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SELF-HEALING TIME ESTIMATION OF ABANDONED MINE AREAS USING REMOTE SENSING

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Abstract

Lately, remote sensing has been an effective tool for monitoring the Earth and environmental changes. Landsat with its legacy is providing available data for time-based research. The aim of this paper is to estimate the time of the self-healing progress of an abandoned mine area using Landsat satellite images. In this study, five Landsat satellite images were used. As a study area, the abandoned Damjan mine in the southeastern part of the Republic of N. Macedonia has been chosen. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) values were used to classify Landsat images into barren land, bared soil, mixture of vegetation, vegetation, and water bodies. The NDVI values lower than zero are considered to be the area affected by the mine. The healing of the mine has been established using the annual growth rate analysis. It was found that the area has been healing approximately 10 % every year and a prediction was made for the study area till the year 2030.

Key words: *Mine, remote sensing, environment, Landsat, annual growth rate*

INTRODUCTION

Since the beginning of civilization, mankind has been mining to meet needs or to make tools and weapons. "Lion Cave" is the oldest known mine, which was found in archaeological excavations in Swaziland, in Africa. By the radio-carbon dating method a date of about 41 000 BC was obtained for this hematite mine. However, this is the extreme range of carbon dating, the mine may be older than this date. It is thought that these ores were mined until at least 23 000 BC. At Lion Cave it is estimated that at least 1200 tons of soft hematite ore had been removed in ancient times [1]. Ancient mine fields found also in Hungary are thought to be mines of an identical era, where Neanderthals may have mined flint for weapons and tools [2].

Mining is one of the essential business activities of welfare society. The purpose of mining is to provide raw materials that are needed by the industry, for national and economic development. On the other hand, during and after mining operations, land degradation, gas emissions, hazardous waste, dust, and noise inevitably occur. Industrialization and demand for raw materials are constantly increasing due to rapid population growth, consequently, the destruction is widespread.

On one hand, mining is strengthening the economy and it supports national development for people welfare. On the other hand, mining causes big impact on and devastation of the ecological environment, which is ignored most of the time. After mining operations, especially with the open-pit method, topography, geological structure, relief, water regime, climate and landscape become unbalanced and the vegetation is completely vanished around the work area. Environmental impacts of mining operations can be divided into two categories. Direct impacts: mine buildings, plants, infrastructure, and waste disposal sites directly destroy the soil and vegetation in the area they are located. Indirect impacts: water quality, climate, soil structure, human and animal health were badly affected around the mining sites, abandoned mines, waste disposal sites and ore dressing plants.

Mining operations can be summarized as temporary land use depending on the mine life. Human-induced changes in land use alter the biogeochemical system which affects the physical climate system.

Effective management and monitoring of soil resources require spatial data at various scale in order to incorporate land use patterns, geomorphology, topography, hydrologic and vegetation parameters. In mining areas, large amounts of land have been occupied and destroyed through mining subsidence, excavation damage, and pollution [3]. In the process of removing the desired mineral material, vegetation is unavoidably destroyed. The recovering of the damaged area can be very slow if the mine is being abandoned and no action has been taken for closing the mining area.

Remote sensing may be the only feasible means of providing such spatially distributed at multiple scales and on a consistent and timely based data [4]. With the development of the remote sensing technology, Landsat images have become a real treasure for monitoring the changes on the Earth caused by natural or human-induced changes. Remote sensing technology and data have been used in a number of studies connected with mining and even more about environmental consequences connected with mines activities [5-8]. With remote sensing data the relationship between the NDVI and temperature fluctuation in post-mining sites have been investigated [9].

In this paper, five Landsat satellite images were used in order to determine land healing of an abandoned mine within a period of 29 years, using NDVI, NDWI, statistical predictions and GIS tools. The aim of this paper is to determine the approximate time that the nature/land cover needs to self-heal the damages that have been made due to mining extraction using remote sensed images from Landsat.

MATERIAL AND METHODS

The methods include Normalized Difference Vegetation Index (NDVI) analysis, Normalized Difference Water Index (NDWI) [10] analysis, growth rate analysis and predictions. For all five Landsat satellite images NDVI analyses were made. The NDVI analyses were made using the NDVI equation:

$$NDVI = \frac{IR - R}{IR + R} \tag{1}$$

where IR stands for the Infra-red band and R stands for the visible red band.

The comparison between the two different sensors, Landsat 5 and Landsat 8 was not a problem since the difference of the vegetation indices comparison has shown that there are subtle differences between both sensors [11].

Values for NDVI range from 1.0 to -1.0. Higher values indicate higher concentration of green vegetation. Lower values indicate non-vegetated features, such as water, barren land, ice, snow, or clouds [12]. The NDVI values were classified into four land-cover types, for values smaller than 0 it was considered to be barren land or water area, values between 0 and 0.2 correspond to barren soil, from 0.2 to 0.5 to mixture of soil and vegetation, and values above 0.5 correspond to fully vegetated area [13].

The areas with values lower than 0 were considered to be the mine areas (barren land) since the images were clean from cloud, snow or ice in the study area.

After the NDVI classification, reclassification was made, and the area of each class has been calculated according to the resolution of the satellite images. NDWI analyses were made for distinguishing barren land from water area.

Water features have positive values, while soil and terrestrial vegetation features have negative values, owing to their typically higher reflectance of NIR (near infrared) than green light [10].

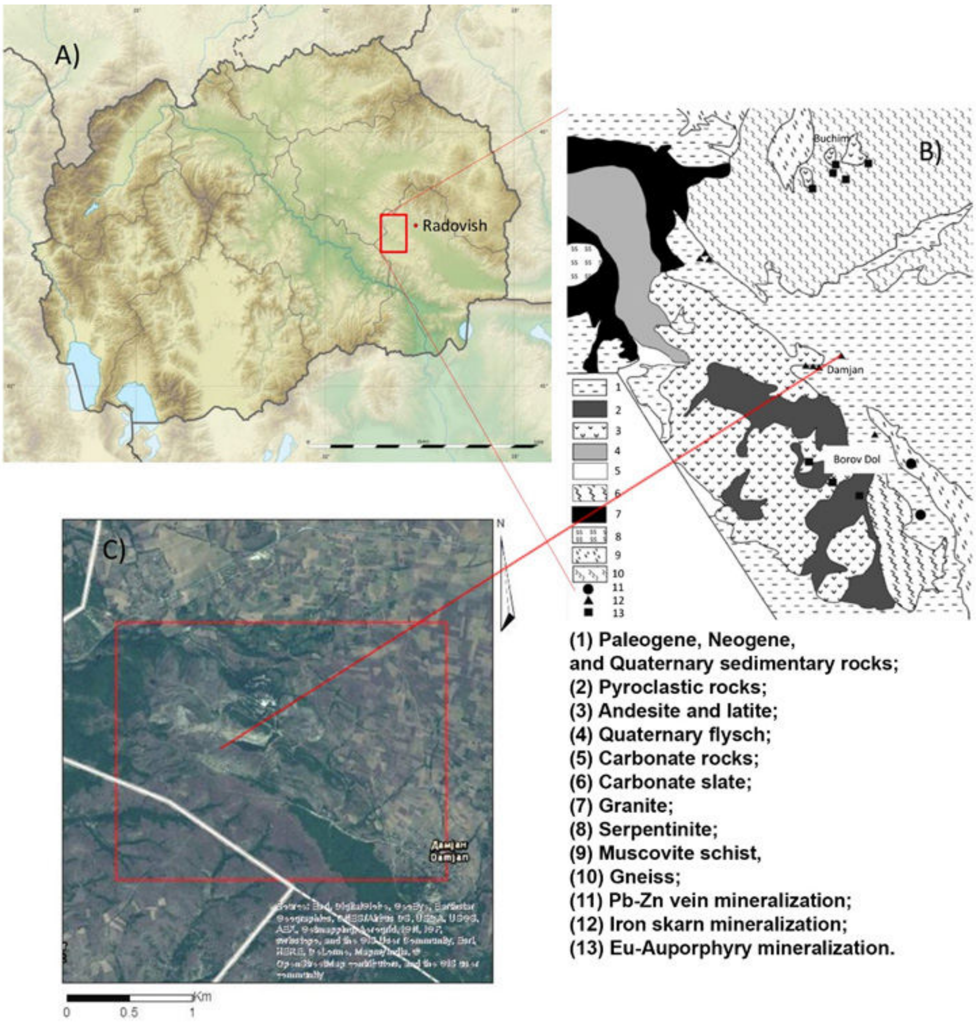

Figure 1. A) Map of the Republic of N. Macedonia [14]; B) Geological map of the Buchim–Damjan–Borov Dol ore district. [15]; C) Base map of the Study area.

Similar to the NDVI principles, the NDWI is calculated as follows [10]:

$$NDWI = \frac{Green - NIR}{Green + NIR} \tag{2}$$

where Green stands for visible green band and NIR stands for near infrared band.

For the NDVI values lower than 0, a growth rate analysis was made using the following equation [16]:

$$GrowthRate = \left[\left(\frac{Final\ Value}{Starting\ Value}\right)^{\frac{1}{n}} - 1\right] * 100 \tag{3}$$

where the Final Value is the last known value, the Starting Value is the first known value, and n is the number of periods, in this case, number of years.

Equation 3 is used for calculating the annualized average rate of growth between two given years, assuming that growth takes place at an exponentially compounded rate [17]. A negative value indicates that the zone of a particular category is shrinking.

In this paper as a starting value the values from 1986 and the final values from 2015 were taken. In that case, n has been taken to be 29 years. As an accuracy assessment, the Growth Rate of all possible periods was made, and it was compared with the one used for the analysis. Finally, a prediction of the mine area for 2030 year was made.

Data

Landsat 5, launched on 1 March 1984, was successfully collecting remotely sensed data from the Earth until 2011, and it is the longest-living satellite. Its data are valuable and are being used for all kind of research. Landsat 8 has been launched on 11 February 2013, and it is still active. The data from the Landsat archive can be downloaded for free from the USGS web page.

In this paper, four Landsat 5, and one Landsat 8 satellite images were used. To avoid misleading results, the images were picked from the same season respectively and they are clear of clouds (Table 1).

Study area

The Damjan mine is located in the southeastern part of the Republic of N. Macedonia near the city Radovis, in the central part of the mine area Buchim-Damjan-Borov ravine (Figure 1-A). The mine is a deposit of iron ore with established reserves of approximately 6.5 million tons of ore with 35 % iron [18]. The geology of the study area has been defined as Paleogene, Neogene, and quaternary sedimentary rocks (Figure 1-B) [15]. The study area includes the mine and its surrounding environment, a total covering of 5.4 km^2 (Figure 1-C).

RESULTS AND DISCUSSION

The results from the NDVI analysis have shown a decrease in the barren land area that is considered to be the mine. Using different Growth Rate periods, the result for the average percentage value has been shown to be -10.83 % (Table 2), while using the starting and final values from 1986 and 2015 respectively, the decrease has been shown to be -10.56 %. The NDVI results from all years, 1986, 1990, 2003, 2009 and 2015 have been represented in Figure 3. The predicted values for the mine area in 2030 are showing that the mine area will be 832 m^2, which shows us that there will be still consequences to the nature from the abandoned mine. The results from the NDWI analyses helped us separate the results from the NDVI results, barren land from water bodies, lower than 0. The results are shown in Table 1.

The results are showing the change from barren land to bared soil the NDVI values of which are higher than zero, which indicates the presence of vegetation. The values higher than 0.2 NDVI values and lower than 0.5 indicate a higher presence of vegetation together with bared soil, while NDVI values higher than 0.5 represent fully vegetated soils. The details for the change of the NDVI values are shown in Table 1 and Figure 2.

Table 1. Used satellite images, NDVI and NDWI results in square meters

Satellite	Date	NDVI <0/(m^2)	NDVI 0-0.2/(m^2)	NDVI 0.2-0.5/(m^2)	NDWI 1</(m^2)
Landsat 5	24.08.1986	113024	3313637	1819784	7009
Landsat 5	02.07.1990	76225	3060426	1966103	2628
Landsat 5	22.07.2003	20151	1926675	2896584	14018
Landsat 5	22.07.2009	8761	570380	3719299	6133
Landsat 8	07.07.2015	4440	517283	4315652	1776

Table 2. Growth Rate periods

Period	86-90	90-03	03-09	09-15	86-03	86-09	86-15	90-09	90-15	03-15	Mean
Growth rate %	-9.3	-9.7	-12.9	-10.7	-9.6	-12.0	-10.5	-10.7	-10.7	-11.8	-10.8%

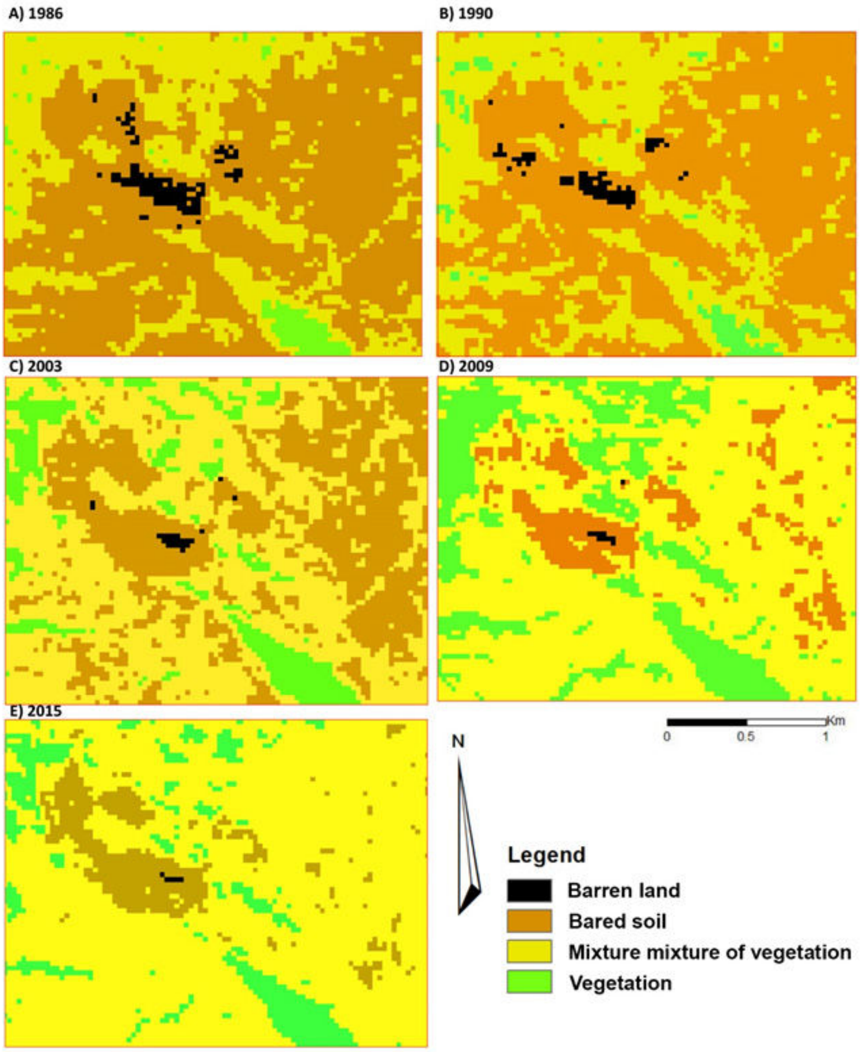

Figure 2. NDVI reclassified maps A) Landsat 5 on 24.08.1986; B) Landsat 5 on 02.07.1990; C) Landsat 5 on 22.07.2003; D) Landsat 5 on 22.07.2009; E) Landsat 8 on 07.07.2015

In Figure 3 a chart is presented with the actual values of the NDVI results lower then 0, supposed to represent the barren lands in the study area, or the mine. The equation of the trend line is presented in Figure 4 and the result of the squared R is 0.997.

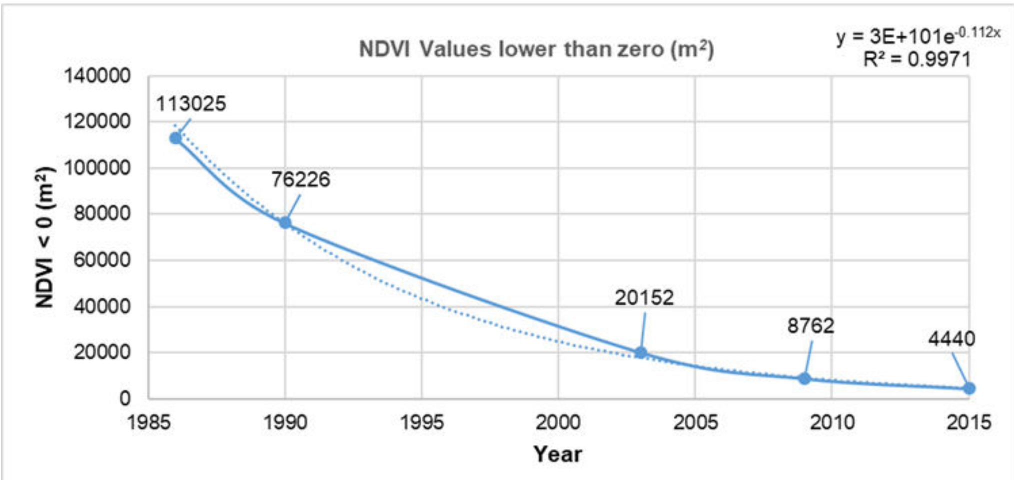

Figure 3. Actual NDVI values lower than zero indicating barren lands

The annual growth rate results for the NDVI values in range 0.2 - 0.5 are showing that the mixture vegetation area has a growth of 3 % per year. The exponential correlation of the growth of the mixture of vegetation area related to the years is 0.995, while the correlation between the decline of the bare land related to the years is 0.956 (Table 1).

Using the results and available data, a prediction for the mine self-healing was made. According to the prediction, the mine area in 2030 will be 832 m^2 (Figure 4).

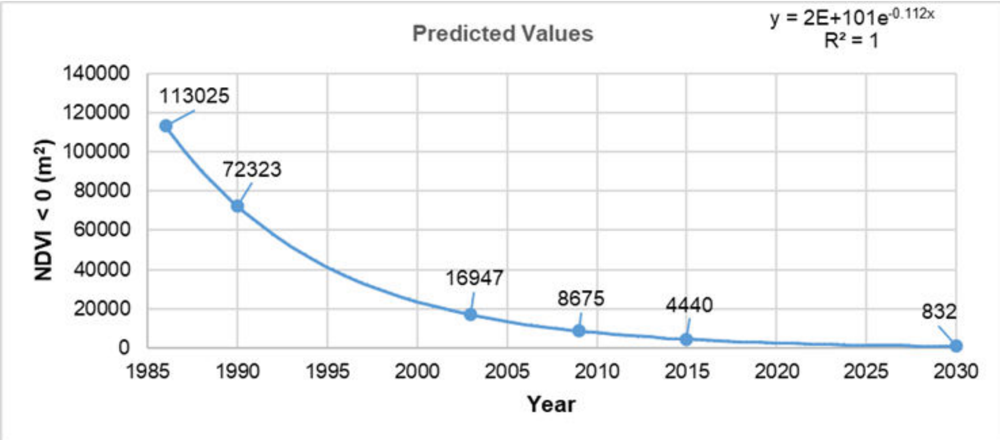

Figure 4. Predicted values for the mine self-healing until 2030

CONCLUSION

One of the most serious environmental concerns at abandoned mines is open-pit mine faces. Public health and safety hazards at abandoned mine sites can include accessible mine openings, hazardous mine wastes, abandoned infrastructure, and ground surface instability [19]. Thus, closing of open-pit mines is important both for the environment and for the public health. Awareness of the damage caused by the abandoned mine pits should be on a higher level. Although some improvements have been made over the last few years with some regulation, there are still abandoned open pits all over the world.

This paper is a small example of the damage that one not very large abandoned open-pit mine can do to the environment. One of the most used remote sensing vegetation indices, NDVI, can indicate not only the vegetation health, but also the condition of the land. Values smaller than zero are generally areas that cannot grow vegetation, such as human activities, rocks, or barren lands. Low NDVI values indicate bare land.

The good correlation between the increase of the NDVI values and the years are an indicator that the used methodology can be used for analyzing abandoned mine pits and their healing progress. The results showed that the abandoned mines healing process is very slow and that the damage is almost undoable. Even though the land is slowly regenerating, still the open-pit will remain to exist for years.

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ВРЕМЕНСКА ПРОЦЕНКА НА ЗАРАСНУВАЊЕТО НА НАПУШТЕНИ РУДАРСКИ ОБЛАСТИ СО КОРИСТЕЊЕ НА ДАЛЕЧИНСКО НАБЉУДУВАЊЕ

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Резиме

Во последните неколку години, далечинското набљудување стана ефикасна алатка за следење на Земјата и промените кои се јавуваат во животната средина. Landsat програмата, со својата огромна база на податоци обезбедува достапни информации за истражувања базирани на временски карактер. Целта на овој труд е да се процени времето на зараснување со вегетација на напуштени рударски области со користење на далечинско набљудување користејќи сателитски снимки од Landsat програмата. Во оваа студија беа користени пет сателитски снимки на Landsat од различен временски период. Како студија на случај е избран напуштениот рудник Дамјан во југоисточниот дел на Република С. Македонија. Вредностите на Нормализираната Разлика на Вегетативниот Индекс (анг. NDVI) и Нормализираната Разлика на Водениот Индекс (анг. NDWI) беа користени за класифицирање на фотографиите од Landsat сателитот во области дефинирани како пуста земја, разголена почва, мешавина од вегетација, вегетација и водни области. Вредностите на NDVI пониски од нула се сметаат за области кои се зафатени од работењето на површинскиот рудник. Зараснувањето со вегетација на површината од рудникот е утврдено со помош на анализа за годишна стапка на раст која се базира на сателитските снимки. Во студијата е утврдено дека областа зараснува со вегетација која има приближна стапка на раст од околу 10 % за секоја година и исто така е направено и предвидување за изгледот на рударската област се до 2030 година.

Клучни зборови: *Рудник, далечинско набљудување, животна средина, Landsat, годишна стапка на раст*