Unearthing the Lonar Crater Using Hyperspectral Remote Sensing and Validating Through Non-destructive Approach

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Abstract. Remote Sensing is a prominent technology, applied at all fields of earth science. It is useful in the identification and mapping of minerals, vegetation, different materials and backgrounds by capturing the electromagnetic energy reflected from them. The analysis of remote places or structures is possible with the help of remote sensing with economic and timely manner. So, the proposed work focuses on exploring the Lonar crater with the help of remote sensing. The earth surface is enriched with number of useful minerals. Minerals are very important resources contributing in the wealth of a country. So, this work focused on mineral mapping and mineral identification at Lonar Crater by using high resolution hyperspectral images acquired by Hyperion sensor. The validation of minerals identified with hyperspectral imaging was completed by the use of nondestructive approach of spectroradiometer.

The various minerals are identified by imaging analysis and validated through non-destructive approach. The significant results of the proposed methodology are: i) the type of rock at the Lonar crater is identified as basaltic igneous rocks, ii) the origin of Lonar crater is due to the extrusive volcanic activity and iii) The Lonar lake is saline in nature. The Spectral Classification using SAM gave accuracy of 89.01% with 0.8753 kappa coefficient and SVM technique, gave the accuracy of 97.25% with 0.9688 kappa coefficient indicating more match with the ground truth.

Keywords: Minerals · Hyperspectral · Remote Sensing · Support Vector Machine

1 Introduction

Remote sensing is a technology which records the electromagnetic energy transmitted or reflected by the earth surface. The amount of energy reflected or transmitted is measured and analyzed for the variety of applications. Our eyes can sense only the gray tones and different intensities for the solar radiations. With the help of remote sensing the radiations can be sensed outside the visible range of 400 nm to 700 nm. The variety of

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applications of remote sensing are land use and land cover mapping, mineral mapping [1], agriculture mapping, change detection with respect to land cover, vegetation analysis, water table applications, mineral identification [2] and lithological mapping [3], fault fracture analysis, snow analysis and many more.

The impact craters are the geological structures on the earth. They are the dominant landforms on the surface of the Earth, Moon and planets in the outer Solar System. The volcanic craters form due to internal collapse or eruption. Whereas the impact craters usually have rims which are raised and low elevation floors as compared to surrounding terrain. The famous example of small impact crater on the Earth is Meteor Crater. The craters are formed due to shock wave which radiates into the earth crust when an asteroid or a comet hits the earth surface. A shock wave gets reflected back in the direction of the earth surface. There are two types of impact structures: simple structures and complex structures and basins. The simple impact craters are of size less than 4 km in diameter having overturned and uplifted rock rims, bowl shaped surrounding depression. It is partially filled with breccia. Whereas the complex impact structures are having diameter more than 4 km with uplifting at center and clumped rim. It is partially filled with breccia as well as rocks melted due to impact. The impact craters give important information about the landforms, terrestrial impact craters [4]. The various studies have been performed on crater or lake analysis [5, 6] using the electrical, physical, magnetic, geochemical techniques, geological and remote sensing techniques. But the Lonar crater is still not explored till today through remote sensing. Hence the proposed work focuses on exploring the Lonar crater through remote sensing.

The meteorite craters in India are Lonar lake, Ramgarh and Dhala Lake. Lonar crater is the world's largest basaltic crater. It is identified as the meteorite impact crater by various researchers through their study. It is situated at Lonar of district Buldhana, Maharashtra. Its shape is almost circular and also seems like bowl shaped. The diameter of the Crater ream is 1.8 km. The nature of the Lonar lake water is alkaline and saline. The regional dip of crater is zero, with dips between 5° and 25°. There are large variations in the estimation of crater from 13,000 years to about 52,000 years. Lonar Lake has a mean diameter of 1.2 km and is about 137 m below the crater rim. Lonar Crater is an excellent site for focusing various studies like shock magnetization, impact crater formation and ejecta flow dynamics. Ramgarh crater is located near Ramgarh village; district Mangrol, Rajasthan, India. The diameter of this crater is 3.5 km. The Glass resembling rock samples of this crater contains iron, nickel and cobalt in abundance. It is having the elevation of about 200 m above the surrounding terrain so it can be easily spotted from a distance of 40 km [7].

The origin of Lonar crater is the result of extrusive volcanic activity [8] and few researchers commented that origin of Lonar crater is due to meteoritic impact [9, 10]. The proposed work also proved the origin of Lonar crater is the impact of extrusive volcanic activity. The focus is on the identification of minerals at the crater and its surrounding area. Mirabilite, epsomite, ulexite and kainite identified through proposed methodology proved the salinity of the Lonar Lake water. The identification of mineral Sodium carbonate shown that the soda is present at Lonar lake.

The findings of various studies through geochemical, chemical, petrological, magnetic, electric and geological experimentation were validated through the proposed

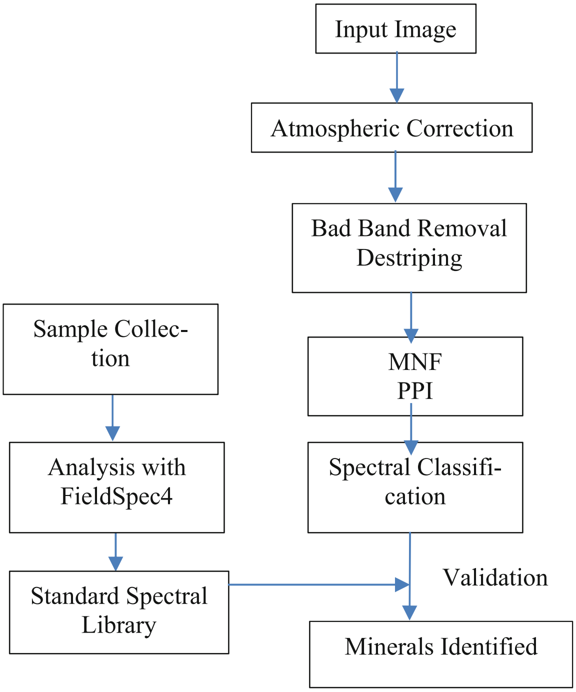


Fig. 1. Methodology for Proposed Work

methodology. The mineral augite is present in basalt rocks and it is scattered throughout the Lonar crater. The rocks at crater are fine grained extrusive formed through lava. The augite mineral is identified through Spectral Angle mapper(SAM) and SFF(Spectral Feature Fitting) techniques indicating the type of rock as igneous basaltic rock [8]. Mineral mapping, mineral identification and lithological discrimination uses hyperspectral imagery of Hyperion [11], AVIRIS [12], and HyspIRI [13].

2 Methodology

Hyperion data is used for mineral mapping and identification. The Hyperion is a hyperspectral sensor of EO1 satellite. The images are in HDF (Hierarchical Data Format) and GeoTIFF Format. The Hyperion data is available in three levels, Level 0, Level 1R (L1R) and Level 1 GST. The L1R image is having dimensions 256 × 242 × 3128. Pre-processing of Hyperion images is performed for handling the noise which reduces the quality of images. The atmospheric materials cause noise in image and this noise is handled using FLAASH (Fast-Line-of-sight Atmospheric Analysis of Spectral Hypercubes) technique of atmospheric correction. Out of 242 spectral bands, there are few bands called bad bands containing no information for spectral analysis. These bad bands are removed by using a software developed in python.

The diagram of methodology for the proposed work is in Fig. 1.

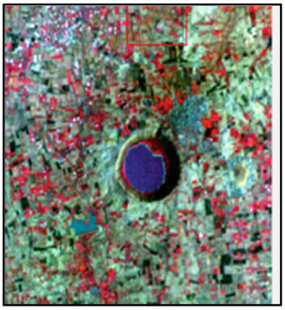


Fig. 2. MNF Output

The stripes in the image are removed by taking average of two adjacent column pixel values and replacing the stripe pixel values with this average value. The preprocessed images are used in spectral classification for mineral mapping and mineral identification. The Minimum noise fraction (MNF) technique is used to remove the noise and also to reduce the dimensionality of the image.

The spectral subset is taken for marking the region of interest as Lonar crater and surrounding. Then Pixel purity index (PPI) technique and n-D visualization operation is performed. The endmembers are identified by using spectral classification. The highest score of SAM were used for identifying potential endmembers in corresponding n-D classes. The spectral library is built for those endmembers. This spectral library is resampled and compared with standard USGS (United States Geological Survey) spectral library of minerals. Finally, the minerals are identified. The spectral classification is performed using these endmembers.

The Soil and rock samples are collected from Lonar crater and analyzed with spectro-radiometer Fieldspec4. The spectral library for these samples is built in ENVI software. This spectral library and USGS standard spectral library are used for validating the results of imaging analysis using Hyperion data.

3 Results and Discussion

3.1 Preprocessing of Input Image

Input dataset is downloaded from the website of USGS. The L1R image of this dataset is the level 1 image used for the spectral analysis. The image swath is 7.5 km. The Spectral subset is taken for reducing the complexity of further analysis. The Bad bands and bad columns are removed. The FLAASH technique is applied for handling the noise present due to atmospheric conditions. Then the MNF (Minimum noise fraction) is applied for reducing the dimensionality. Eigenvalue more than 1 is considered as significant value and it is used in selecting endmembers for building the spectral library. 10 bands having eigenvalues more than 3 are selected after MNF. The output is shown in Fig. 2.

Pure pixels are identified using pixel purity index (PPI) technique. The output of PPI is shown in Fig. 3. The 10 bands selected in MNF are used to find the pure pixels. These pure pixels are then used for forming the ROI classes useful for spectral classification. The pure pixels are rotated and extreme pixels are identified and used to form the clusters.

Fig. 3. PPI Output

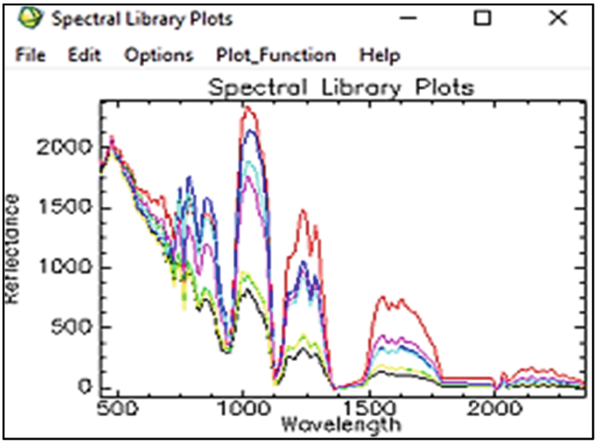


Fig. 4. Spectral Library

3.2 Spectral Classification

The classes or pixel clusters are exported in ROI tool as endmembers. The spectral signatures are plotted and the spectral library is built for these endmembers and is shown in Fig. 4.

Then spectral resampling is done further to make those endmember spectra in the range of standard spectral library. This image spectral library is resampled with USGS standard spectral library of minerals. SAM classification technique is used for identifying the endmembers. The Highest score of SAM technique shows the presence of that corresponding mineral. In the proposed work, the endmembers identified at the crater rim and inside the lake are ulexite, epsomite, Mascagnite, chlorite and opal mainly by using spectral analyst. It validated the presence of minerals through imaging analysis

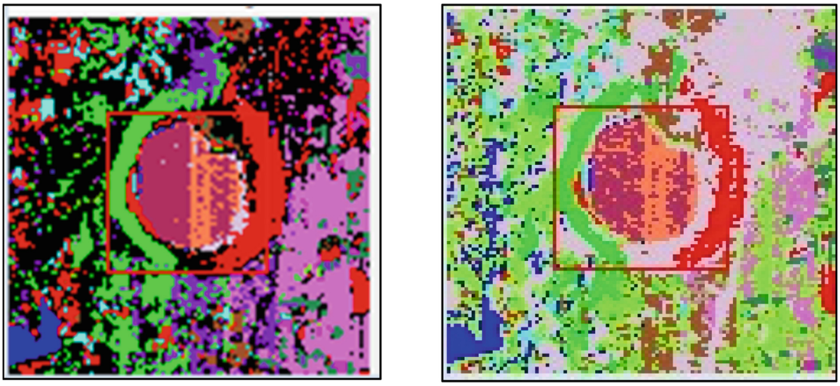


Fig. 5. Spectral Classification Output of a) SAM b) SVM

which were identified by various researchers earlier and those are Gaylussite, calcite, augite, chlorite and Mascagnite. Other endmembers identified at and near the crater are epsomite, ulexite, opal, mirabilite, Mesolite, kainite and pyrite. SAM (Spectral Angle Mapper) technique is used for classification using these endmembers and output of SAM is as shown in Fig. 5 (a). The spectral classification is performed for these endmembers using SVM and the output is shown in Fig. 5 (b).

The SAM technique delivered accuracy of 89.01% with 0.8753 kappa coefficient. The Support vector machine technique is used for classification with radial basis function kernel and 0.1 probability threshold. The output rule image is saved and confusion matrix is built by using ground truth from image endmembers. SVM delivered accuracy of 97.25% with 0.9688 kappa coefficient indicating more match with ground truth.

3.3 Field Work and Validation

The Samples of soil and rock were collected from study area for validating the results of imaging analysis using Hyperion data. The soil and rock samples are analyzed using spectroradiometer FieldSpec4 in laboratory. The ViewSpecPro and RS2 software are used for building spectral library for soil samples. The latitude and longitude of the study location is 19°58′33.1"N 76°30′45.3"E respectively. Figure 6 (a) is a photo while collecting the soil sample and Fig. 6(b) is the soil sample photo at field.

Samples are analyzed in dark room laboratory using Fieldspec4 device. Initially the device requires 15 min warm-up and then it is optimized. The proper settings for light source are set by optimizing the device. This device requires calibration before spectral data collection using white reference Spectralon. The moist soil samples were dried, sieved twice with 2 mm^2 and 4 mm^2 size sieves. The fine soil sample and rock samples were tagged and then studied in dark room laboratory. The samples were kept on black paper for collecting spectral data using ASD FieldSpec4. The neon lamp is made on and its light is adjusted to focus on the sample.

The Fig. 7 shows ASD FieldSpec4 in laboratory during spectral data collection of soil sample.

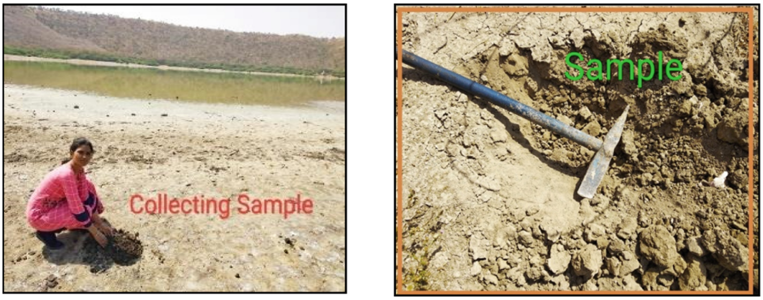


Fig. 6. On-Field (a) Sample Collection (b) Soil Sample

Fig. 7. Spectral Data Collection using ASD FieldSpec4 in Laboratory

Proper FOV (Field of View) angle was set for collecting the data. 10 spectral samples were captured through the gun of FieldSpec4 for each soil and rock sample. The captured spectral data is saved in asd format. This data is exported in ENVI software for building spectral library. Figure 8 shows the Spectral Library plot for soil sample.

The spectral resampling is performed between field sample spectra and USGS standard spectral library. The spectral analysis is performed with SAM and SFF algorithms. The weights of 1 are set for both algorithms in spectral analyst and executed. The results of analysis are interpreted below.

3.3.1 Soil Sample Analysis

Mesolite is a popular zeolite mineral. Its ice-clear crystals are hallmark of this mineral. Mesolite is present in many localities but only a few have large crystal masses. Some of them are in Canada, the United States, France, Iceland, and India. It occurs in volcanic rock cavities, typically found in basalt but also found porphyrite, and hydrothermal veins. Mesolite is identified with 29.5%. Amphiboles are significant in rock formation

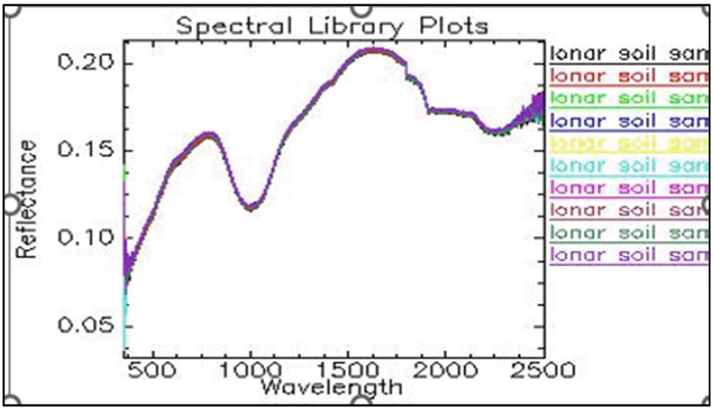


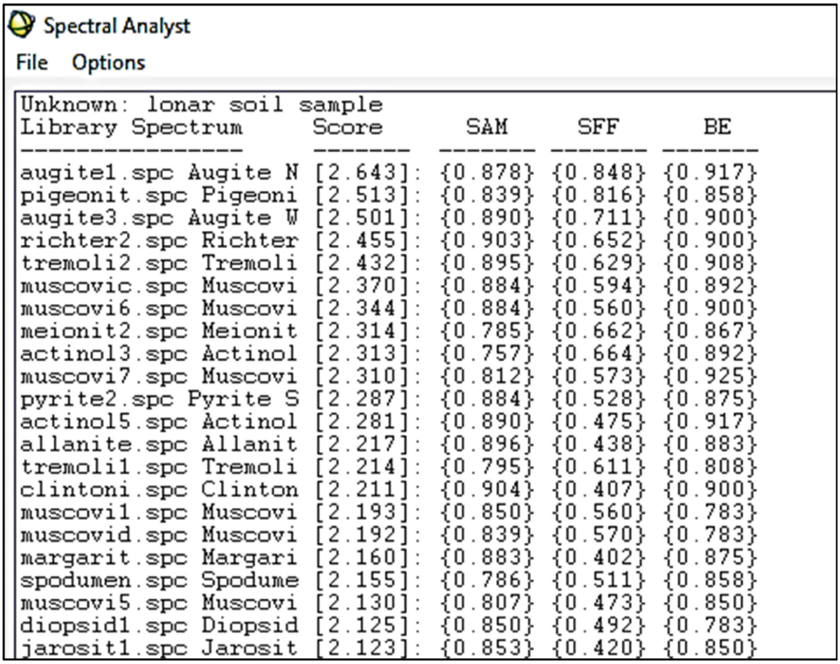
Fig. 8. Spectral Library of Soil Sample

and it is identified with 58.2%. Also, plagioclase consists of endmembers of anorthite and albite along with quartz. Plagioclase is found in all metamorphic rocks and igneous rocks. Lonar rocks are mainly consists of clinopyroxene, plagioclase and altered glass [14] and the proposed work marks their presence. Mirabilite is the evaporative element at saline lakes. Though it is unstable but its presence is reported. The minerals identified by imaging analysis and those are validated through non-imaging analysis are augite, Richterite, pyrite, albite, limonite, illite, jarosite, chlorite, uralite, manganite, muscovite, actinol, allanite, Fassaite, mirabilite, amphibolite and hematite.

The few minerals like augire1, pigeonite, richterite, muscovite, pyrite, actinol, etc. score is as shown in Fig. 9.

Epsomite is found as deposition due to saline springs and lakes. It is found in arid regions and it is outcrop of sulfide bearing magnesian rocks. It is formed due to evaporation at saline lakes and mineral springs and its association is with rozenite and mirabilite. Ulexite is borate mineral mostly found in saline lakes and arid regions. Opal is a crystalline form of silica consisting of regular arrangements of silica spheres. Its association is with chalcedony, quartz, calcite, topaz, goethite, cinnabar, magnesite and all these minerals are identified at current study area.

Gypsum concrete is used as a floor underlayment. This building material consists of cement, sand, plaster and gypsum as well. Near about 3% of Gypsum is added in the cement in for slow down the process of setting of cement. Gypsum2 is identified with 42.5% with spectral analyst. The presence of gypsum marks having urbanization involving cement construction nearby Lonar crater. The salinity at crater is proved with the presence of mirabilite, epsomite, ulexite, eugsterite and kainite mineral. The type of rocks at this crater are igneous basalt which is proved with the presence of mineral augite. The origin of crater is due to extrusive volcanic activity and this is proved with the presence of minerals Mesolite, pigeonite and augite. Albite and anorthite minerals marked the presence of plagioclase. Plagioclase is the strong indicator of impact.



Library Spectrum	Score	SAM	SFF	BE
augite1.spc Augite N	[2.643]:	{0.878}	{0.848}	{0.917}
pigeonit.spc Pigeoni	[2.513]:	{0.839}	{0.816}	{0.858}
augite3.spc Augite W	[2.501]:	{0.890}	{0.711}	{0.900}
richter2.spc Richter	[2.455]:	{0.903}	{0.652}	{0.900}
tremoli2.spc Tremoli	[2.432]:	{0.895}	{0.629}	{0.908}
muscovic.spc Muscovi	[2.370]:	{0.884}	{0.594}	{0.892}
muscovi6.spc Muscovi	[2.344]:	{0.884}	{0.560}	{0.900}
meionit2.spc Meionit	[2.314]:	{0.785}	{0.662}	{0.867}
actinol3.spc Actinol	[2.313]:	{0.757}	{0.664}	{0.892}
muscovi7.spc Muscovi	[2.310]:	{0.812}	{0.573}	{0.925}
pyrite2.spc Pyrite S	[2.287]:	{0.884}	{0.528}	{0.875}
actinol5.spc Actinol	[2.281]:	{0.890}	{0.475}	{0.917}
allanite.spc Allanit	[2.217]:	{0.896}	{0.438}	{0.883}
tremoli1.spc Tremoli	[2.214]:	{0.795}	{0.611}	{0.808}
clintoni.spc Clinton	[2.211]:	{0.904}	{0.407}	{0.900}
muscovi1.spc Muscovi	[2.193]:	{0.850}	{0.560}	{0.783}
muscovid.spc Muscovi	[2.192]:	{0.839}	{0.570}	{0.783}
margarit.spc Margari	[2.160]:	{0.883}	{0.402}	{0.875}
spodumen.spc Spodume	[2.155]:	{0.786}	{0.511}	{0.858}
muscovi5.spc Muscovi	[2.130]:	{0.807}	{0.473}	{0.850}
diopsid1.spc Diopsid	[2.125]:	{0.850}	{0.492}	{0.783}
jarosit1.spc Jarosit	[2.123]:	{0.853}	{0.420}	{0.850}

Fig. 9. Spectral Analysis score of SAM for Soil Sample

3.3.2 Rock Sample Analysis

The rock samples marked the presence of minerals jarosite, antigorite, pyrophyllite, Richter, fassaite, pyrite, manganite, zircon, barite, quartz, sphalerite, sphene, cinnabar, lazurite, rutile, hematite and cuprite with SAM technique. SAM scores for some minerals are shown in Fig. 10.

Fassaite is a variety of mineral augite having very low iron contents. It is formed at cavities between limestone and volcanic rocks. Fassaite is identified with 57.4% by SAM technique. Also, this mineral is reported due to meteorites. Augite is a rock forming pyroxene mineral and it is found in intermediate igneous rocks like basalt and andesite. Zircon ($ZiSO_4$) is a silicate mineral found primarily in felsic igneous rocks. It is a gemstone used as low-cost alternative for diamond and found as minor constituent of metamorphic and sedimentary rocks. Barite mineral is barium sulphate ($BaSO_4$) which occurs in hydrothermal ore veins. Hematite mineral available in abundant in shallow crust and on earth's surface. Hematite (Fe_2O_3) is an iron oxide mineral and large quantities are mined for industrial production throughout the world. Quartz is present in all metamorphic, igneous rocks and it is identified with 66% by SAM algorithm. Sphalerite is identified by SAM with 63.7%. Sphalerite deposits are found due to hydrothermal activity or contact metamorphism and deposited in fractures, cavities and veins.

The spectral matching plot for mineral chlorite is as shown in Fig. 11. It is identified by SAM with 55%.

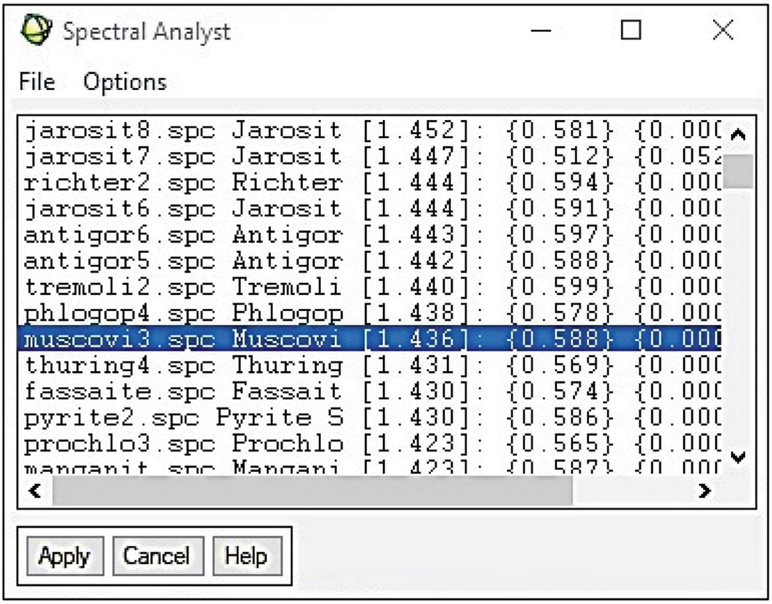


Fig. 10. Spectral Analysis score of SAM for Rock Sample

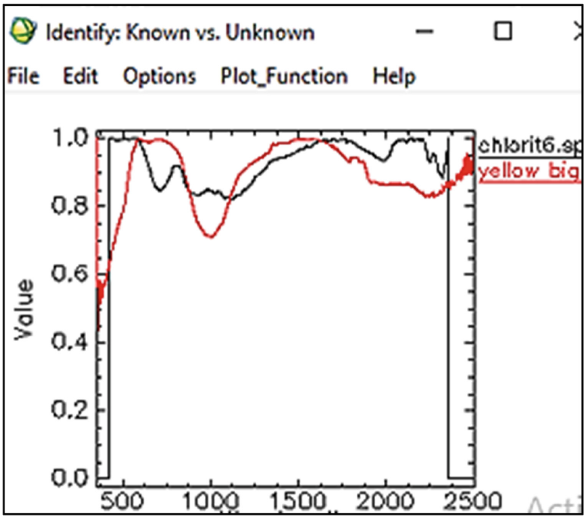


Fig. 11. Spectral Matching for Chlorite

Sphene or titanite occurs as accessory mineral metamorphic rocks. It is a minor ore of rare titanium mineral. It is a titanium calcium silicate mineral with chemical composition CaTiSiO4(O, OH, F). It is identified with 72.6% by SAM algorithm. Cinnabar (HgS) is identified with 71.9% and it occurs due to volcanic activity and deposited in veins. It is a mercury sulfide mineral.

Overall, the rocks at Lonar crater are formed majorly due to metamorphic activity. The presence of zircon indicates rocks are igneous and metamorphic. Also, hematite and plagioclase mineral indicate the Lonar crater is the result of Impact of meteorite.

4 Conclusion

Hyperspectral remote sensing is having variety of applications in the field of geology, in agriculture field, in mineral exploration, and environmental studies like flood monitoring, pollution related studies, earth quakes, tsunami, landslides monitoring etc. The proposed work focused on exploring the Lonar crater using remote sensing. It validated the presence of minerals Gaylussite, calcite, augite, chlorite and Mascagnite through imaging analysis which were identified by various researchers earlier. Other endmembers identified at and near the crater are sodium carbonate, epsomite, ulexite, opal, mirabilite, Mesolite, kainite and pyrite through imaging analysis. The minerals identified by imaging analysis and validated through non-imaging analysis are augite, Richterite, pyrite, albite, limonite, illite, jarosite, chlorite, uralite, manganite, muscovite, actinol, allanite, Fassaite, mirabilite, amphibolite, anorthite and hematite.

The significant minerals identified in different rock samples are Halite, pigeonite, Augite, magnetite, chlorite, calcite, chromite, jarosite, albite, quartz, Eugsterite, Hepatite, cuprite, pyrite, limonite and allanite.

The proposed work hints the presence of anorthite and albite which in turn hints the presence of plagioclase indicating the origin of Lonar crater as volcanic eruption. The important constituent of igneous rock is Quartz proving the type of rocks at crater as igneous. The presence of quartz is indicated through soil and rock samples. The existence of minerals Mirabilite, ulexite, epsomite, Eugsterite and kainite proved the salinity of the Lonar Lake water. Halite a rock salt mineral, is identified which is a natural sodium chloride. Epsomite is the major constituent found at Lonar lake through proposed methodology. It is most commonly found on walls of caves, mines or outcrops of sulfide-magnesium rocks as a deposition due to saline springs and saline lakes.

The presence of Pigeonite, Mascagnite, Mesolite and Augite at Lonar Crater indicates that this crater is the result of extrusive volcanic activity. Also, the presence of Augite, pyroxene, plagioclase, chlorite, Olivine and Mesolite are the signs of basaltic igneous rocks as the type of rocks at Crater. The presence of sodium carbonate indicates salinity of the lake water. The mineral gaylussite proves the alkaline nature of lake and also the source of calcite at crater. Clinoptilolite is identified with very good matching score and it is usually found due to volcanic glass shards in tuff and as vesicle fillings in basalts. Sodium levels are generally higher in clinoptilolite. Mordenite is a found in volcanic deposits and in basalt rocks and is identified with good score using proposed methodology. The hematite mineral found in rock sample indicates the Lonar crater as the result of Impact of meteorite.

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