SUMMER RESEARCH FELLOWSHIP PROGRAMME 2020

STUDY ON LUNAR MARE ORIENTALE'S IL'IN CRATER USING EMPIRICAL REMOTE SENSING AND FUZZY LOGIC TECHNIQUES: A CASE STUDY OF PLANETARY EXPLORATION

8 WEEK REPORT

GUIDED BY:

Dr.S.Arivazhagan

Assistant Professor

Department of Applied Geology

Gandhigram Rural Institute – Deemed University

Gandhigram – 624 302

Dindigul District, Tamil Nadu, India.

SUBMITTED BY:

M.Rachel

Registration Number – EPSS69

B.E. – Electronics and Communication Engineering,

Paavai Engineering College.

Pachal, Namakkal – 637018

TABLE OF CONTENTS

LIST OF FIGURES

	has medium area of red and same output for 2nd combination of band 234 has maximum, band 342 has medium, band 423 has minimum and same output 3rd combination of band 345 has maximum, band 453 has medium, band 534 has minimum.	
4.20	Fuzzy Logic this output is for Sensitive to Iron for 1st combination Band 312 has Minimum area of green, band 123 has medium area of green, band 231 has maximum area and for the 2nd combination for band 423 has minimum, band 234 has medium, Band 342 has Maximum, and for 3rd combination Band 534 has minimum, Band 345 has medium, Band 453 has maximum area.	20
4.21	Fuzzy Logic rules this output for High in Titanium for 1st combination of Band 231 has medium area of blue, Band 312 has maximum, Band 123 has minimum and for the 2nd combination band 342 has medium, band 423 has maximum , band 234 has minimum and for the 3rd combination band 453 has medium, and 534 has maximum, band 345 has minimum area.	21

LIST OF TABLES

STUDY ON LUNAR MARE ORIENTALE'S IL'IN CRATER USING EMPIRICAL REMOTE SENSING AND FUZZY LOGIC TECHNIQUES: A CASE STUDY OF PLANETARY EXPLORATION.

ABSTRACT

For exploring the planetary bodies and associated are being used to study through the remote sensing along with some principles and applications. In this project we use Remote sensing technique for planetary exploration. Remote sensing is a technique to study information about an object or phenomenon without a physical contact with an object. The advantages of the remote sensing. It is used to collect data very easy as variety of bands for space exploration. The purpose of remote sensing for mineral exploration, lithological mapping, surficial deposit, structural mapping, environmental geology, event mapping and monitoring, planetary mapping etc., In the present study, the PCA and Fuzzy logic methods have been used to study the surface characters and their depositions of the Mare Orientale Basin of Il'in crater in the lunar region, it was first fully described by the German Astronomer Julius Franz (The Moon) in 1906, and has named the mare as "Eastern sea", it is a multi-ringed crater, the inner and outer Montes Rook and the outermost ring are the Montes located on the western border of the Cordillera, it is located near side and far side of the moon with coordinates of 19.4ºS 92.8ºW, mapping of crater such as diameter, area, composition, depth of the basin, it resembles as target ring bulls eye. The main purpose of the study is to monitor and gather information of recieving data from range of surface materials by the method of Principal component analysis and band ratio the satellite images for the clear view of surface materials, it has done by image processing of PCA in Envi and the output band ratio images classified using fuzzy logic method for range of surface materials by matlab.

Keywords or phrases: Remote sensing, Il'in crater, Principal component Analysis, surface materials, Mare Orientale basin, fuzzy logic.

1. INTRODUCTION

Mare orientale basin is one of the remarkable feature basin compared to the otherbasins on the Moon. The German Astronomer Julius Franz who named the mare as eastern sea. It is located in the Moon's southwestern limb between boundary of far and nearside, left-hand edge as seen from the Earth and superlative example for the preserved "multi-ring basin" on the Moon. In this lunar surface the basin is fairly flooded with the mare deposits. The lunar has formed basins like Orientale which plays an important in the early history of moon. Since they were extremely disruptive, has confronted altering events that caused substantial fracturing, melting and end formation of mare deposits in the crust. In base of topography analysis should be followed as in part of determine characteristics such as dimensions of the basin, with multi ring formation of crater. The Orientale basin has 930 km in a diameter and covers an area of 700, 0000 km^2 *[Head 1974; Whitten et al., 2011]*, the earlier studies says that the thickness of the mare was less than 1– 2 km *[Head 1974; Solomon and Head 1980]* and *[Greeley, (1976) and Scott et al., (1977)]* highlighted that the mare thickness could be up to 1km. The recent LRO wide-angle Camera (LROC), the depth of the Maunder crater situated in the Mare Orientale is estimated as 6.04 km. Orientale consists of five mare ponds, the largest of which covers an area of 8,890 km^2 and the smallest of which is 145 km. The North lengthened flat extent is a Lacus Veris it is also known as spring lake. The Researchers examined that this orientale basin is formed due to impact of meteorite about 3.8 billion years. The properties are compositional variation of surface materials to study about the characteristics of the surface materials present in the Il'in crater filled with mare, the large impact events produce copious volumes of shock melted, liquid rock, most of which lines of transient crater and floor deposit of the crater and through these study will able to study in which form we will get the input *[Howard and Wilshire, (1975); Grieve et al., (1977); Cintala and Grieve, (1998)]*. Through image processing we can identify the types of minerals in the lunar crater by using Matlab and Envi. In connection with that, the present study is aiming to investigate from the M^3 satellite image the topography characters of the basin (depth, diameter, and area).

2. Study Area

The study area is Mare Orientale basin it is one of the oldest basin formed in lunar surface due to impact of meteorite. By this impact the events produce as shock melted, liquid rock, floor deposit of the crater and collision caused ripples in the crust, which results in the formation of circular Multi Ring features it resembles as a target ring bulls eye, they are inner and outer Montes Rook and the outermost ring is Montes Cordillera. The early studies says that it is an Moon's most impact basin. However, it is younger than Imbirium basin. The Multi ring features are showing that the mostly reliable rough mountain ranges with mare deposits, through this impact the Il'in crater is formed. The Il'in crater is a circular and bowl shaphed crater, it is located on the far side of the moon, it lies in the western half of Mare Orientale basin, in the central of the basin the lava is flooded with lunar mare, the Il'in crater is larger than crater Hohmann. By image processing we can identify the types of compositional variations and their relevant surface characteristics in lunar crater by using Matlab and Envi. The location map of Il'in crater is shown in Fig 2.1.

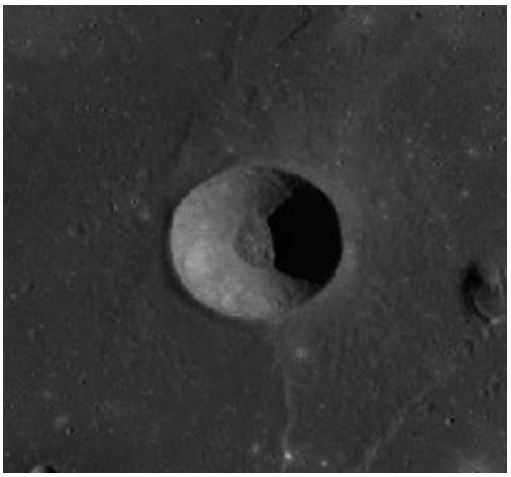


Fig 2.1. Original Picture of the Il'in crater on the far side of the moon by LRO

3. Materials and Methodology

3.1 Materials

The Moon Mineralogy Mapper (M^3) is one of the instrument from the 11 payloads in Chandrayaan-1, it is contributed to the India's first mission to moon launched on October 22, 2008 at Sriharikota on board of ISRO for a two year mission of 100km polar orbit. The M^3 with high resolution compositional maps will help in understanding the early evolution of the lunar surface. The M^3 is to characterize and map lunar surface mineralogy of lunar geologic evolution. It helps in understanding the highland crust, basaltic volcanism, impact craters. The M^3 is a high pushbroom imaging spectrometer operates in a range of 0.7 to 3.0 μm . The goals is to translate the accurate measurement of absorption features of rocks and minerals. The M^3 measurements are obtained for 640 spatial elements and 261 spectral elements. This translates to 70 m/pixel spatial resolution and 10nm spectral resolution from a nominal 100 km polar orbit for Chandrayaan-1, the field of view is 40 km in order to allow contiguous orbit-to-orbit measurements at the equator that will minimize the condition of lightning. The spectral range 0.7 to 2.6 μm capture the absorption bands for the most important lunar minerals. By the study of *[Pieters et al., (2009)]* the M^3 operates from the visible into the near- infrared of 0.42- 3.0μm where highly diagnostic mineral absorption band occurs. The M^3 has 85 contiguous bands, in the present study the satellite image of Il'in crater from M^3 data consist of 73 bands, for studying the compositional variations of surface characters the method used is Principal Component Analysis for the bands which consist of clear view of surface characters is done with Envi software and to implement the range of surface characters for the computed bands with set of rules by if-then logic through fuzzy logic method is done by Matlab software.

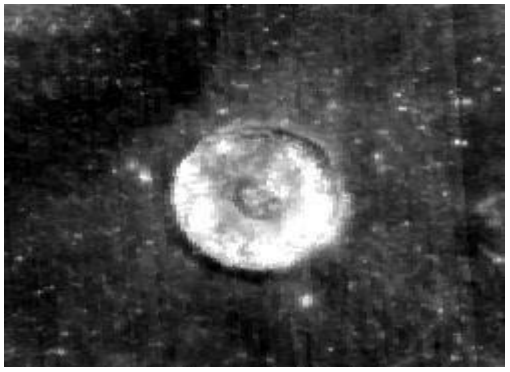


Fig3.1. Original Band Image

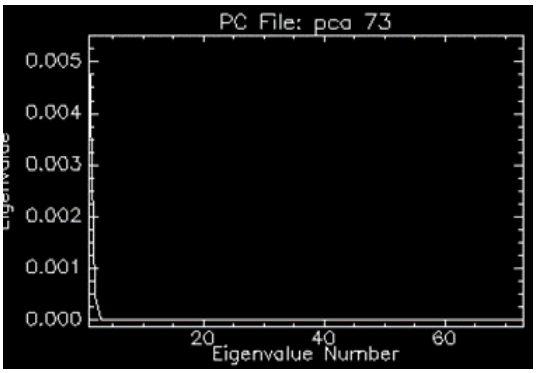
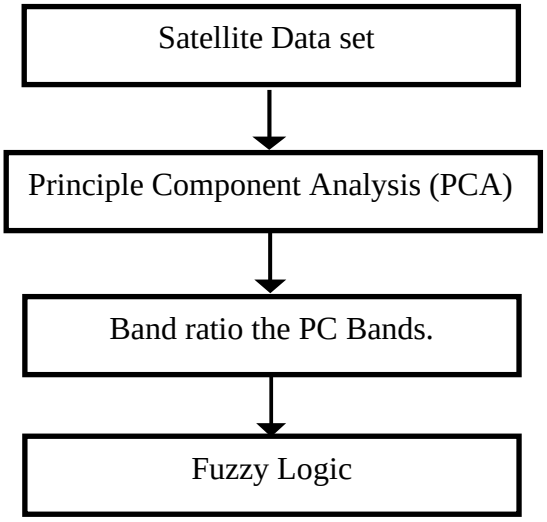


Fig3.2. PCA plot for 73 bands

3.2 Methodology



3.2.1 Principal Component Analysis (PCA)

The Principal Component Analysis is a method that converts original data into new set of data to capture the essential information. It is a linear transformation that converts multiband images to new set of image bands. In Envi the input image is computed to covariance or correlation matrix depends on the data processed, then the eigen vectors of the covariance or correlation matrix is calculated *[Rodarmal and shan., (2002)]*. In this study the satellite image consists of 73 bands, this data processed with PCA for 73 spectral bands and the PCA converted bands were band ratioed until the view of clear surface materials, the surface materials were clearly visible for 1-5 bands, from these bands it is computed as band ratio for 9 combinations the images were displayed for 9 combinations with RGB in the PCA band ratio images, the band ratio combinations are band 123, band 312, band 231, band 234, band 423, band 342, band 345, band 534 and band 453.The surface materials in red is poor in titanium, green is sensitive to iron, blue is rich in titanium as per the study of *[Shkuratov et al,2003]*. The band ratio combination did in this study based on this similar works of *[Rodarmel and Shan, (2002), R.P. Gupta et al., (2013), Mia and Fujimitsu, (2012)]*.

The image classified based on the Band ratios with RGB is given below

For 123,

R= Band2/Band 1; G= Band3/Band2; B= Band1/Band3.

For 312,

R= Band1/Band3; G= Band2/Band1; B=Band3/Band2.

For 231,

R= Band3/Band2; G= Band1/Band3; B= Band2/Band1.

For 234,

R= Band3/Band2; G= Band4/Band3; B= Band2/Band4.

For 423,

R= Band2/Band4; G= Band3/Band2; B= Band4/Band3.

For 342,

R= Band4/Band3; G= Band2/Band4; B= Band3/Band2.

For 345,

R= Band4/Band3; G= Band5/Band4; B= Band3/Band5.

For 534,

R= Band3/Band5; G= Band4/Band3; B= Band5/Band4.

For 453,

R= Band5/Band4; G= Band3/Band5; B= Band4/Band3.

3.2.2 FUZZY LOGIC:

The Fuzzy logic is to set rules for to implement the fuzzy set for the classified image. It is a set without a crisp and clearly defined boundaries, the elements contain in the fuzzy set is only with partial degree of membership. The fuzzy logic is a reasoning for generalizing yes or no as Boolean logic, if we give true the numerical value will be 1 or if we give false the numerical value be 0. In Matlab the fuzzy logic toolbox is a best method to solve the problem which allows using logic of if- then rules for systems's behaviour. This Toolbox is an execution of functions built on this software, it is used for numeric computing environment and provides tools for creating and editing fuzzy inference systems by using

Matlab. There are two types of systems in fuzzy logic as follows Fuzzy Interface System and Adaptive Neuro fuzzy Interface system. In this present study we use Fuzzy Interface System. The PCA Bands of 9 combinations were divided and classified into 3 input variables named as red, green and blue, the output is named as surface materials the input and output display range is [0, 255] using Mamdani method, this process is done by method of *[Vini, Aakanksha, Aditi, Ambika and Ankita, 2013].* The similar works of this method *[Jabari and Zhang, 2013, Afirah and Sharifah, 2016, Barrile and Bilotta, 2008].*

FIS Properties: There were three input variables named as red, green, blue. For the each input variables the properties to be classified into 1st, 2nd and 3rd combinations and the output variable will be the range of surface materials for classified band ratio images of PCA bands.

Member Functions: There will be 3 member functions for each input variables it will be classified for the band ratio of 9 combinations using fuzzy logic. The first combination for each input variables are red, green and blue, their member functions for each input variable is given as Band 123, Band 312, Band 231. The second combination of input variables for red, green, blue, their member function for each input variable is given as band 234, band 423, band 342 and the third combination for each input variables of red, green, blue, their member function for each input variables is given as band 345, band 534, band 453 and for all three input variable combinations the output is named as surface materials (i.e. it is the accuracy assessment of band ratio images) its member function is given as Low in titanium, sensitive to iron and High in titanium with range of surface area as maximum, medium and minimum as triangular form.

The parameter range of output variable,
Maximum= [175 215 255];
Medium= [75 125 175];
Minimum= [0 35 75].

For example, the fuzzy set rules based on if- then logic,
If Band 123 in red **then** it is low in titanium,
If Band 312 in green **then** it is sensitive to iron,
If Band 231 in blue **then** it is high in titanium,

For the output of maximum range of surface materials the 3 combinations with input variables with band ratios are given as

For 1st combination of maximum;

Red= Band 123; Green= Band 312; Blue= Band 231 For 2nd combination of maximum;

Red= Band 234; Green= Band 423; Blue= Band 342 For 3rd combination of maximum;

Red= Band 345; Green= Band 534; Blue= Band 453.

For the output of medium range of surface materials the 3 combinations with input variables with band ratios are given as

For 1st combination of medium;

Red= Band 312; Green= Band 123; Blue= Band 231. For 2nd combination of medium;

Red= Band 423; Green= Band 234; Blue= Band 342 For 3rd combination of medium;

Red= Band 534; Green= Band 345; Blue= Band 453.

For the output of minimum range of surface materials the 3 combinations with input variables with band ratios are given as

For 1st combination of minimum;

Red= Band 231; Green= Band 312; Blue= Band 123. For 2nd combination of minimum;

Red= Band 342; Green= Band 423; Blue= Band 234. For 3rd combination of minimum;

Red= Band 453; Green= Band 534; Blue= Band 345.

Table 3.1 Input parameters

S.no	Input variables	1st combination of MF	2nd Combination of MF	3rd Combination of MF	Parameters range
1	Red	Band 123 Band 312 Band 231	Band 234 Band 423 Band 342	Band 345 Band 534 Band 453	[175 215 255] [75 125 175] [0 35 75]
2	Green	Band 123 Band 312 Band 231	Band 234 Band 423 Band 342	Band 345 Band 534 Band 453	[75 125 175] [0 35 75] [175 215 255]
3	Blue	Band 123 Band 312 Band 231	Band 234 Band 423 Band 342	Band 345 Band 534 Band 453	[0 35 75] [175 215 255] [75 125 175]

Table 3.2 Output Parameters

S.no	Output	MF	Parameters range
1	Surface materials	Minimum Medium Maximum	[0 35 75] [75 125 175] [175 215 255]

Table 3.3 Rules of fuzzy sets

S. No	I/p combination	RED	Output of Low in titanium	GREEN	Output of Sensitive in iron	BLUE	Output of High in Titanium
1	1st combination	Band 123	Max area	Band 231	Maximum	Band 312	Maximum
2	1st combination	Band 312	Medium	Band 123	Medium	Band 231	Medium
3	1st conmbination	Band 231	Minimum	Band 312	Minimum	Band 123	Minimum
4	2nd combination	Band 234	Maximum	Band 342	Maximum	Band 423	Maximum
5	2nd combination	Band 423	Medium	Band 234	Medium	Band 342	Medium
6	2nd combination	Band 342	Minimum	Band 423	Minimum	Band 234	Minimum
7	3rd combination	Band 345	Maximum	Band 453	Maximum	Band 534	Maximum
8	3rd combination	Band 534	Medium	Band 345	Medium	Band 453	Medium
9	3rd combination	Band 453	Minimum	Band 534	Minimum	Band 345	Minimum

4. Results and Discussion

4.1 PCA Results

From the method of Principle Component Analysis(PCA), the satellite image bands

consist of 73 bands were evaluated into PCA bands, the surface characters is clearly visible for 1-5 bands, it is classified into 9 combinations with RGB image such as band 123, 312, 231, 234, 423, 342, 345, 534, 453 is given below from **(Fig.4.1- Fig.4.9.)** and for the accurate assessment of surface characters the 9 combinations were band ratioed with the PCA Bands and classified as a RGB images is given below from**(Fig 4.10.- Fig 4.18.)**, the compositional variations describes as the Red surface represents it is low in titanium or high in glass content, the green surface represents it is sensitive to iron, the blue surface represents high in titanium, some of the similar works based on this study *[Shkuratov et al., 2003, Lucey et al., 1998, 2000a]*. Based on *[Shkuratov et al., 2003]* the surface materials were described, in the early study of *[Lucey et al, 1998]* the surface materials range and types of minerals were studied in this work.

4.2 Fuzzy Logic Results:

The fuzzy logic is a concept of reasoning with the logic of if- then rules based on the system behaviour, the fuzzy logic is to set rules for the classified images of 9 combinations band ratio PCA Bands, then the 9 combinations of band ratio PCA Bands were divided into 3 sets of combination for to satisfy the rules is set to do the fuzzy logic using mamdani method by triangular member function, the input variables were Red, Green and Blue and the member functions which describes the surface characters of each classified band ratio images as a 3 set of combinations such as the 1st combinations are 123, 312, 231, the 2nd combinations are 234, 423, 342 and the 3rd combinations are 345, 534, 453, the output variable is a range of surface materials and their member function such as low in titanium, sensitive to iron, High in titanium and the area is described as maximum, medium and minimum, the rules set for the execution of fuzzy logic is in **(Table 3.3).** The rules set for fuzzy sets with if- then logic is given below:

For the maximum range of output the results of the fuzzy set rules for Maximum range of surface materials shown in **(Fig 4.19.).**

The rules for the **first** combination of band ratio images were set as

If the Band123 in red **then** it is low in titanium or high glass content,

If band 312 in green **then** it is sensitive in iron,

If Band 231 in blue **then** it is high in titanium.

The rules for the **second** combination of band ratio images were set as

If band 234 in red **then** it low in titanium or high glass content,

If band423 in green **then** it is sensitive to iron

If band 342 in blue **then** it is low in titanium.

The rules for the **third** combination of band ratio images were set as

If band 345 in red **then** it is low in titanium or high glass content,

If band 534 in green **then** it is sensitive to iron,

If band 453 in blue **then** it is high in titanium.

For the Medium range of output the results of the fuzzy set rules for Medium range of surface materials shown in **(Fig 4.20.)**

The rules for the **first** combination of band ratio images were set as

If band 312 in red **then** it is low in titanium,

If band123 in green **then** it is sensitive to iron,

If band 231 in blue then it is high in titanium,

The rules for the **second** combination of band ratio images were set as

If band 423 in red **then** it low in titanium or high glass content,

If band 234 in green **then** it is sensitive to iron

If band 342 in blue **then** it is low in titanium.

The rules for the **third** combination of band ratio images were set as

If band 534 in red **then** it is low in titanium or high glass content,

If band 345 in green **then** it is sensitive to iron,

If band 453 in blue **then** it is high in titanium.

For the Minimum range of output the results of the fuzzy set rules for Minimum range of surface materials shown in **(Fig 4.21.)**

The rules for the **first** combination of band ratio images were set as

If band 231 in red **then** it is low in titanium,

If band 312 in green **then** it is sensitive to iron,

If band 123 in blue then it is high in titanium,

The rules for the **second** combination of band ratio images were set as

If band 342 in red **then** it low in titanium or high glass content,

If band 423 in green **then** it is sensitive to iron

If band 234 in blue **then** it is low in titanium.

The rules for the **third** combination of band ratio images were set as

If band 43 in red **then** it is low in titanium or high glass content,

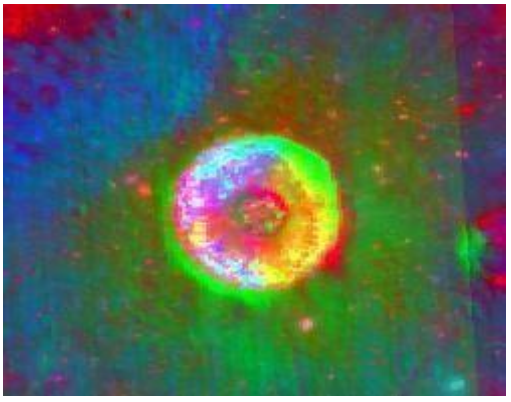
If band 534 in green **then** it is sensitive to iron,

If band 345 in blue **then** it is high in titanium.

This method is done by *[Vini, Aakanksha, Aditi, Ambika and Ankita, 2013],* from these set of rules the band ratio of PCA band images were classified by if- then logic through fuzzy logic using Matlab. The similar work of this method, the way of setting the rules with if- then logic by *[Ruby Bharti and Jitentra Kurmi, 2017].*

4.1.1 PCA Image Analysis

The PCA bands of 9 combination as RGB classified images given below,



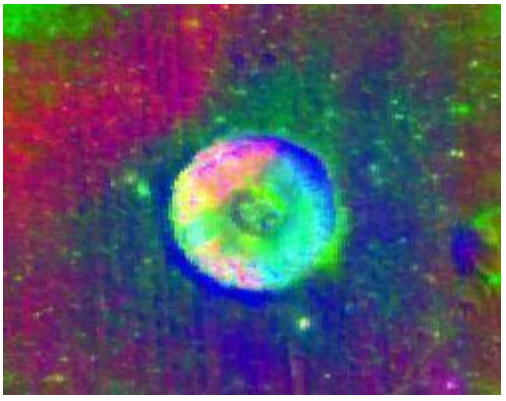


Fig 4.1. PCA 1 RGB combination of 123. Fig 4.2. PCA 2 RGB combination of 312.

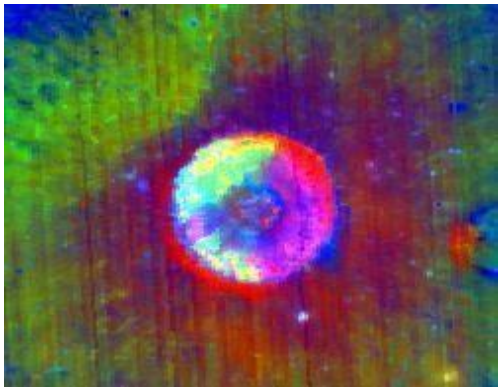


Fig 4.3. PCA 3 RGB combination of 231.

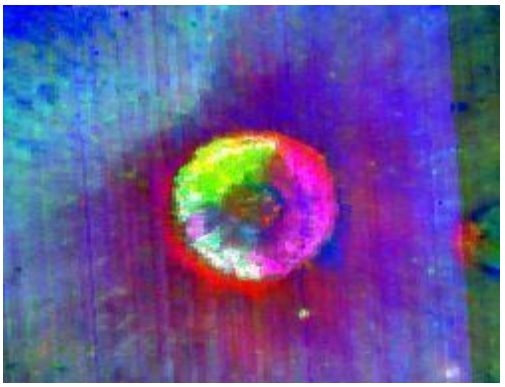


Fig 4.4. PCA 4 RGB combination of 234.

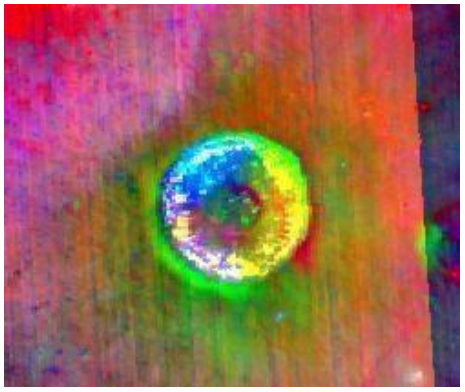


Fig 4.5. PCA 5 RGB combination of 423.

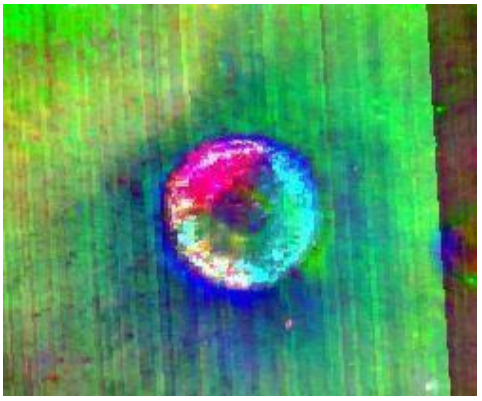


Fig 4.6. PCA 6 RGB combination of 342.

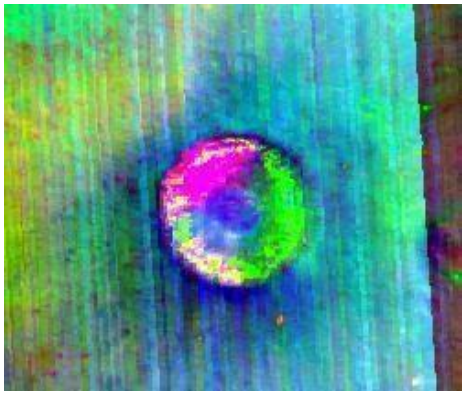


Fig 4.7. PCA 7 RGB combination of 345

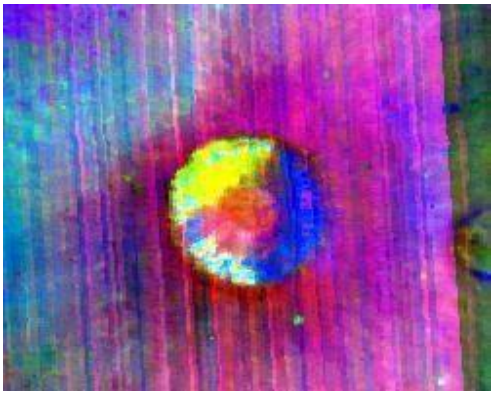


Fig 4.8. PCA 8 RGB combination of 534

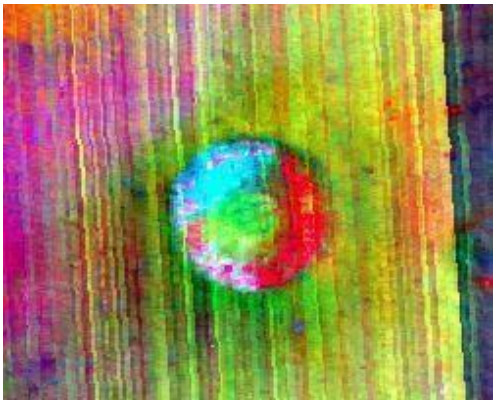


Fig 4.9. PCA 9 RGB combination of 453

4.1.2 Band Ratio PCA bands image analysis

The 9 combination of PCA band ratios with RGB classified images are given below,

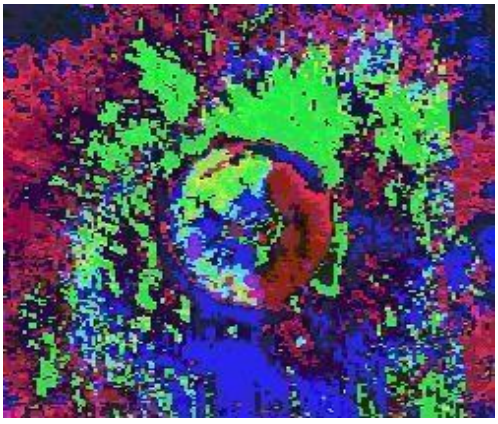


Fig 4.10. Band Ratio image for 123

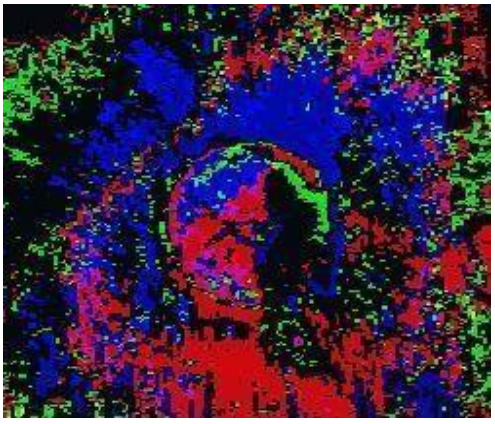


Fig 4.11. Band Ratio image for 312

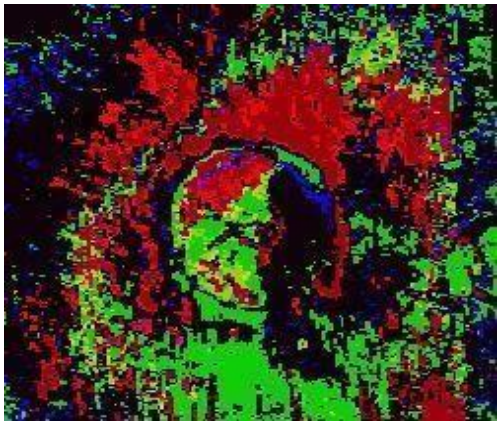


Fig 4.12. Band Ratio image for 231

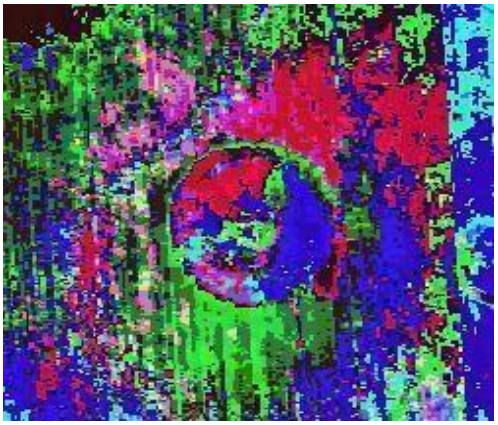


Fig 4.13. Band ratio image for 234

Fig 4.14. Band ratio image for 423

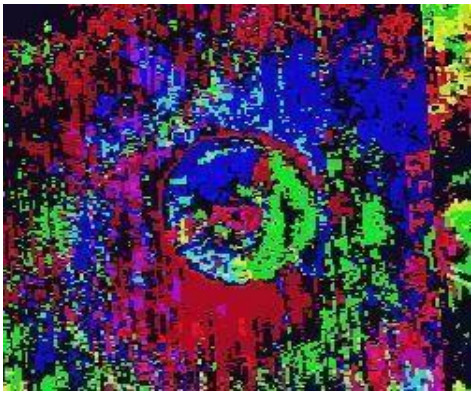


Fig 4.15. Band ratio image for 342

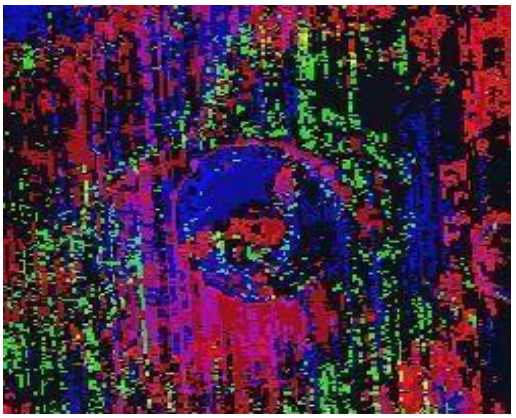


Fig 4.16. Band ratio image for 345

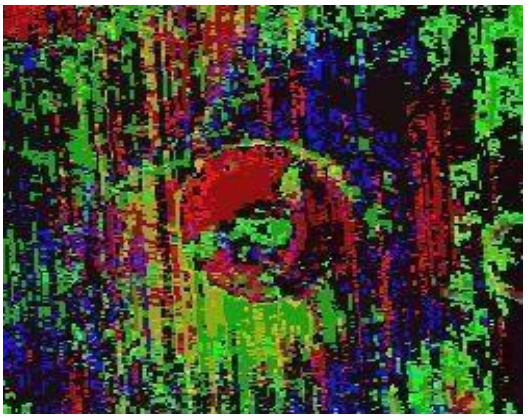


Fig 4.17. Band ratio image for 534

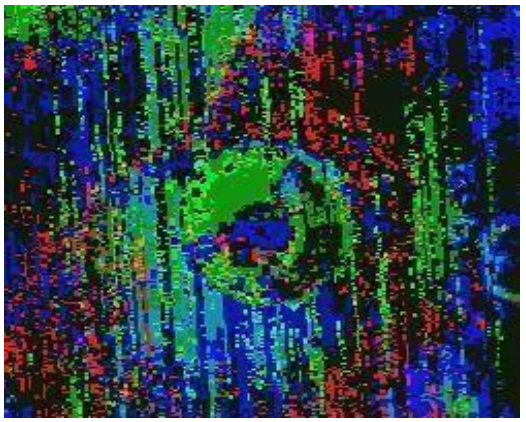


Fig 4.18. Band ratio image for 453

4.2.1 Results of Fuzzy Logic Rules:

The output results of fuzzy set rules based on if then logic is given below,

Output for Low in titanium represented in red:

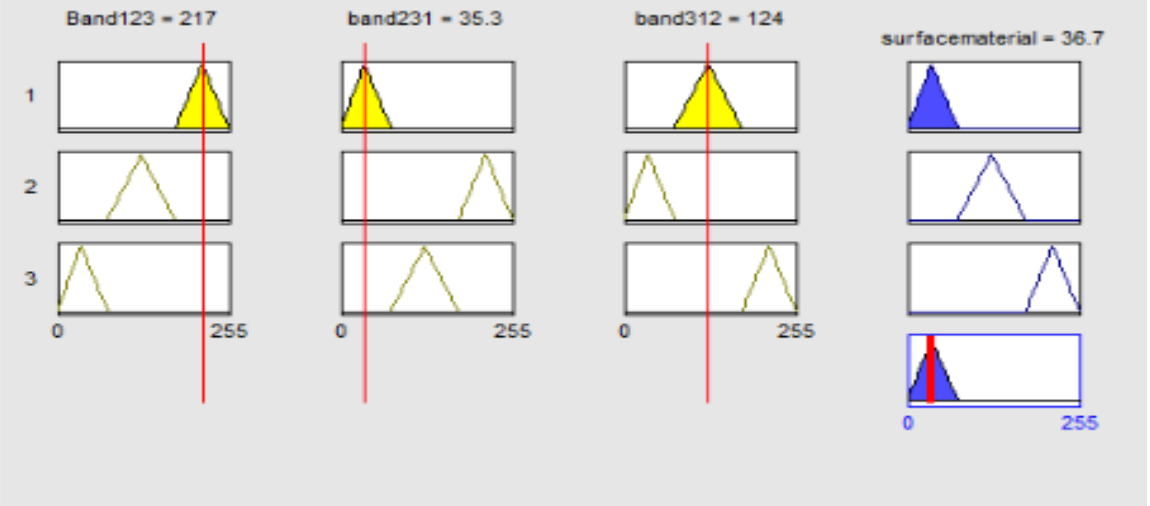


Fig 4.19. Fuzzy Logic rules this output for low in titanium for 1st combination of band 123 has maximum area of red, band 231 has minimum area of red, band 312 has medium area of red and same output for 2nd combination of band 234 has maximum, band 342 has medium, band 423 has minimum and same output 3rd combination of band 345 has maximum, band 453 has medium, band 534 has minimum.

Output for Sensitive to Iron represented in Green:

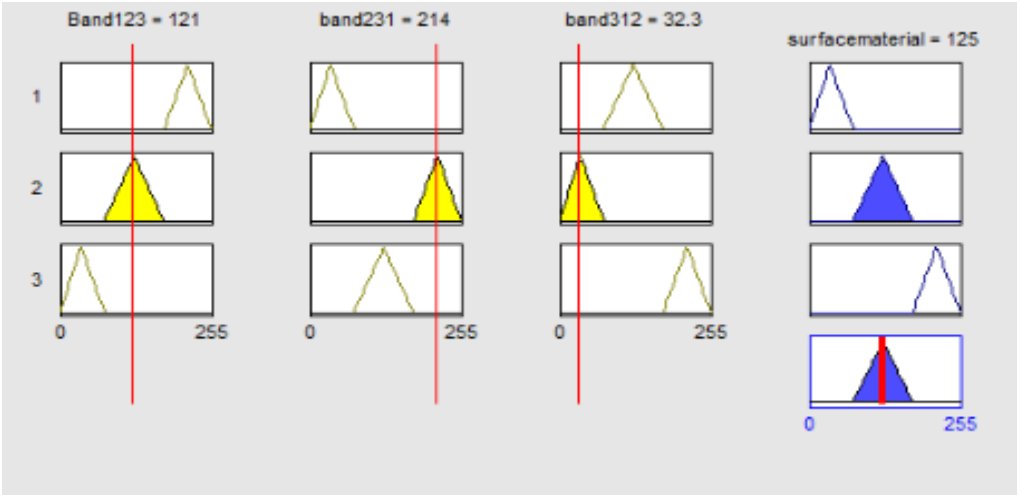


Fig 4.20. Fuzzy Logic this output is for Sensitive to Iron for 1st combination Band 312 has Minimum area of green, band 123 has medium area of green, band 231 has maximum area

and for the 2nd combination for band 423 has minimum, band 234 has medium, Band 342 has Maximum, and for 3rd combination Band 534 has minimum, Band 345 has medium, Band 453 has maximum area.

Output for High in Titanium represented in Blue:

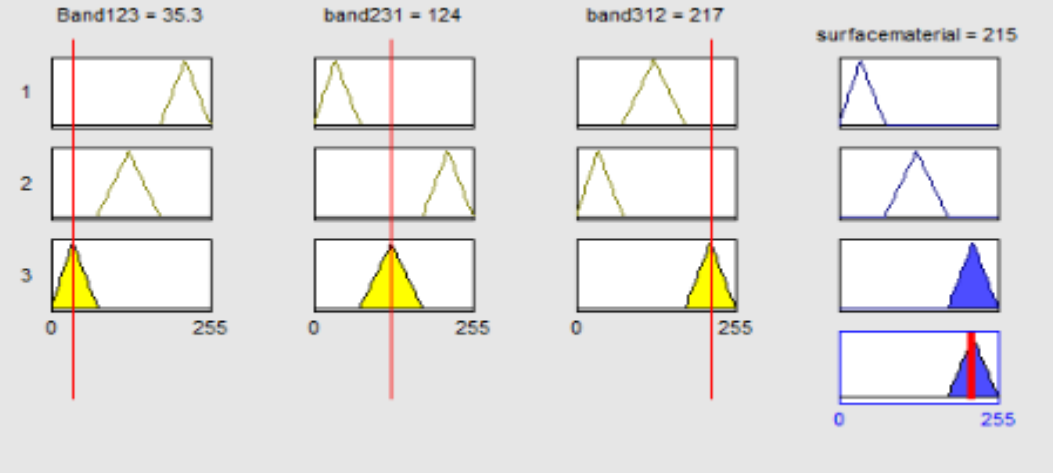


Fig 4.21. Fuzzy Logic rules this output for High in Titanium for 1st combination of Band 231 has medium area of blue, Band 312 has maximum, Band 123 has minimum and for the 2nd combination band 342 has medium, band 423 has maximum , band 234 has minimum and for the 3rd combination band 453 has medium, and 534 has maximum, band 345 has minimum area.

5. Conclusion:

In the present study, the M^3 high resolution satellite image has been used to study the surface characters and their materials of the Orientale's Il'in crater. In addition to that, the empirical technique of PCA bands has been processed for clearly to visualize the surface characters of the crater through the band combinations of 123, 312, 231, 234, 423, 342, 345, 534, 453. Moreover, the Band ratio of PCA bands enhances the conceivable and ample vision to observe the characters of the surface in an accurate range. At finally the fuzzy logic method was adopted to highlight the perfect band combination that could be shown the agreeable presence of the surface characters and features. The rules has been set with the logic of if- then for the range of surface materials from the 3 sets of band ratio combinations, the images were classified based on fuzzy set rules. The compositional variations of surface materials describe as the Red is low in titanium or high in glass content, the green shows it is sensitive to iron and the blue shows it is high in titanium.

6. References:

1. V Malik. 2013. Satellite Image Classification Using Fuzzy Logic. International J. of recent technology and engineering. 2277-3878.

2. R Gharbia. 2014. Fusion of multi-spectral and panchromatic satellite images using principal component analysis and fuzzy logic. IEEE International Conference on Fuzzy Systems. 1118 - 1122. DOI: 10.1109/FUZZ-IEEE.2014.6891873.

3. RP Gupta. 2013. A Simplified Approach for Interpreting Principal Component Images, Advances in Remote Sensing. 2. 111-119. doi:10.4236/ars.2013.22015.

4. S Jabari. 2013 Very High Resolution Satellite Image Classification Using Fuzzy Rule-Based Systems. Algorithms 6. 762-781. doi:10.3390/a6040762

5. A Taufik. 2016. Land cover classification of Landsat 8 satellite data based on Fuzzy Logic approach. IOP Conf. Series: Earth and Environmental Science 37 012062 doi:10.1088/1755-1315/37/1/012062

6. YG Shkuratov. 2003. Composition of the lunar surface as will be seen from SMART-1: A simulation using Clementine data. J. of Geophysical Research. https://doi.org/10.1029/2002JE001971

7. C Rodarmal. 2002. Principal Component Analysis for Hyperspectral Image Classification. Surveying and Land Information Systems, Vol. 62, No. 2, pp.115-000.

8. P Geladi. 1989. Principal component analysis of multivariate images. Elsevier Science. DOI: 10.1016/0169-7439(89)80049-8

9. J S Deng 2008. PCA-based land-use change detection and analysis using multitemporal and multi sensor satellite data. International Journal of Remote Sensing 29(16):4823-4838

DOI: 10.1080/01431160801950162.

10. Q Su. 2014. Lunar terrain and mineral's abundance automatic analysis. Elseiver Science.