KPU International Journal of Engineering & Technology
Volume 3, Issue1, Sep. 2023
e-ISSN:2790-0819, p-ISSN:2790-0800

Date Received: 2023-05-07
Date Accepted: 2023-06-25
Date Published: 2023-09-15

Copper mineral exploration and metamorphic rock investigation using remote sensing: A case study in the Shaida Copper Mine, Herat, Afghanistan

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Abstract

The Shaida copper mine is located on the Herat fault to Badakhshan and the old alpine zone of Harirud, and in terms of geological age, it belongs to the Mesozoic (Cretaceous) to Cenozoic era. There are many copper mines in Afghanistan which are still unknown. The main purpose of this research is to explore and predict the nature and type of copper mines in Afghanistan, which uses remote sensing and multispectral ASTER and Landsat (OLI) images to explore and investigate the metamorphic rocks of the Shaida Herat copper mine in western Afghanistan. Necessary corrections were applied to satellite images. To explore and investigate the transformation parameters, different satellite image processing algorithms, including principal component analysis (PCA) and inter-band ratios (BR) and spectral angle mapping (SAM), and the most spectral similarity (MLC) are used. Principal component analysis in bands PC1, PC2, and PC7 shows the maximum absorption range for providing copper mineralization. The inter-band ratio was used to examine stones and minerals (calcite, alunite, and kaolinite and to examine mafic rocks and carbonates). The algorithm of the most spectral similarity is used in the investigation of metamorphic rocks and to evaluate the performance of the algorithms, the spectra of the reference library provided by the United States Geological Survey (USGS) have been used. The evaluation and validation of alteration zones in the Shaida copper mining area provide the most spectral similarity algorithm with an accuracy of 0.61%, and the evaluation and validation of exploration in the Shaida copper mining area provide the spectral angle mapping algorithm with an accuracy of 0.68%. According to this research, the conditions of the formation of copper mines are oxide and sulfide mania. It is predicted that the reserve of the Shaida copper mine will increase over time as a result of detailed exploration and more detailed studies, and the increase in oxide and sulfide minerals of copper is economically important.

Keywords: Copper mineral, mining, metamorphic rocks, remote sensing

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1. Introduction

Remote Sensing (RS) is the science of information acquisition, processing, and interpretation of data and satellite images obtained from sensors that record the interaction between matter and electromagnetic energy [1]. Due to the use of satellite images, remote sensing is one of the important sources of information in many "geological" applications, such as mining exploration at local, regional, and global scales, monitoring exploration operations and mining, use of land cover, and environmental studies [2]. Over the last few years remote sensing science has been the best method in terms of time, resource, and cost [3]. Use of RS and GIS technology in the exploration of mines and investigation of metamorphic rocks and investigating geological structures are the basic goals of this technology [4].

In terms of geological research of Russian scientist Silavin from the years 1976 to the early 1800s the area of Afghanistan is extremely complicated in terms of geology. The development of rocks and geological structures in the territory of Afghanistan reaches the tectonic stages before Baikal [5]. The geology of Afghanistan's minerals was also presented by a team of Russian and Afghan engineers who prepared the geological map of Afghanistan in Moscow in 1980. Only in Afghanistan, the amount of copper reserves is estimated more than 68,500 million tons (Figure 1) [6]. This research and subsequent research aim to explore and predict the nature of copper mines in Afghanistan. In this research, the exploration of copper minerals and the investigation of metamorphic rocks in the Shaida copper mine of Herat, which is one of the platform areas in Afghanistan, have been discussed. Aerial photos and satellite images can be used to analyze the changes in the extent of sight according to the period [7]. Based on the studies conducted by many researchers, it is possible to detect metamorphic minerals and rocks using optical satellite image information [8] which in this research - multi-spectral satellite Landsat (OLI) is used.

ASTER sensor has 14 bands, three of which are in the visible and near-infrared VNIR with a resolution of 15 meters and six bands in the short infrared SWIR which has a spatial resolution of 30 meters. It has five TIR thermal bands with a resolution of 90 meters. (OLI) Landsat sensor has 11 bands, 8 spectral bands, one panchromatic band with a spatial resolution of 15 meters, and 2 thermal bands with a spatial resolution of 90 meters [9].

Principal component analysis (PCA), Spectral angle mapping (SAM), and Interbrand ratio (BR) were used to explore copper minerals and to check the metamorphic rocks in

the period from 2013 to 2021, the algorithm of the most spectral similarity (MLC) was used. The result of this research shows that the evaluation and validation of changes in the Shaida copper mining area show the most spectral similarity algorithm, with 0.61% accuracy. The evaluation and validation of the spectral angle mapping algorithm in the Shaida copper mining area provide an accuracy of 0.68%.

In this research, based on the studies of Russian and Afghan engineers in 1980, the Shaida copper mine has conditions for oxide and sulfide formation. It is predicted that copper minerals will increase over time based on tectonic developments and movements (Herat fracture to Badakhshan) [10] and that these movements cause an increase in copper minerals in the Shaida copper mine. From an economic point of view, copper oxide and sulfide minerals are very important.

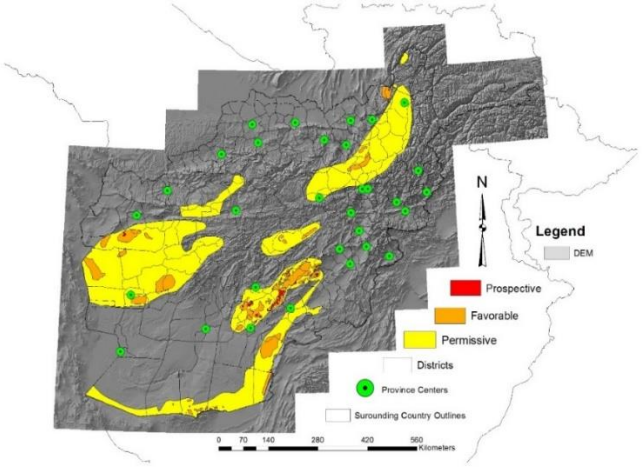


Figure 1: Location map of Afghanistan's copper mines. Red borders for Prospective limits, orange borders for Favorable limits, yellow color Permissive, and green color State center (www.USGS.Gov2004).

Study area

The Shaida copper mine in Herat is located in the common area between Pashtun Zarghoon and Adraskan at 33°47′24″N and 61°49′30″E (figure 2). The Shaida copper mine with 1.1% of pure material, 4 meters wide and 150 meters long, 2.4–8 meters thick, 2400 meters area is situated 65 km from Herat province. The copper reserves of this mine are 5 million tons, which were specified in the joint survey of Russia and Afghanistan in 2018. The Shaida copper mine is related to the tectonic zone of Farah and Qala-e-Naw, which is in the Turkmen segment of Iran and Harirud fault, and the subsidence of Herat as a position (Figure 3) [11]. In this region, the rocks are young, and in terms of geological age, they reach the Mesozoic (Perm, Cretaceous) to Cenozoic eras (Figure 4). In terms of folding, it is related to the old Alp and Harirud zone [12].

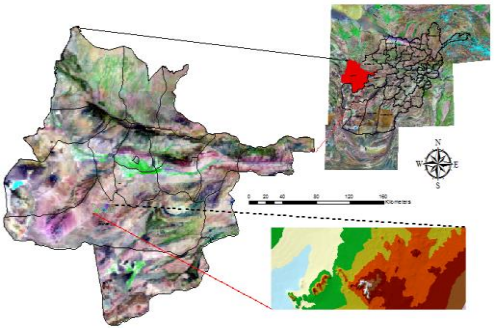


Figure 2: A) DEM map of Afghanistan, B) Map of Landsat ETM+ satellite zone, C) Location map of Shaida copper mine (Jorris et al. 2002).

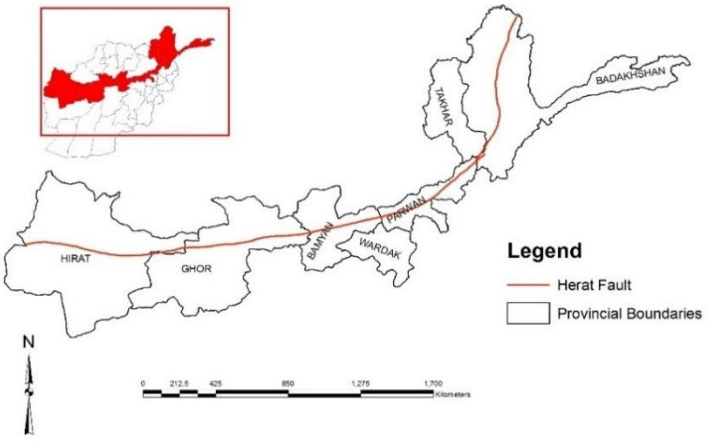


Figure 3: Map of Harirud fracture (Desi, A., 1975)

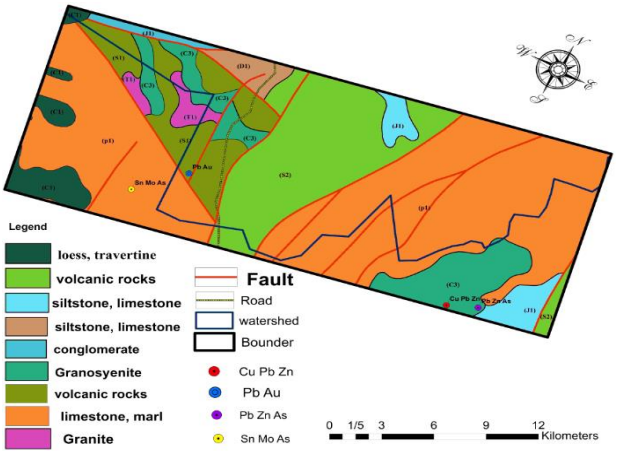


Figure 4: Geological map of Shaida copper mine in Herat (Afghan Geological Map 2005)

2. Data preprocessing

Materials and Methods

In this research, to explore and investigate the metamorphic rocks multi-spectral ASTER and Landsat (OLI) satellite images were used which includes data preparation, processing of satellite images, and preparation of a mineralogical map and preparation of metamorphic rock map of the Shaida copper mine. For atmospheric correction of Shaida, VNIR, and SWIR bands of ASTER and R, G, and B bands of Landsat (OLI) (Quick Atmospheric correction) algorithm and for correction of TIR band ASTER will use (Thermal atmospheric correction). Image geometric correction operations of ASTER and ground referencing them using crosstalk correction (Crosstalk) on the ASTER images were done. The general research processes are shown in (Figure 5).

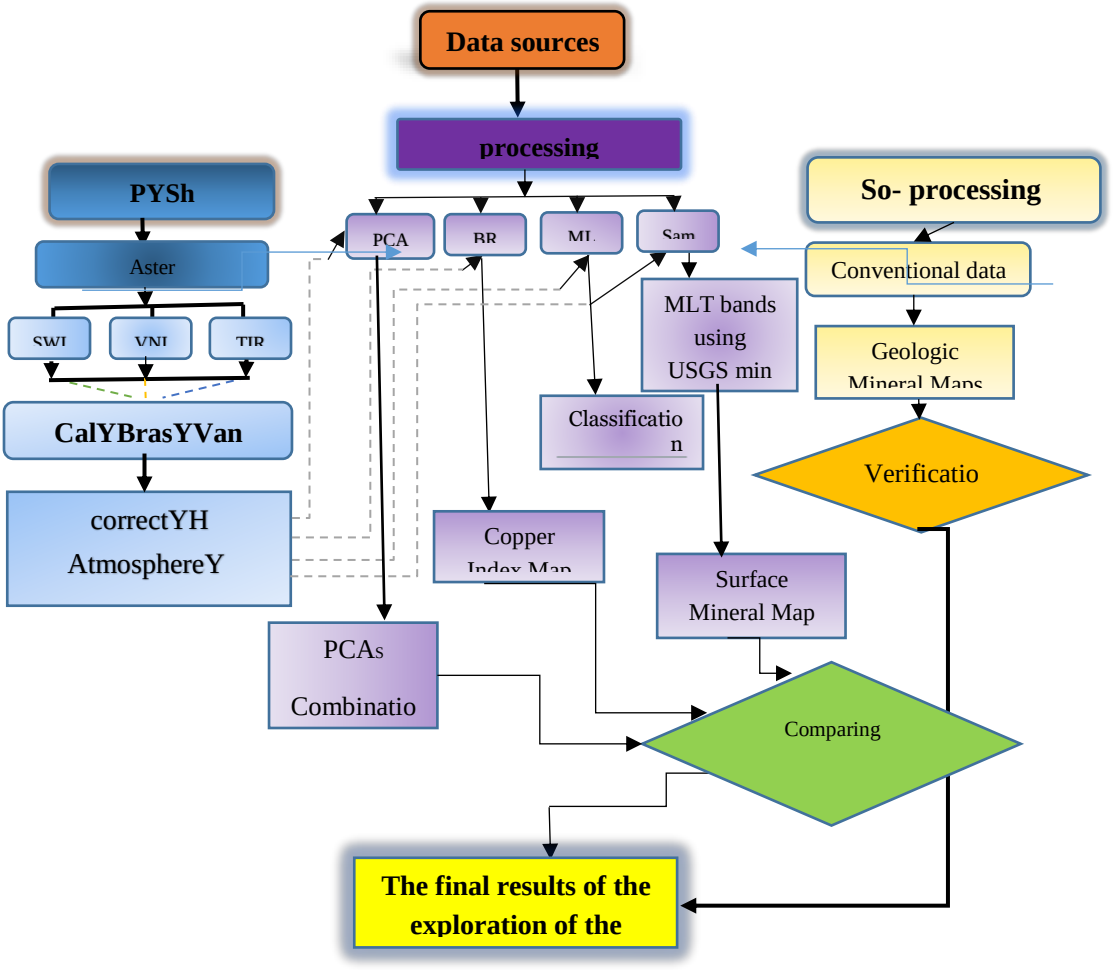


Figure 5: The general research process

Satellite data processing

Principal component analysis (PCA)

PCA is used to reduce the interference effect of materials, especially vegetation, and also extensively for metamorphic mapping [13]. This vector algorithm of a matrix and variance-covariance or one correlation matrix can be computed [14]. This method is into two modes of standard (use of all bands) and suitable bands (here bands containing absorption and reflection characteristics of the desired minerals) is used with the lowest correlation (Figure 5).

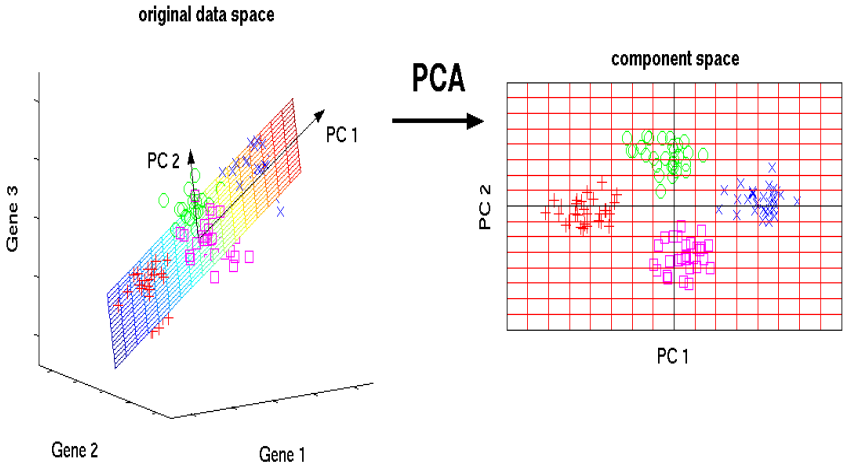


Figure 6: The structure of the principal component analysis algorithm in two general modes of standard component analysis and appropriate component analysis.

In the method of principal component analysis or reduction of input bands, while avoiding the interference effect of certain spectra (such as plants), the discussion of highlighting the desired minerals should be increased [15].

The principal component analysis distinguishes copper minerals from other phenomena where characteristic values are shown. In the bands PC1-PC2-PC7 which has suitable values for highlighting, characteristics of copper minerals have been provided based on the RGB. The red colors inside the ellipses show the copper minerals in this area, and the green color shows the areas where other minerals such as quartz or minerals that are in the composition of copper sulfide and minerals with prominent oxide exist. Blue and purple colors show areas where non-mineral materials are highlighted (Figure 7).

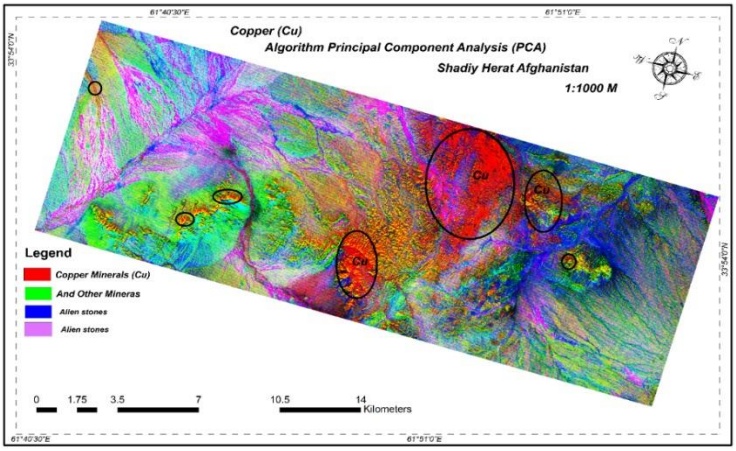


Figure 7: RGB map from the method of principal component analysis with R:7, B:2, and G:1 copper mineral using ASTER satellite images. Elliptical shapes with red pixels show copper minerals. The green pixels show other minerals in the copper mineral limit, and the blue and pink pixels indicate soil and other natural materials around the mine environment.

Spectral angle mapping (SAM)

This type of mapping (has been widely used by researchers in recent years to identify minerals. This algorithm was presented by a researcher named Boardman as part of a spectral angel mapping image processing system [16]. SAM is used as part of a diagram in the scattered space drawn by the values of the pixels in the bands of an image. In this diagram, pixel spectra are presented against target spectra which calculate each of the sampled points. A smaller angle between the pixel spectrum and the reference spectrum indicates a higher similarity (Figure 8). The spectral angle is relatively insensitive to changes in pixel brightness, as the direction of the vector remains constant, and only the size changes [17].

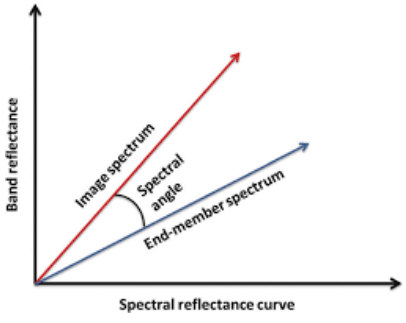


Figure 8: The structure of the implementation of the spectral angle mapping algorithm.

$$a = cos^{-1}[\frac{\sum_{j=1}^{nb} b_i r_i}{[\sum_{j=1}^{nb} E_J^2]^{\frac{1}{2}} \sum_{j=1}^{nb} r^2]^{\frac{1}{2}}} \quad 1$$

- Here n_b indicates Band numbers, b_i laboratory spectrum, and r_i reference spectrum [18].

In this research, for copper minerals classification Spectral angle mapping algorithm was used based on the standard of the ASTER spectrometer library and the USGS website.
To identify copper minerals, using SAM classification systems and spectral libraries of the USGS geological site and based on spectral behaviors, copper minerals have been identified (Figure 9).
In this research, copper minerals including Chalcopyrite, Malachite, Azurite, Quartz, Bornite, and chalcocite are classified (Figure 9). The SAM method displays the areas related to copper minerals. Here the yellow pixels show chalcopyrite minerals, the green pixels show Bornite minerals, the orange pixels show quartz minerals, the pink pixels show malachite minerals, the red pixels show azurite minerals and the blue pixels show chalcocite minerals. The spectral behavior of copper minerals extracted from ASTER sensor images is presented in (Figure 10).

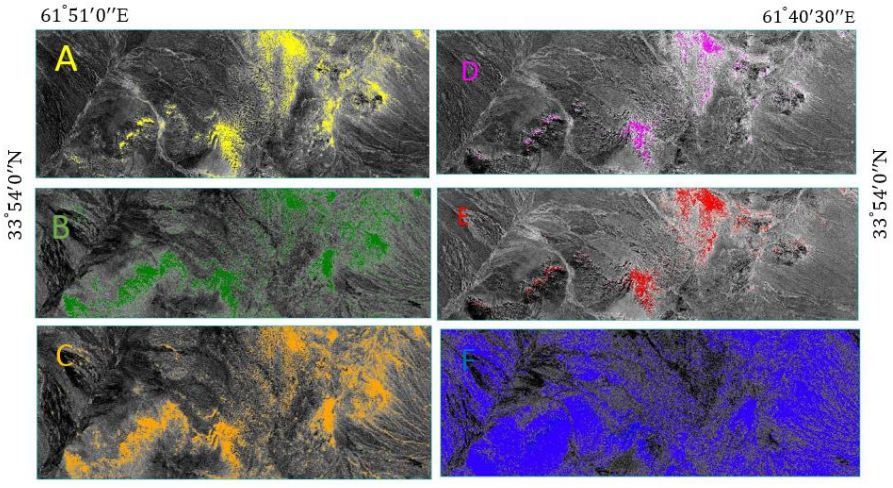


Figure 9: Output map of copper mineral identification by SAM spectral angle analysis method. Here it shows A- chalcopyrite, B- bornite, C- quartz mineral, D- malachite, E- azurite mineral, and chalcocite mineral.

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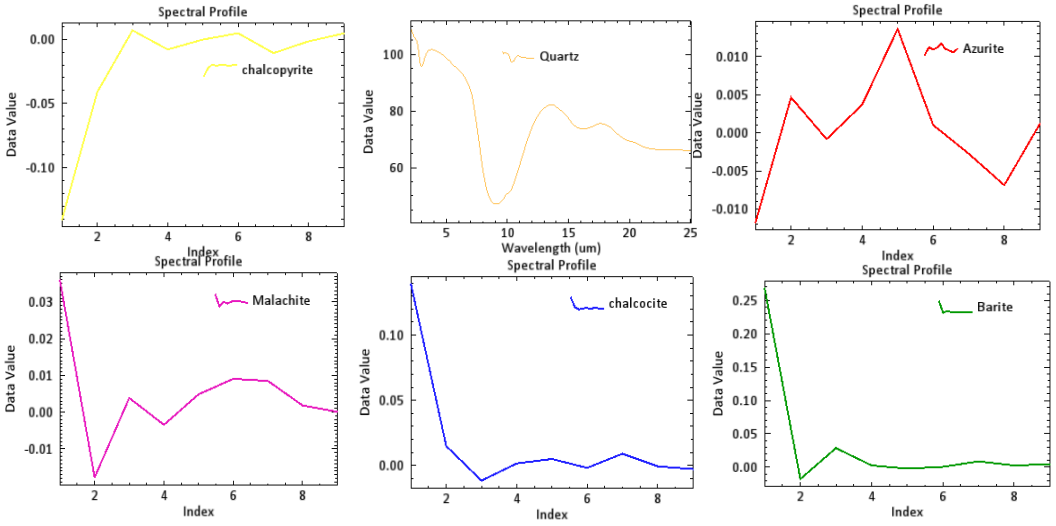


Figure 10: Spectral behavior of copper minerals extracted from ASTER sensor images

Algorithm of band ratio (BR)

This is the algorithm that by knowing the characteristics of maximum absorption and maximum reflection of different minerals, can highlight different phenomena [19]. The result of dividing the pixel identification degree values in one spectral band by another spectral band is called band ratio [20]. This method makes the difference between brightness levels more obvious and makes the border between effects clearer. Technically, band ratio is a certain number of band values divided by the DN number of another band value [21].

The band ratio (BR) for the absorption feature is the sum of the number of bands that represent the values and the band denominator. which is located in the closest absorption feature (Figure 14) [22]. The basis of this algorithm is based on the band ratios of four mathematical operations. In this research, the band ratios method is used to check mafic rocks (Figures 11 and 12).

$$OH\ bearing\ altered\ minerals\ Index(OHI) = \left[\frac{band7}{band6}\right]\left[\frac{\text{band4}}{\text{band6}}\right] \quad 2$$

$$\text{Kaolinite Index(KLI)} = \left[\frac{\text{band4}}{\text{band5}}\right]\left[\frac{\text{band8}}{\text{band6}}\right] \quad 3$$

$$\text{Alunite Index (ALI)} = \left[\frac{\text{band7}}{\text{band5}}\right]\left[\frac{\text{band7}}{\text{band8}}\right] \quad 4$$

$$\text{Calcite Index(CLI)} = \left[\frac{band6}{band8}\right]\left[\frac{band9}{band8}\right] \quad 5$$

$$Carbonate\ Index(Cl) = \left[\frac{band13}{band14}\right] \quad 6$$

$$Mafic\ Index(MI) = \left[\frac{band12}{band13}\right] \quad 7$$

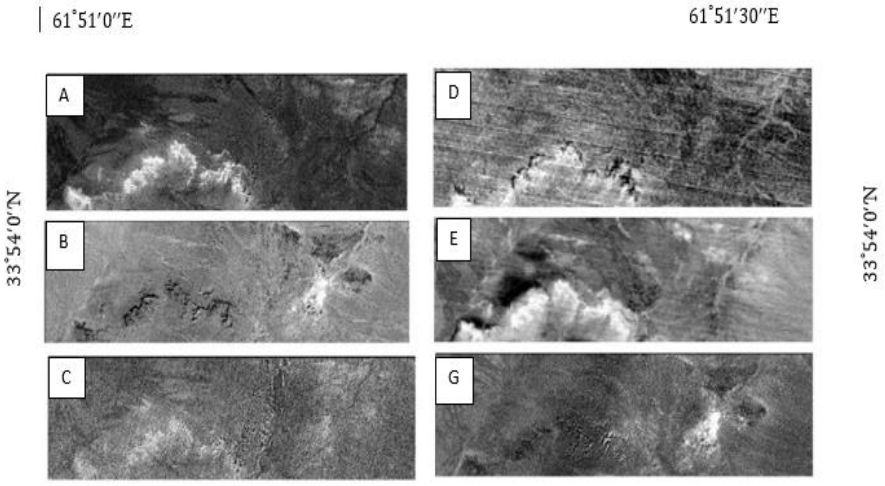


Figure 11: Output map of the band ratio algorithm A - band ratio (b6/b8+b8/6) of bright pixels representing minerals (calcite) B-band ratio (b4/b5+b8/b6) of bright pixels representing minerals (kaolinite) - ratio C Band (b7/b5+b7/b8) bright pixels of minerals (alunite) D-band ratio (b13/b14) of bright pixels of minerals (carbonates) E- band ratio (b12/b13) of bright pixels of mafic stones G- The band ratio (b7/b6+b6/b4) of the bright pixels of the alteration rocks.

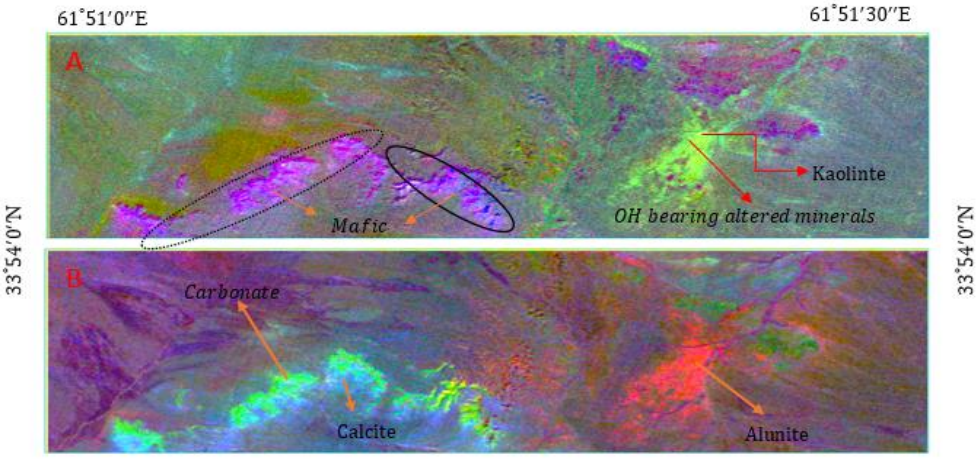


Figure 12: A) RGB image of band ratio R:7/6+4/6, G:4/5+8/6, B:12/13; B) RGB image of band ratio R:7/5+7/8, G:6 /8+9/8, B:13/14.

In the output of image, A, green and light yellow pixels represent rocks (alteration) and minerals (kaolinite), and pink to red pixels represent rocks (mafic).
In the output of image B, green and turquoise pixels represent mineral (carbonate) and mineral (calcite), and red to reddish pixels represent mineral (alunite).

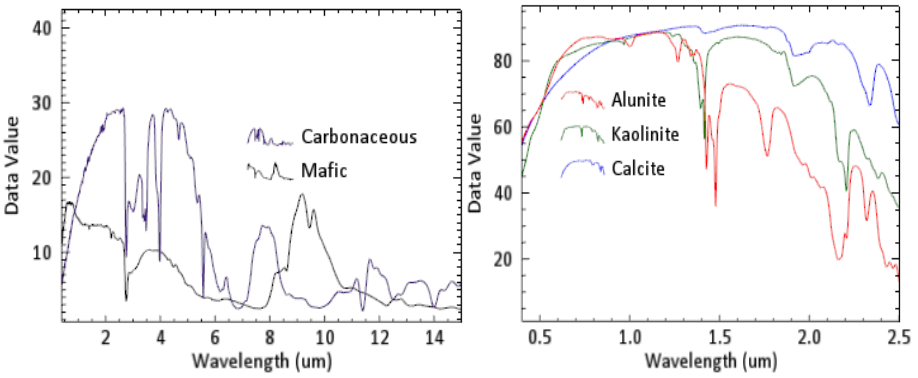


Figure 13: Spectral behaviors of minerals and carbonate rocks, mafic, calcite, Alunite, and Kaolinite using the spectral behavior of the ASTER sensor library.

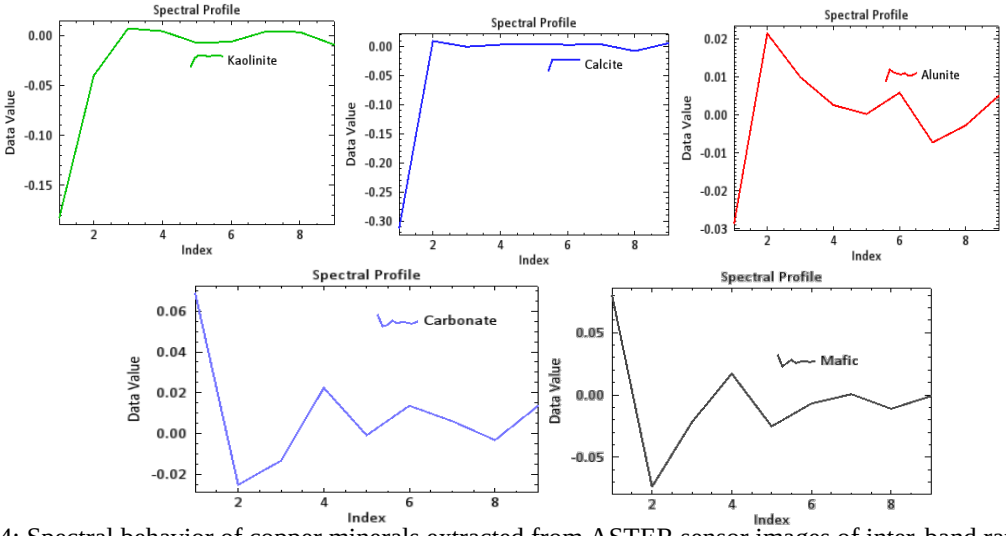


Figure 14: Spectral behavior of copper minerals extracted from ASTER sensor images of inter-band ratio algorithm.

The most spectral similarity algorithm MLC

This algorithm is one of the most famous statistical algorithms for classification, which is among pixel-based methods [23]. In the classification of the most similarity, the class is assigned to the pixel that has the highest probability of belonging to that class [24].

In this research, Landsat satellite images (OLI) have been presented in the Shaida copper mine to investigate the changes in metamorphic rocks in the period from 2013 to 2021 (Figures 15 and 16).

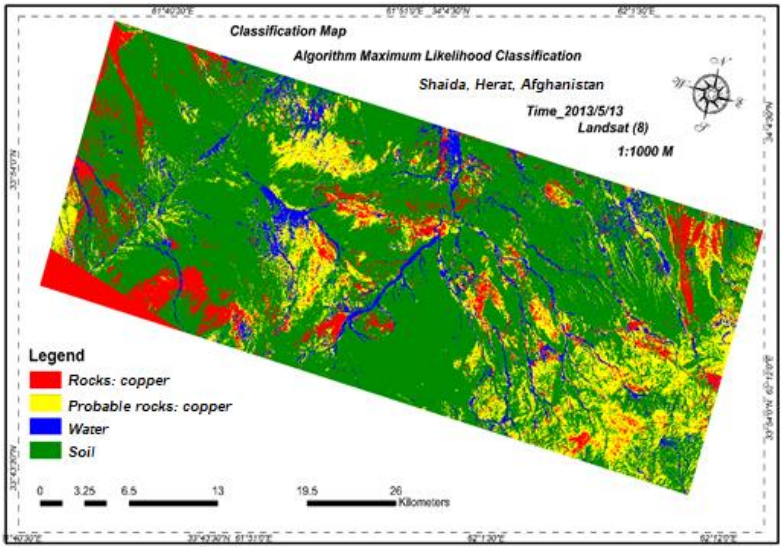


Figure 15: Classification map of alteration stones with MLC algorithm in 2013. Red colors show the rocks that contain copper minerals. Yellow colors are areas where there is a possibility of copper minerals among mafic rocks. The blue colors are the amount of water in the Shaida region. The green colors are the amount of soil, sand, etc. available in the area.

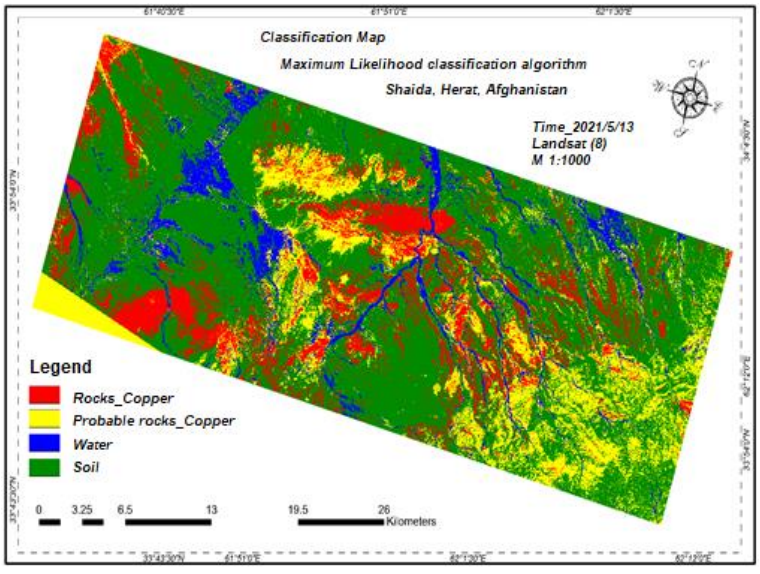


Figure 16: The classification map of alteration rocks with the MLC algorithm for 2021. Red colors show rocks that contain copper minerals, the yellow colors are the areas where there is a possibility of the presence of copper minerals among the mafic rocks. Blue colors are the amount of water that exists in the Shaida region. The green colors are the amount of soil, sand, etc. available in the area.

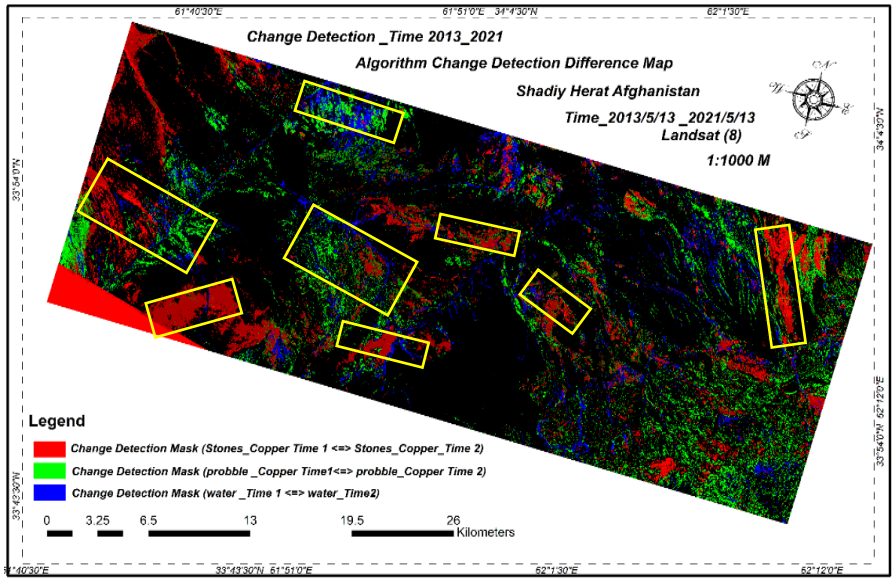


Figure 17: The map of the number of changes from the first time to the second time based on the classification of the most spectral similarity. The yellow rectangles show the areas where copper minerals have changed from the first period to the second period. Red colors show the number of rock changes in which copper mineral compounds are more. The green colors show the minerals and materials including soil and rocks, in which the changes have occurred from the first time to the second time, and the blue colors show the amount of water changes.

Investigating the formation conditions of copper minerals and predicting the nature of copper in the Shaida copper mine

Copper is a periodic table element with the chemical symbol of Cu. Copper is a metallic element with high electrical and thermal conductivity whose main feature is malleability. Copper minerals are classified into different types in terms of formation conditions [25] which include all kinds of oxides, sulfides, silicates, chlorides, and hydroxides. The types of copper deposits include porphyry copper deposits along with skarn and vein deposits and magmatic copper deposits. Volcanogenic massive sulfide-type copper deposits [26].

The results of this research are obtained in the prediction section of this result which the copper minerals exist in the Shaida mineral deposit. In this area, minerals are oxide and sulfide types. The amount of copper minerals in oxide minerals is more in the earth's crust. Natural interactions cause the transformation of sulfide rocks into oxide rocks. Copper oxide rocks are mostly formed from sulfates, carbonates, and sometimes silicates. Sulfide rocks, unlike oxidized rocks, are located lower and deeper than the earth's crust. Most of the copper ores are sulfur rocks. Sometimes in nature, copper is found in free form. This copper is found in the form of small grains inside the conglomerate, although

larger pieces have also been found [27]. In terms of studies and research conducted from 1976 to the early 18th century by V. A. Slavin and Wolfat Witkin in 1980 on the tectonics and geology of Afghanistan Shaida copper mine has oxide and sulfide formation conditions and in terms of stratigraphy and paleontology, Herat province and Shaida copper mine includes the Mesozoic era (Cretaceous) to the Cenozoic era [28].

Based on the founding of this research most of the copper minerals in the Shaida copper mine are azurite, chalcopyrite, malachite, chalcocite, and bornite.

3. Discussion

Considering that in this study two goals such as the preparation of an exploratory map and examination of alteration rocks exist, therefore these two issues are discussed separately.

A- Preparation of exploratory map: - In this study, to better determine the exploratory map and mineralogy of the Shaida copper mine, principal component analysis and inter-band ratio and spectral angle classification methods have been used. According to the fact that each method has advantages and disadvantages, there are three maps such as PCA, BR, and SAM to check how well each method works in characterizing copper minerals.

B- Preparing a map of alteration rocks: -Maximum spectral similarity maps are the most rejection-tolerant category of methods and in the method of maximum spectral similarity, it is assumed that the distribution of educational data of each class is normal.
In the method of maximum spectral similarity after data collection, n is the total number of reference points, ni is the number of pixels that are actually in the category of points, ni+ is the number of reference pixels in the class and n+i is the number of pixels placed in the class according to the detection method. The overall accuracy is also obtained by dividing the sum of correctly segmented pixels by the total number of reference data. The accuracy and detection of each image are done by the parameters of the overall accuracy of the Kappa coefficient of the calculated confusion matrix and the confusion matrix resulting from two classification methods, MLC is shown in Table 1, and the Kappa coefficient and overall accuracy are calculated using the equations 8 and 9 respectively.

$$k = \frac{n\sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_i + n + i}{n^2 - \sum_{i=1}^{k} n_i + n + i} \quad (8)$$

$$Overall\ accuracy = \frac{correctiy\ classified\ totals}{Reference\ data\ totals} \quad (9)$$

Accuracy (70+39+60+80)/346= (249/346) = 0.71% 0.71*100=71% MLC

Kappa Coefficient = 0.61% = 0.61*100 = 61%

Accuracy = 173/282 = 0.61% SAM

Kappa coefficient = 0.47%

Table 1: Maximum likelihood ambiguity matrix classification

Collection	Water	Soil	Possible copper mineral	copper mineral	Class
94	16	8	0	70	copper mineral
40	1	0	39	0	Possible copper mineral
100	13	60	2	25	Soil
112	80	10	10	12	Water
346	107	78	51	110	Collection

4. Conclusion

Preparation of an exploratory map and alteration map of the studied area using satellite images is a fast and reliable method. ASTER, Landsat (OLI) satellite data of the exploratory region is used to investigate the metamorphism of the Shaida copper mine and processing methods such as principal component analysis (PCA), inter-band ratio (IBR), spectral angle mapping (SAM) and maximum spectral similarity (MLC) were also used. In this research, by applying the mentioned processing methods, the minerals azurite, malachite, quartz, chalcopyrite, chalcocite, bornite, calcite, alunite, and kaolinite were identified in the exploration area of the Shaida copper mine. According to the geological studies of the Shaida copper mining area, most of the copper alteration rocks are present, which are related to the conditions of oxide and sulfide formation. However, in the Shaida area, porphyry copper rocks are less available, and if they are available, they are in the depths of the deposit layers. The obtained results and images show that these methods have acceptable results in determining and separating the copper and metamorphic extents in the exploration area of the Shaida copper mine. Also, the optimal method for determining regional alterations is the MLC spectral similarity method and the effective method for mineral exploration is the SAM (spectral angle mapping) method. From the results of this research on the formation of copper minerals and the prediction of copper-rich areas, it can be seen that in addition to the Shaida copper mine, there are copper oxide and sulfide mines in other parts of the country, which can be

investigated and explored in the future using remote sensing methods which are used in this research.

Reference

[1] Dr. Ankara Rajendran, Dr. Subhi Nasir, Mapping of manganese potential areas using ASTER satellite data in parts of Sultanate of Oman, May 2013International Journal of Geosciences and Geomatics ISSN: 2052-5591

[2] Dry Jian Yang, Prof. Dr. Le Yu (April 30, 2020). Special Issue. Applications of RS and GIS Integration in Natural Resources and Environmental Science: Remote (ISSN 2072-4292). This special issue belongs to the section Environmental.

[3] Guha. Himanshu. Evaluation of ASTER TIR data-based lithological indices in Malanjkhand Copper Mines of Madhya Pradesh, India. 03 Nov 2019.https://doi.org/10.1080/25726838.2019.1684018

[4] Alshaya, MS, Alshaya, MS, Mohammed, AM, Javed, A., & Alba root, MA Manual and Automatic Extraction of Lineaments From Multispectral Image in Part Manual and Automatic Extraction of Lineaments From Multispectral Image is Part of Al-Rawdah, Shabwah, Yemen by Using Remote Sensing and GIS Technology. International Journal of New Technology and Research (IJNTR). ISSN: 2454-4116, Volume-3, Issue-2, February 2017 Pages 67-73.

[5] Sahel, A., 2015, Structural setting and evolution of the Afghan orogenic segment – A review, in Brunet, MF, McCann, T., and Sobel, RR, eds., Geological Evolution of Central Asian Basins and the Western Tien Shan Range, London: The geological society of London, p. 427.

[6] Abdullah, S. & Chmyriov, VM (eds). 2008. Geology and Mineral Resources of Afghanistan. 2 Volumes. British Geological Survey, Occasional Publications, 15. http://www.bgs.ac.uk/downloads/browse. cfm? sec=7&cat=83.

[7] De Oliveira Andrade's Filo C. De FáTima Rossetti D. Effectiveness of SRTM and ALOS-PALSAR data for identifying morpho-structural lineaments in northeastern Brazil, Pages 1058-1077, Nov 2010, https://doi.org/10.1080/01431161.2010.549852

[8] A. Gasman. C. Gomez, H. Zohar, A. Masse, D. Doctor. PCA and SVM as geo-computational methods for geological mapping in the south of Tunisia, using ASTER remote sensing data set.Arabian J. Geosocial., 9 (20) (2016), pp. 1-12,10.1007/s12517-016-2791-1

[9] Ibtissame Bentahar.Mohammed RajiComparison of Landsat OLI, ASTER, and Sentinel 2A data in lithological mapping: A Case study of Rich area (Central High Atlas, Morocco). Volume 67, Issue 3, 1 February 2021, Pages 945-963. https://doi.org/10.1016/j.asr.2020.10.037

[10] John Ford Schroder, Naima Eqrarb, Hamidullah Waizyc, Hemayatullah Ahmadi c and Brandon J. Weihs. Review of the Geology of Afghanistan and its water resources. 13. May 2021. http://orcid.org/0000-0002-8995-0234

[11] Abdullah, Sh., Chmyriov, VM, Stazhilo-Alekseev, KF, Dronov, VI, Gannan, PJ, Rossovskiy, LN, Kafarskiy, A.Kh., and Malyarov, EP, 1977, Mineral resources of Afghanistan (2nd edition): Kabul, Afghanistan, Republic of Afghanistan Geological and Mineral Survey, 419 p.

[12] Aghanabati, A. & Ghorbani, M. 2011. Metallogenetic Map of the Middle East, 1:5 000 000. Geological Survey of Iran, Commission for the Geological Map of the World (CGMW/CCGM), Paris.

[13] GJ Orris, JD BlissMine and mineral occurrences of AfghanistanOpen-File Report 2002-110, https://doi.org/10.3133/ofr02110

[14] Desio, A., 1975, Geology of central Badakhshan (North-East Afghanistan) and surrounding countries, Italian expeditions to the Karakoram and Hindu Kush, scientific reports III, geology-petrology: Leiden, EJ Brill, p. 628.

[15] Geologic Map of Quadrangle 3264, Nawzad-Musa-Qala (423) and Dehrawat (424) Quadrangles, Afghanistan. US Geological Survey Open-File Report 2005-1115-A, compiled by Robert G. Bohannon and Charles R. Lindsay.

[16] Kaufmann, H., 1988- Mineral Exploration along the Aquila-Levant Structure by Use of TM Data, Concepts, Processing, and Results. International Journal of Remote Sensing, 9, 1639-1658. doi 10.1080/01431168808954966.

[17] Ibtissame Bentahar.Mohammed RajiComparison of Landsat OLI, ASTER, and Sentinel 2A data in lithological mapping: A Case study of Rich area (Central High Atlas, Morocco). Volume 67, Issue 3, 1 February 2021, Pages 945-963. https://doi.org/10.1016/j.asr.2020.10.037

[18] Freak D. van der Meer, Harald MA van der Warf, Frank JA van Ruitenbeek, Chris A. Hecker, Wim H. Bakker, Marleen F. Noomen, Mark van der Meijde, E. John M. Carranza,J. Boudewijn de Smeth, Tsehaie Woldai, 2012- Multi- and hyperspectral geological remote sensing: A review. Volume 14, Issue 1, February 2012, Pages 112-128. https://doi.org/10.1016/j.jag.2011.08.002

[19] Golchin Hajibapir, Mohammad Lotfi, Afshar Zia Zarifi, Nima Nezafati1 Application of Different Image Processing Techniques on Aster and ETM+ Images for Exploration of Hydrothermal Alteration Associated with Copper Mineralizations Mapping Kehdolan Area (Eastern Azarbaijan Province-Iran), Open Journal of Geology, 2014, 4, 582-597, http://dx.doi.org/10.4236/ojg.2014.411043

[20] Honarmand, M., Ranjbar, H. and Shahabpour, J. (2012) Application of Principal Component Analysis and Spectral Angle Mapper in the Mapping of Hydrothermal Alteration in the Jebal-Barez Area, Southeastern Iran. Resource Geology, 62, 119-139 .http://dx.doi.org/10.1111/j.1751-3928.2012.00184.x

[21] Girouard, G., Bannari, A., El Harti, A., & Durocher's, A. (2004, July). Validated spectral angle mapper algorithm for geological mapping: a comparative study between Quick Bird and Landsat. In Ext ISPRS Congress, Geo-Imagery Bridging Continents, Istanbul, Turkey (pp. 12-23). Grainger, JH, Ratkoski, AJ, & Hoke, ML (2004, August). The sequential maximum angle convex cone (SMACC) endmember model. In Defense and Security (pp. 1-14). International Society for Optics and Photonics

[22] Gopinathan Pa, Parthian Sb, Magnetron Tc, Ayad M. Faddily Al-Quashed, Ashok K. Singe, Pradeep K. Singe, Mapping of ferric (Fe3þ) and ferrous (Fe2þ) iron oxides distribution using band ratio techniques with ASTER data and geochemistry of Kanjamalai and Godumalai, Tamil Nadu, south India. Remote Sensing Application: Society and Endearment 18(2020)100306:http://www.elsevier.com/locate/rsase

[23] Mamadou Traorea, Jonas Didero Takodjou Wambob, Cyrille Prosper Ndepetec, Senem Tekinea, Amin Beiranvand Pourd Aidy M Muslimd, Lithological and Alteration Mineral Mapping for Alluvial Gold Exploration in the South East of Birao area, Central African Republic Using Landsat-8 Operational Land Imager (OLI) Data 9 June 2020, doi:https://doi.org/10.1016/j.jafrearsci.2020.103933.

[24] Hashim M, Park Y, Hong JK. 2017. Mapping alteration mineral zones and lithological units in Antarctic regions using spectral bands of ASTER remote sensing data. Geocarto Int. doi:10.1080/10106049.2017.1347207

[25] Qi Chen1, & Zhifang Zhao, Qigang Jiang, Shucheng Tan, Yinggui Tian, Identification of metamorphic rocks in Wuliangshan Mountains (Southwest China) using ASTER data 29 May 2018 Arabian Journal of Geosciences (2018) 11:311, https://doi.org/10.1007/s12517-018-3635-y

[26] Rowan.LC, Mars.JC, 2003, Lithologic mapping in the Mountain Pass, California area using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data, Journal of Remote Sensing of Environment, Vol: 84, p: 250-266.

[27] Azizi.H., Tarverdi.MA, Akbarpour.A., 2010, Extraction of hydrothermal alterations from ASTER SWIR data from east Zanjan, northern Iran, Journal of Adv Space Res, Vol: 46, p: 99–109.

[28] Donald G. Barceloux,Dr. Donald Barceloux, Copper 06 Aug 1999 https://doi.org/10.1081/CLT-100102421

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