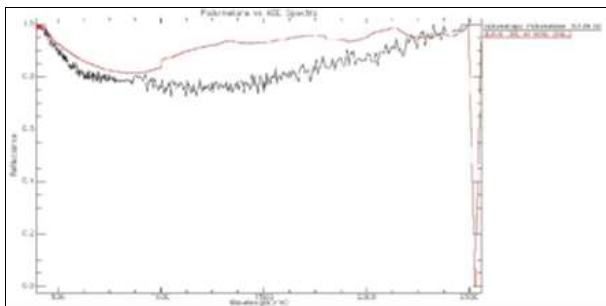


Fig 14: Matching plot between Psilomelane vs ASD spectra

The pure pixel at location 139, latitude (22.951 N) and longitude (74.451 E) was selected. The spectral signature (spectra) was generated as shown in Figure 16 and it was matched with spectra of known mineral library as shown in Figure 17. it was clearly showing that the maximum absorption point at wave length 2225nm and second maximum absorption point at wavelength 1418nm, between the range of visible and near infrared (400nm-1000nm) and in range of short wave infrared waves (1400-2500nm)

having maximum matched of spectral pattern (circle in red color) as shown in Figure 18.

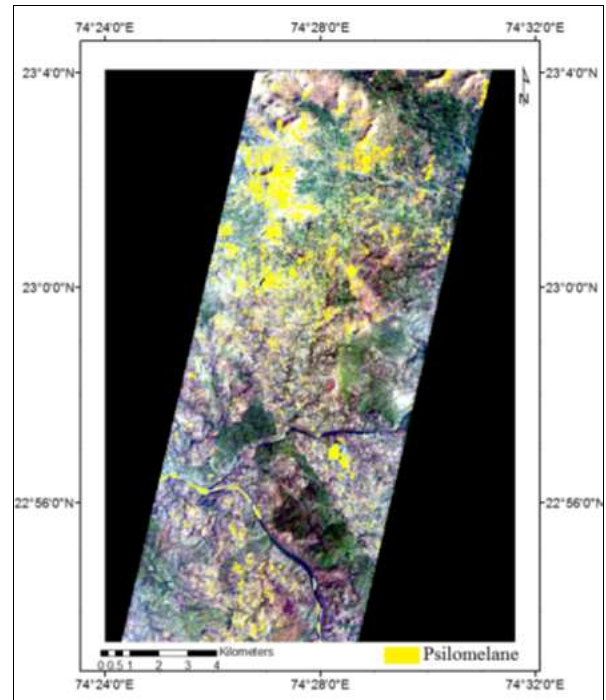


Fig 15: Final mapped image of Psilomelane on RGB

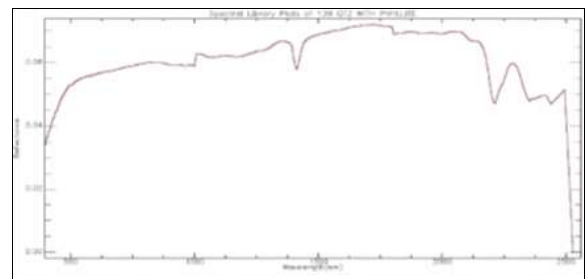


Fig 16: ASD spectra at location 139 near to Patt River

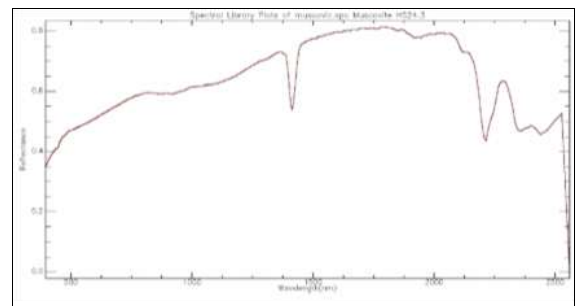


Fig 17: Spectra of Muscovite mineral

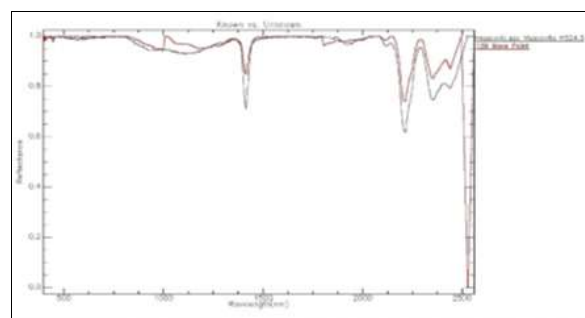


Fig 18: Matching plot between Muscovite vs ASD spectra

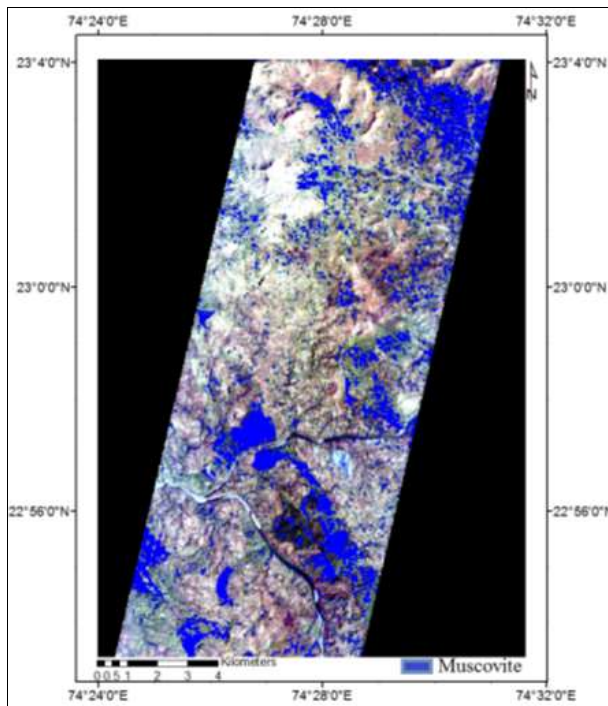


Fig 19: Final mapped image of Muscovite on RGB

Based on the analysis of Hyperspectral image and classification technique, it is found that 37.07% (54.72 km²) of total study area (147.60 km²) is mineralized which consists of mainly manganese ore and muscovite. The detailed verification of classified images have been done using field spectro-radiometer and ground truthing. Verified locations in the field were transfer on to hyperspectral data for validation. The selected pure pixels from Hyperspectral imagery have been used to generate spectra, which was matched with spectra generated from ASD spectro radiometer instrument and the available USGS spectral library. The field rock samples collected from study area were used to generate thin section for petrographic study. It is concluded from all the analysis that the study area consists of Psilomelane, Muscovite, Pyrite and Phyllite. The whole process is automated using the code available in ENVI library and automatic model has been worked out to generate the mineral mapping of any area.

References

1. Adler S, Berkl A, Bernstein' LS, Richtsmeierl S, Acharyal PK, Matthew' MW *et al.* Flaash, A Modtran4 Atmospheric Correction Package for Hyperspectral Data Retrievals and Simulations.
2. Bisun Datt, Tim R, McVicar, Tom G, Van Niel, David LB. Jupp, Associate Member, IEEE, and Jay S. Pearlman, Senior Member, IEEE, Preprocessing EO-1 Hyperion Hyperspectral Data to Support the Application of Agricultural Indexes, IEEE 2003.
3. Green AA, Craig MD, Cheng Shi. The application of the minimum noise fraction transform mi the compression and cleaning of hyper-spectral remote sensing data, Proceedings of KARTS '88 Symposium, Edinburgh Scotland Re\$ ESA SP-284 (IEEE 88CH;?4W-6).Published by Esrl Publications Division, August 1988.
4. Frassy F, Dalla Via G, Maianti P, Marchesi A, Rota Nodari F, Gianinetta M. Minimum noise fraction transform for improving the classification of airborne

Hyperspectral data: two case studies, 5th workshop on Hyperspectral image and signal processing: evolution in remote sensing 2013.

5. Boardman JW. Geometric mixture analysis of imaging spectrometry data, Proc. Int. Geoscience and Remote Sensing Symp 1994;4:2369-2371.
6. Farzeen Chaudhry1, Chao-Cheng Wu1, Weimin Liu1, Chein-I Chang1, Antonio Plaza. Pixel purity index-based algorithms for End member extraction from Hyperspectral imagery, Recent Advances in Hyperspectral Signal and Image Processing ISBN: 81-7895-218-1. 2006.
7. Clark RN, Swayze GA, Wise R, Livo E, Hoefen T, Kokaly R *et al.* USGS digital spectral library splib06a: U.S. Geological Survey, Digital Data Series 2007, 231.
8. Wei Y, Liu Z, Song Y, Chen Y. Spectral Mixture Analysis of Impervious Surface in Changchun, China Based on Normalized Image, IEEE 978-0-7695-3563-0/08. 2008.