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Interpreting Results of Band Maths Operations in Sentinel-2 Image

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ABSTRACT

Many studies have been done on environmental pollution of the Reps region regarding Acid Mine Drainage, but there are no studies with the help of remote sensing which is a science of collecting data without a physical contact. In this setting, the purpose of this research work is to monitor the environmental impact of the abandoned mines in water, vegetation and non-vegetation areas by exploring Sentinel-2 data in Reps regions. The information utilized in this paper has been developed from the program of European Space Agency Copernicus. After the selection of the Reps region it has been explored the products in the Sentinel Application Platform. According to our data, the incorporation of visual optical of flora, ground covering and humidity as well as computing Spectral Angle Mapper can help us in the early identification of Acid Mine Drainage. The combination of field studies with remote sensing increase the overall efficacy in detecting pollution and protecting the environment.

Keywords: Optical image, water bodies, NDWI, NDVI, ferric iron, spectral angle mapper.

1. INTRODUCTION

The term "remote sensing" implies detecting the surface of the Earth from space by utilizing the highlights of electromagnetic waves radiated, reflected, or diffracted by the detected objects to explore and protect the environment. [1, 2].

Copper mining waste storage typically includes three types of waste: tailings, dump and waste rock, and overburden. Copper waste is an iron-rich hazardous waste, which contains heavy metals such as Cu, Zn, Co, Pb. When pyrite is uncovered in water and air, it experiences a chemical response called “oxidation.” Oxidation of pyrite takes put through two primary stages. The primary organization is that of the arrangement of iron sulphates and the concentration of H particles beneath conditions of an acidic pH whereas the moment is the total oxidation of Fe^{2+} to Fe^{3+}. The Oxidation of Fe^{2+} is escalated beneath the activity of microscopic organisms [3].

The oxidation preparation produces acidic conditions which can hinder plant development at the surface of a squander heap. Revealed, non-vegetated, orange-coloured surface materials make some squander shake ranges significantly unmistakable, and they are the first self-evident result of these acidic conditions. In case that water penetrates into a pyrite-laden squander rock, the coming about oxidation can ferment the water, empowering it to break down metals such as silver, zinc and copper. This generation of acidic water is commonly alluded to as corrosive or Acid Mine Drainage (AMD) [4].

AMD is the formation and movement of highly acidic water rich in heavy metals. From [5] it has been seen that acidic water forms in the chemical reaction of surface water and shallow subsurface water with rocks which contain sulphur-bearing minerals which results in sulfuric acid [5]. The ferric iron was delivered to oxidize more pyrite or hydrolysis to auxiliary stages like schwertmannite and jarosite [6]. Based on the mine squanders or pyritic shales were uncovered from the air and pure water, the weathering of pyrite takes put at such a rate that it can cause contamination and geotechnical problems inside many a long time [7].

The state of the art in research synthesis has impressively progressed during the last decade. According to our literature review, one of the alternatives described for enhancing the accuracy of the ultimate comes about is the consideration of optical indexes of vegetation, terra firma, and H_2O to extend the preparing information run and raise generally viability [8-11]. Multispectral Sentinel-2 data are utilized primarily through the application of a limit on Spectral Indices that have been proposed around the world [12-14]:

- Normalized Difference Vegetation Index (NDVI),
- Normalized Difference Water Index (NDWI), and
- Modified NDWI (MNDWI) to classify water pixels among others.

Meanwhile, the NDWI index can be utilized primarily for clear water spectra hence is restricted for sullied water bodies (an assortment of spectra) just like the mining environment [15].

Over the final decade, several papers have highlighted the potential key part of satellite information in the environment and in specific the NDVI since it may be a possibly cheap, efficient, repeatable, and irrefutable observing strategy for natural administration [16].

Scientists have researched and have illustrated further detecting and spectroscopic investigation for AMD distinguishing proof, characterizing the ghostly reflectance of AMD and its relationship to water quality parameters [17-19]. Spectral Angle Mapping (SAM) is an algorithm, which utilizes multi-dimensional angles to match the target pixels to reference spectra. The method calculates a metric spectral resemblance by simply computing the inclination between spectra's which have the vector dimension of the number of bands [20-24].

Many studies have been done in Albania regarding the Dumps of the Fan river region (Reps and Rubik) constituted as the hottest spot in the region, in terms of the problem of heavy metal pollution [25-27]. Nevertheless, remote sensing studies have been limited to studies with Sentinel-1 data [28, 29]. The condition of the "sterile" damps in regions of Reps, Rrëshen and Rubik by their rinsing and sliding is considered a risk for the pollution of the Fan River [25, 26]. From the studies, Pyrite turns out to be the main reason for AMD in this region. From the analysis and assessment of environmental risk, it results that the ecosystem of Fan valley in the Reps - Rubik region, is severely damaged by the copper mining and processing industry, as in the alienation of the environment from a natural to an industrial environment, with violent anthropogenic influence, as well as in heavy metal pollution [27].

This research work aims to apply simple band operations in a Sentinel 2 scene of the region of interest to highlight different kinds of spectra. The main tasks are as follows:

- To extract water features (clean water and hyper acidic water) by NDWI and by performing the Band ratio (B4/B3) for identifying Ferric iron.
- To extract water, vegetation, and soil by NDVI.

- To compute Spectral Angle Mapper between our Sentinel 2 scene and the reference spectra for Pyrite.

Due to the oxidation of sulphide minerals deposited near mines principally pyrite (FeS2) leads to AMD, our question is if we can evaluate properly the AMD by performing Spectral Angle Mapper analysis.

2. MATERIALS AND METHOD

2.1 Study area

Albania is one of the seriously mining nation that has comprised of various mines where prepared chrome, copper, coal, ferronickel, limestone, bitumen, tar sand, etc. One of the important is Reps region which is located in the Lezhe county at the Mirdita district, see Figure 1. The Reps milling and concentration facilities operated until 1994, producing several tons of waste and tailings, mostly stocked in two main piles alongside the Fan river. The condition of the rising "sterile" dams in regions Reps, Rrëshen and Rubik and their sliding are considered a risk for the pollution of the Fan River because of AMD.

Figure 1. Location of Reps in Albania. Google maps: satellite image.

2.2 Data set

The multispectral information put to use within the scope of this term paper is collected by the European Space Agency (ESA) Copernicus program which is comprised of five satellite families each one focusing on a specific aspect of earth observations. Sentinel-2 comprises 13 bands spanning around 440–2200 nm in the electromagnetic spectrum: four bands at 10 meters, six bands at 20 m, and three bands at 60 m spatial resolution. To access Sentinel-2 data we use Copernicus Open Access Hub by registration and after registering we gain access to the images. Firstly, we have selected the region of interest and then explored the Sentinel-2 product in the SNAP program (the Sentinel Application Platform) which maybe a common design for all Sentinel Tool kits. [30-32].

2.3 Extraction of data

In this paper, we have searched in the Copernicus Open Hub for the sensing period 01.10.2020 to 31.10.2020, for Sentinel-2 product type S2MSI2A, Cloud cover (0 TO 2), where we have found the image which covers the Reps region, see Figure 2. After selecting Mirdita district as our region of interest, we have explored it in the SNAP program [32].

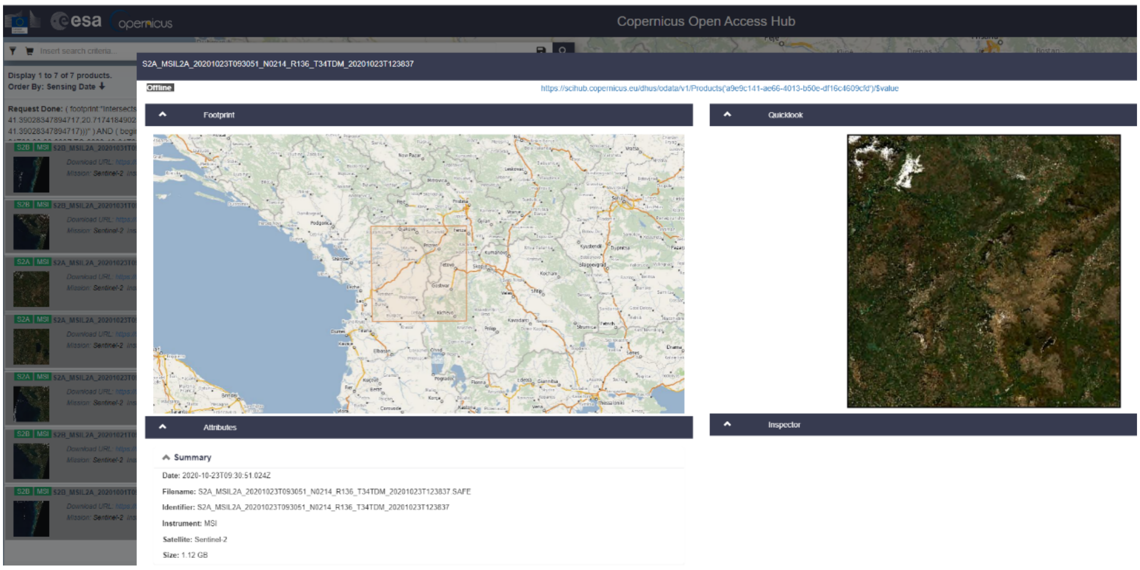

Figure 2. Search in the Copernicus Open Access Hub for image products from Sentinel 2 satellites covering the Reps region

2.4 Subset and Resampled the product

The workflow for Sentinel-2 image consists of pre-processing (to reduce) data volume we made spatial and spectral subset while to put all the bands in 10 m pixels resolution we made resampling). In Figure 3 we have presented the image after subset and resampling.

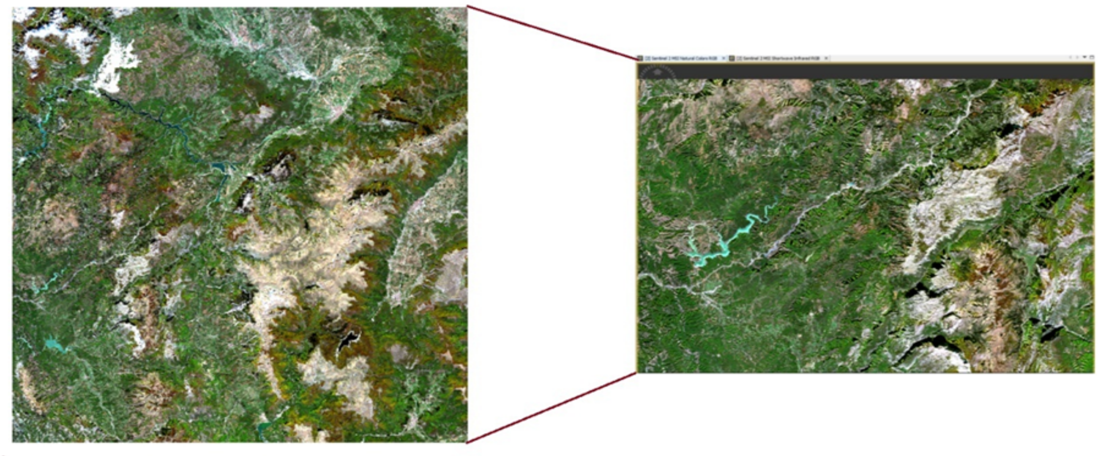

Figure 3. Image covering Reps region being subset and resampled

2.5 Band operations

2.5.1 Normalized Difference Water Index: NDWI

NDWI is used for extracting the water features. We have used NDWI due to clear water spectra that have high reflectance values around 550 nm and low reflectance values around 900 nm. Expression for NDWI: (Band3 - Band8)/ (Band 3 + Band 8). This ratio will produce values greater than 0 for clean water spectra and negative values < 0 for other types of spectra. It is not the case for hyper acidic water which absorbs most of the light and these water bodies are displayed as a flat spectrum. On the other hand, some materials such as pyritic and sulfuric tailings respond to the index and are mapped as water features.

2.5.2 Band ratio for Ferric Iron

This is an approach that is based on a histogram. We have followed these steps: Create the Histogram of a band, create and activate a water mask, convert the mask to a layer using band math's and apply a Band ratio (Band 4/Band 3) for identifying the ferric iron in the water mask creating a new layer and afterward analysing the water which is affected by AMD. The procedure is formulated on the fact that the mean reflectivity of water pixels (water spectra) is much lower than that of most common materials. Thus, we can use a threshold on a spectral band where the difference in reflectance between water pixels and any other pixels is the greatest. Furthermore, we can use Band 8 and a threshold of 0.1. The additional ferric iron location capacity has been optimized and focused on through Band ratio (B4/B3) due to the water bodies which has been affected by AMD and have a sharp peak in the reflectance around 650 nm (Band 4). This peak can be characterized by using band ratios that has been used by researchers to analyse iron content. A ratio value 0 to 1 shows clean water while greater than 1 will highlight AMD.

2.5.3 Normalized Difference Vegetation Index: NDVI

The NDVI was computed according to state of art thresholds as a popular index to identify and map vegetation. It was computed by Band Maths as (NIR-Red)/(NIR + Red) where NIR and Red were considered the amount of near-infrared and red light, respectively, reflected by a surface and measured by satellite sensors. Concretely it takes a look at the relationship between B4 and B8 as a ratio of (Band 8-Band 4)/(Band 8+Band 4). Due to each pixel of each band has this mathematic operation the result will be a map of NDVI values between -1 and 1 in which the lower, the further we are from the possibility of having a vegetation area. From -1 to 0 typically we have water, from 0 to 0.3 bare soil and some vegetation may begin even in the value 0.3 but the higher the value of the denser correspond to vegetation. In our research work we have used the values as follows: water is mapped with negative NDVI values bare soil, cloud and snow have NDVI values close to zero while vegetation has values greater than 0.5.

2.5.4 Spectral Angle Mapper: SAM

This method is based on the estimation in the 12th dimensional space (consists of 12 bands) of the spectral resemblance among each pixel and the pyrite (the reference spectrum in our case) described by vectors starts at the coordinate system's origin. By assessing the angle difference between pixel and reference spectra our image can be divided into any number of classes.

In the Figure 4 it has been presented the band operations model that we have applied in our image.

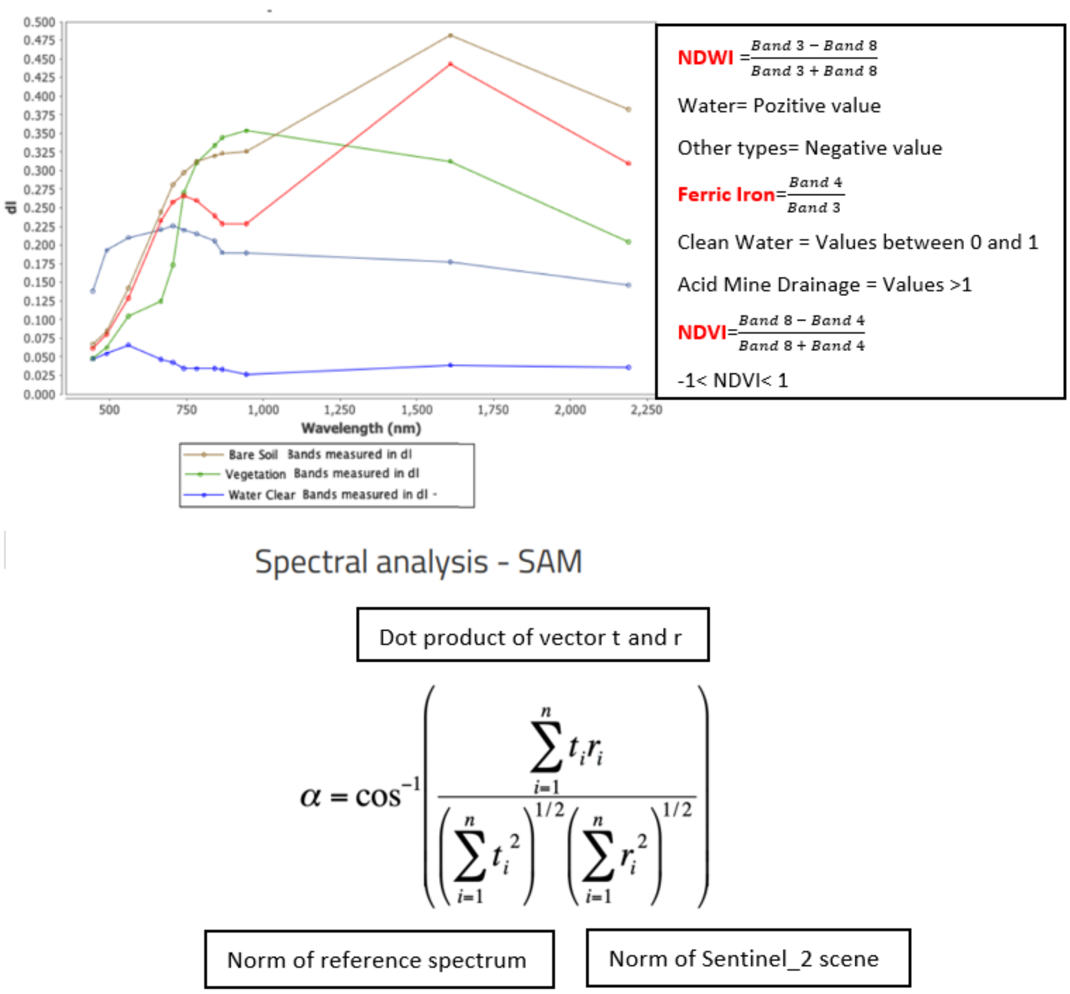

Figure 4. Summary of spectral information by using Band operations (NDWI, Ferric Iron, NDVI and SAM).

3. RESULTS

In this section we will give the technical aspects of computing and also analysis of each band operation in our pre-processed image. Firstly, we had to do the pre-processing where for Sentinel-2 image consisted of only creating a subset. Utilizing it we extracted only one very small spatial part of the interest of the whole Sentinel-2 scene which considerably reduced the file size and limited computation times. It can be done by the command Raster-Subset. In the spatial subset tab, we have extracted our subset from the geographic coordinates, while in the Band subset tab we have selected only Band 1 to Band 12 excluding Band 8A as it is the narrow near-infrared band that is completely within the Band 8.

3.1 Technical aspects and analysing NDWI

NDMI consists in normalizing the difference between bands 3 and 8, producing values greater than 0 for clean water spectra and negative values for other types of spectra. In the grey image, we noticed the high index values in white. By editing the colour map with the colour manipulation tab, we made the water bodies more visible by colouring with grey the pixels with negative values and with blue the pixels with positive values. By comparing with Sentinel 2 image red-green-blue (RGB) composite we have seen that water bodies were well defined, see Figure 5.

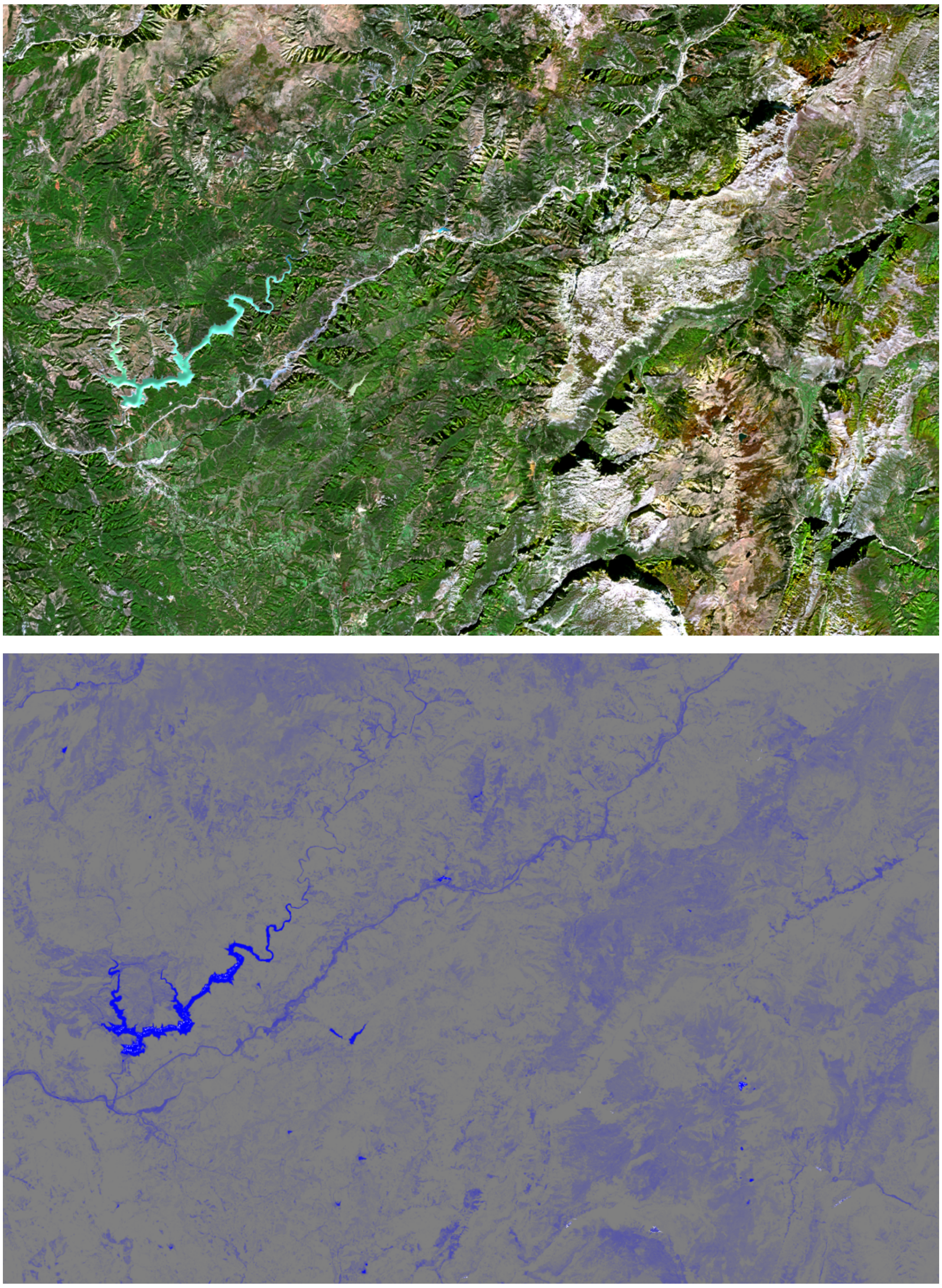

Figure 5. Presentation RGB image and NDWI image: gray colors for pixels with negative values (other spectra) and blue colors for pixels with positive values (water spectra) in the Reps region

Due to the water bodies with hyper acidic water-absorbing most of the light can display the flat spectrum and because some materials such as pyritic or sulfuric tailings can respond to this index and as a consequence are mapped as water features, this approach does not work for evidence of AMD. If we compare the NDWI layer with the RGB composite Positive NDWI values (> 0.1) were associated with features water. This work should be good for most water bodies but not very good in mining environments because

NDWI has not been adapted to spectra of hyper acidic water and some alteration spectra have positive NDWI values making thresholding difficult.

3.2 Technical aspects and analysis Band ratio for Ferric Iron

This approach is reached on the fact that the mean reflectivity of water pixels is much lowered than that of most common materials. Figure 6 depict the presentation of creating the layer "ferric iron" in the Reps region.

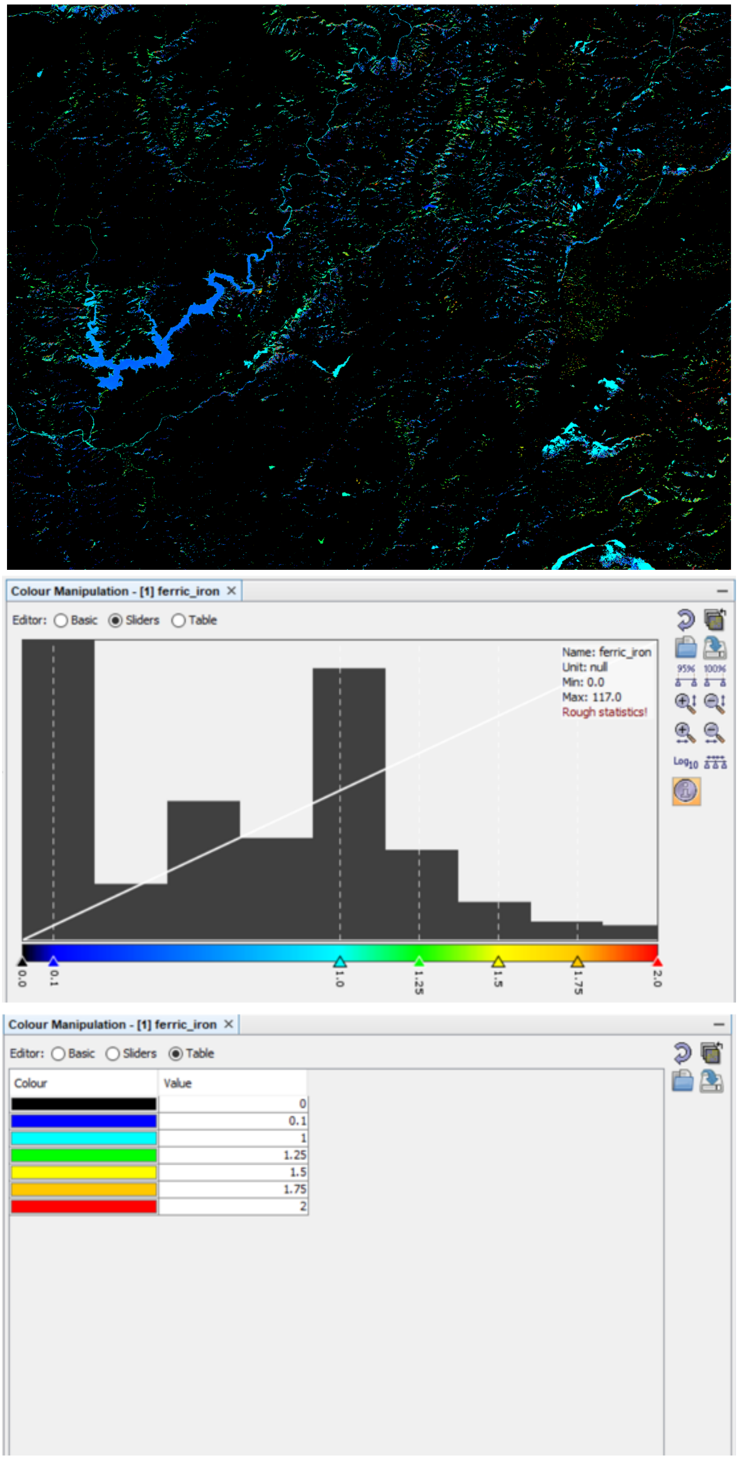

Figure 6. Presentation of creating the layer "ferric iron" in the Reps region.

Firstly, we can use a threshold in the spectral band where the difference in reflectance between water pixels and any other pixels is the greatest. (for example, Band 8). To apply a threshold in a band it is necessary to create a histogram and to select in it a range of values between 0 and 0.1. With this action, a new mask is created in the mask manager of the program and we can activate it. If we see the image now there is the possibility to observe the water features within the open pit, as well as the tailings, are not masked. Secondly, it is necessary to convert the mask into a binary layer which is important for mapping acid mine drainage. After creating the new layer named water mask with the expression "histogram_plot_area==255" we have now a binary image where water pixels have a value equal to 1 and appear in white while non-water pixels have a value equal to 0 and appear in black.

Afterward it has been created a new layer named "ferric iron" in the band math with the expression above for ferric iron multiplied by the water mask. It has been seen a grayscale image where Non-Water Pixels correspond the values 0, Clear Water Pixels have values between 0 and 1, and Water Pixels affected by Acid have values greater than 1. To better see these results, we have changed the colormap using the colour manipulation tab (stretched the sliders, adding four new sliders and edit using the table menu (the first slider has 0 value the second 0.1 and the third 1.0 coloured them in different types of blue (clean water pixels). We set the values of the remaining sliders between 1.0 and 2.0 and coloured them from green to red gradient because these colours will highlight pixels with AMD, see Figure 6.

While interpreting the results we noticed that the water bodies far from the mines are blue, which means that, they are not affected by AMD while water features inside the mine perimeter are coloured in green or red due to their iron content. We can see also how the drainage can be affected by the AMD, in some places, there is clean water and, in some places, there is the confluence with AMD.

3.3 Technical aspects and analysis NDVI

In the Band Maths it has been created the NDVI Band with Raster-Band math and Name NDVI. The expression is the difference between B8 and B4 (we normalize by dividing by their sum). As a result, a grayscale image will be created. We want to extract the water bodies and non-vegetated areas by thresholding these NDVI values. We can illustrate that by choosing masks from the histogram. NDVI has negative values for water bodies, Intermediate values (0.0-0.5) for non-vegetated or bare soil areas, and large values towards 1 for vegetated areas.

By thresholding the NDVI values using the mask manager, we have converted the mask into a layer. Firstly, we have created the mask for the water bodies named S2_water (NDVI should be smaller than -0.05), then, in the same way, we continue with creating the mask for the non-vegetated areas or bare soil areas named S2_non_veg (NDVI > -0.05 and NDVI < 0.5).

In our image, we can see the water mask in blue for the river and also the water bodies as well as the water in the area where the mining operation is no longer present. We can identify the water ponds as well as the river. But there is no view in the regions with clouds and no view of the very small water ponds.

From the mask for the non-vegetated area, we see the mine masked so we can identify the open pit areas but we have some urban structures masked as non-vegetated areas. By comparing with our natural colour view (RGB) even the clouds are identified as non-vegetated areas. We have no exact identifications of the non-vegetated areas which correspond to mining operation areas. In Figure 7 we have presented the application of the water mask and the non-vegetated mask in the Sentinel-2 image.

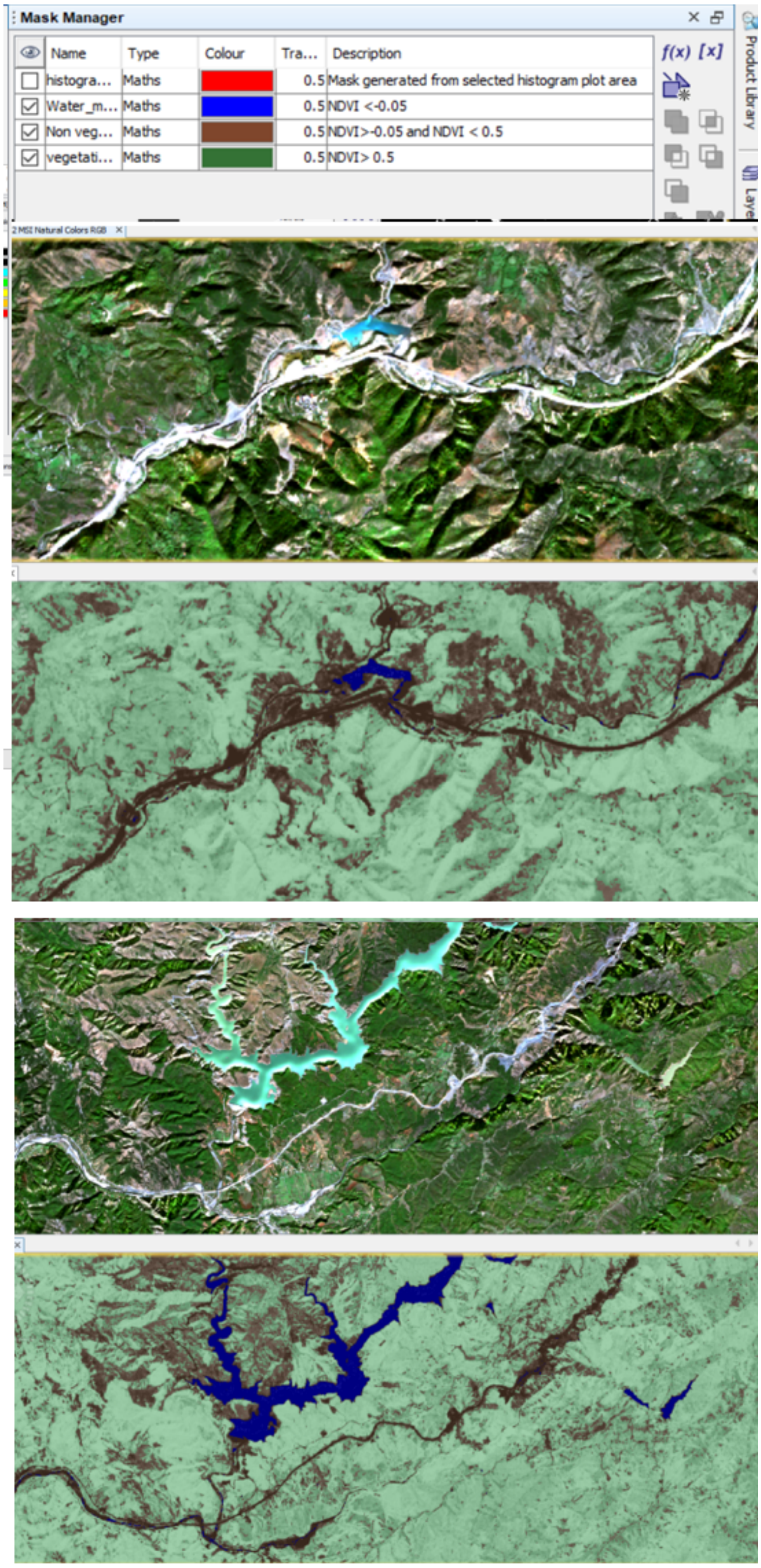

Figure 7. Presentation RGB image and NDVI image: blue colors for pixels with negative values (water spectra) and brown colors for pixels with 0 to 0.5 values (soil spectra) And > 0.5 for vegetation spectra in Reps region

3.4 Technical aspects and analysis SAM

The SNAP workflow has been used to compute Spectral Angle Mapper which consists of computing dot product between pyrite spectra and our image, separately Frobenius norm for pyrite and sentinel 2 images, and the angle between vectors. The angels were in radian. Pixels with small angels were the most similar to our reference spectrum and thus more likely to contain pyrite. Angles below 0.1 usually represent a relatively good match between a pixel and a spectrum while angles greater than 0.15 indicate significant variance concerning pyrite. In figure 8 we see that there are areas with deposits of pyrite placed near the river and also there is the presence of AMD nearby.

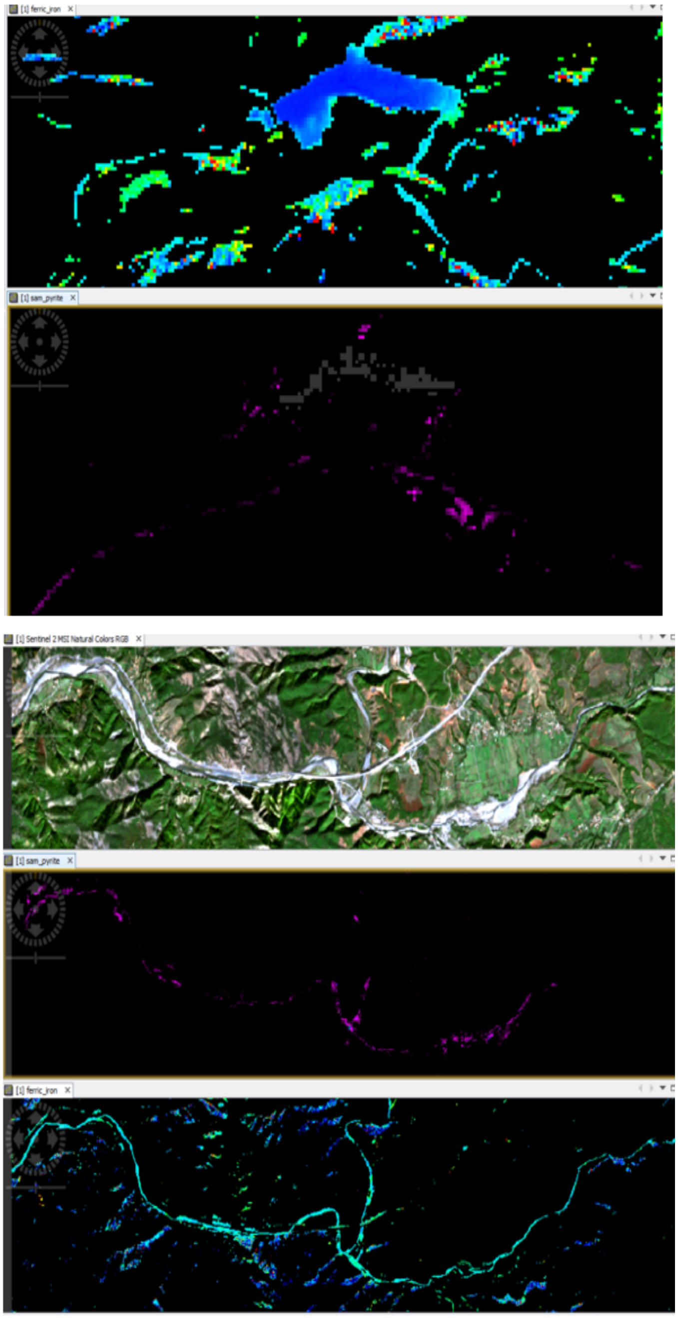

Figure 8. Presentation of SAM image together with ferric iron and RGB image: With violet color, we see that pyrite depositions are near the river and nearby there is also the presence of AMD

4. DISCUSSION

The usage of remote sensing nowadays has become a routine approach for monitoring. That's because it can provide first rate information, which is significantly different from conventional static survey. During the surveying field, farther detecting offers the capacity to see expansive outline zones of the earth's surface different times and to get data for regions that would something else be troublesome or outlandish to test. Various methods have been created to extricate water bodies from diverse remote detecting pictures [33].

Firstly, we will discuss the importance of the problem in our country. In October 2003, a group of researchers from the Institute of Technology Mineral Extraction and Processing (ITNPM), completed the study for monitoring of sterile damps in all the territory of Albania [34]. Another study by a group of authors followed it. This is a continuation of the study previously conducted by this institution and handles sterile massive stocks of coal, copper, iron-nickel mines chromium, dams of their enrichment plants, as well as the legal framework for damps [35]. In 2002, a study presented a brief report on pollution at the former metallurgy and copper refinery at Rubik. From UNEP analytical data, the contents result in several times higher than the allowed values of heavy metals; Cr, Cu, Pb, considering the contaminated territory, a danger to people and the environment as a whole [36]. In another study, very high contents of; Cu, Zn, Pb, As, being several times above the allowed norms, are an important source of pollution [37]. Following studies conducted on heavy metal pollution by the copper industry, some authors confirmed high and very high contents of heavy metals as; Cu, Ni, Pb, Zn, and Mn, which, compared to the allowed EU norms, exceed them several times [38]. Other scientific works are the dissertation that aims to give a more complete picture of the chemical-mineralogical aspect regarding the pollution formed by the Copper industry in the Fani river valley, the potential acid and heavy metal potential that can be relieved by acid leaching of damps of this region, the transport of heavy metals from the Fan River in the hotspots of this region [27].

For the identification of water bodies, we have used the NDWI index taking into consideration the fact that this can be used mainly for clear water spectra and is limited for contaminated water bodies (variety of spectra) like the mining environment [15]. Many authors have studied the pyrite oxidation process within the waste tailings based on the probabilistic method by using the histogram [39]. Many researchers have used this peak to analyse iron content [40]. We can use the band ratio (B4/B3) for ferric iron or the band ratio (B4/B2) for iron oxides, wherein in both cases the value of the ratio greater than 1 will highlight AMD since the reflectance in B4 is greater than in bands 2 and 3. While interpreting the results we noticed that the water bodies far from the mines are blue, which shows that they are not affected by AMD while water features inside the mine perimeter are coloured in green or red due to their iron content. We can also notice how the drainage can be affected by AMD. In some places, there is clean water and, in some places, there is the confluence with AMD.

In this research work, we have used NDVI in Sentinel 2 scene because it helps us to identify the water and soil (non-vegetated areas) at the same time. In our study, just like other authors, the use of NDVI helped us at the same time to identify water bodies as well as the non-vegetation areas concretely areas near abandoned mines [41]. Sentinel-2 image study according to the authors but also from our data can identify cloudy areas like non-vegetated ones [42]. Normalized difference vegetation index was utilized for vegetation cover investigation. This file measures essential efficiency, quantitatively, permitting an estimation of vegetation wellbeing [43]. Bare soil, cloud and snow have NDVI values close to zero, while water has negative NDVI values [44].

SAM allows us to identify target materials from Sentinel 2 multispectral data which in our case is pyrite. It is an important tool as it is widely used by researchers in Earth observation and by exploration geologists.

Similar materials have a similar spectral signature and this is true for any kind of material. As a result, we can classify spectra based on their degree of similarity. We can compare an unknown spectrum with a set of known spectra and define how likely this spectrum is related to one of these spectra. But we can also do just the opposite and define how similar a set of unknown spectra are to a single reference spectrum. The algorithm of Spectral Angle mapper, being a supervised classifier SAM has an easy and fast approach as well as is comprehensible for the user and the illumination differences have no impact on the results [45]. On the other side, the illumination tolerance is accompanied by insensitivity for detecting certain physiologic changes. Our results are in concordance with other authors [46-48].

5. CONCLUSION

NDWI works well for most water bodies, but not very well in the mining environment because NDWI is not adapted to spectra of hyper acidic water. The water bodies far from the mines are blue which speaks for the fact that they are not affected by AMD while water features inside the mine perimeter are coloured in green or red due to their iron content. We can see also how the drainage can be affected by the AMD, in some places, there is clean water and, in some places, there is the confluence with AMD.

The use of NDVI helped us at the same time in the identification of water bodies as well as the non-vegetation areas concretely areas near abandoned mines, but can't help us for identification of AMD. According to our data, Sentinel-2 misses the smallest water ponds however it successfully identifies the bigger water ponds and the river as well. It has no information for cloudy areas. The non-vegetated mask from Sentinel-2 successfully identifies the near mine areas and the urban structure also the cloud area as non-vegetated.

Being a supervised classifier SAM has an easy and fast approach as well as is comprehensible for the user and the illumination differences have no impact on the results.

In general, it has been identified water and the non-vegetation area but it would be more useful in the future to try to identify the part of non-vegetation which corresponds to mining operations utilizing further refinements. According to our research purpose, the proposed methodology will help us in the future for further studies by analysing the effect of mining on soil properties through evaluation of vegetation status utilizing time-series evaluations.

Imaging spectroscopy represents an alternative to conventional methods (chemical analysis-based assessment tools) and an efficient way to characterize mines and assess the AMD discharge.

CONFLICT OF INTERESTS

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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