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Evaluation of vegetation development in reclaimed sites using the NDVI

Petar Petrov, Veneta Stefanova*

University of Forestry, Faculty of Ecology and Landscape architecture, Department of Ecology, environmental protection and restoration, 10 Kliment Ohridski Blvd., 1797, Sofia, BULGARIA

*Corresponding author: venistefanova3@gmail.com

Abstract. This study investigates the recovery processes in reclaimed sites (an old embankment from copper mining), which was reclaimed by various methods in 2010. For the purpose of this study, the maximum average values of the NDVI index for 2018-2021 were used. According to the results of the study, restoration processes are taking place in recultivated areas, and a tendency for the index to increase over time has been observed. The extent of the restorative process depends on the remedial measures that have been carried out. In the reclamation of sites disturbed by copper mining, liming has been found to be a key amelioration. The use of a NDVI index is a viable and reliable method of tracking site recovery and on-going soil formation process.

Key words: remote sensing, NDVI, reclamation mining area.

Introduction

Technological advancements have led to an increasingly high demand for copper, as well as an increase in the intensity of copper ores extraction and processing. Global copper ore production has grown from 630 million tonnes in 2010 to 870 million tonnes by 2020, according to Statista.com.

Environmental disturbance and pollution are caused by the mining activities associated with the extraction of the metal (Castillo, 2013; Beylot &Villeneuve, 2017; Espinoza & Morris, 2017). It has been observed that, in many cases, despite the post-liquidation measures taken on the territory of mines (that have exhausted their reserves), the impact on the environmental components remains significant (Frouz, 2016; Zheleva-Bogdanova, 2010; Macdonald et al., 2015). In addition to a broad geographic scope, the impact extends over an extended period. Restoration of disturbed areas caused by mining is considered one of the most important directions in the field of environmental protection (Leia et al., 2016; Madejón et al., 2011). The objective of the program is to restore the ecological value of territories affected by mining to take advantage of the opportunities provided by the natural ecosystem (Frouz, 2018). To achieve ecological integrity, it is necessary not only to restore the productive capacity of the lands, but also to restore the ecosystem so that it functions in a way that allows it to provide ecosystem services (Leia et al., 2016; Madejón et al., 2011).

To improve vegetation conditions in reclaimed areas, ecological monitoring plays a significant role in improving the planning and implementation of restoration activities (Frouz, 2018; Zheleva-Bogdanova, 2010). Traditionally, soil and plant samples are collected as part of monitoring, however, these methods are expensive and limited to small areas, which necessitates the search for alternatives (Queensland Government, 2018; Western Australia Government, 2014; McKenna et al., 2020). In comparison with traditional methods, remote sensing can provide reliable and timely information regarding vegetation (Province of Alberta, 2020; Buters et al., 2019; Schmidt & Glaesser, 1998; Parks et al., 1987; Maxwell et al., 2014).

Remote sensing and spatial analysis have undergone fundamental changes over two decades. As a result of recent advances in earth observation and drone technologies, it is now possible to assess landscape changes and ecosystem development on a multi-scale rapidly and cost-effectively (Bao et al., 2019; Chen et al., 2018, 2017; Buczyńska, 2020). Remote sensing can be used to evaluate reclamation effectiveness. Furthermore, land reclamation management can be based on the identification of areas of vegetation degradation. Many environmental monitoring studies conducted in mining areas have successfully employed remote sensing technologies, including the calculation of vegetation cover and leaf area index to perform quantitative remote sensing vegetation monitoring (Mather & Koch, 2010; La et al., 2015; Lemordant et al., 2018). By selecting appropriate remote sensing data, it can be possible to conduct efficient, accurate, and comprehensive analyses of post-reclamation effects and ecological monitoring (Fang & Liang, 2014; Zhang et al., 2019).

A vegetation index is an important biological physical indicator for evaluating environmental changes on degraded lands. A vegetation index can be calculated by using the normalized differential vegetation index (NDVI), the coefficient of vegetation index (RVI), or the enhanced vegetation index (EVI). NDVI is most used as a tool to monitor and assess the health of vegetation (Zhang et al., 2019).

This study aims to monitor the development of vegetation in reclaimed land disturbed by copper mining over time using comparative NDVI calculations. The method uses time series NDVI analysis and classifies vegetation health based on the normalized difference vegetation index.

Materials and Methods

Study area

Reclaimed site - an old embankment that was formed during the mining of copper in one of the active large deposits in Bulgaria - is the subject of this study. The site is flat, located at an altitude of 1445 m, facing southwest. In 2010, reclamation activities were initiated. The following three trial sites are located on reclaimed site (Fig. 1):

- The first trial site (TS 1) - the easternmost portion of the site, it has been reclaimed with shale mixed with earth masses.
- The second trial site (TS 2) has been reclaimed with black shale.
- The third trial site (TS 3) has been reclaimed with shale piled in the embankment about 5 - 10 years ago, before 2010.

Site size is approximately 1.25 ha with a length and width of approximately 120 m and 70 m, located east/west. There are two testing options along the length of each trial site: those without liming and those with liming to neutralize acidity.

Initially, the disturbed site was grassed with a mixture of wheat and legumes that has a properly defined structure - an equal proportion of both types of perennial grasses with the following components: wheat perennial grasses: red fescue *Festuca rubra* (20%), timothy *Phleum pratense* (15 %) and ryegrass *Bromus arvensis* (15 %), total wheat grasses = 50%; leguminous perennial grasses: red clover *Trifolium pratense* (20%) and Bird's-foot Trefoil *Lotus corniculatus* (30%), total leguminous grasses = 50%. The trial sites were reforested in 2014. The tree species used are: black pine (*Pinus nigra* Arn.), white pine (*Pinus sylvestris* L.), common spruce (*Picea excelsa* Link.), common fir (*Abies alba* Mill.), common birch (*Betula pendula* Roth.), common sycamore (*Acer pseudoplatanus* L.).

It is shown in Fig. 2 how the terrain looked prior to biological reclamation in 2010, as well as how it looked in 2019. Additionally, two reference areas were selected. The first is chosen to be close to the site and may be influenced. The second site was chosen to minimize the impact of the mine and embankment on the environment.

Materials

To estimate NDVI over four growing seasons, ESA's Sentinel 2 images were used for the period 02.2018 to 08.2021. ESA (European Space Agency, Paris, France) launched the Sentinel-2 optical satellite in 2015. There was a high-resolution, multispectral image device on board that could obtain images in the visible light waveband at 10 meters, the infrared waveband at 20 meters, the red edge waveband at 20 meters, and the shortwave infrared waveband at 20 meters. As a result of the satellite, vegetation growth and land use cover are primarily monitored (Verhulst & Govaerts, 2010). To the study, publicly available data from the European Space Agency, accessible through the Copernicus browser (browser.dataspace.copernicus.eu), were used.

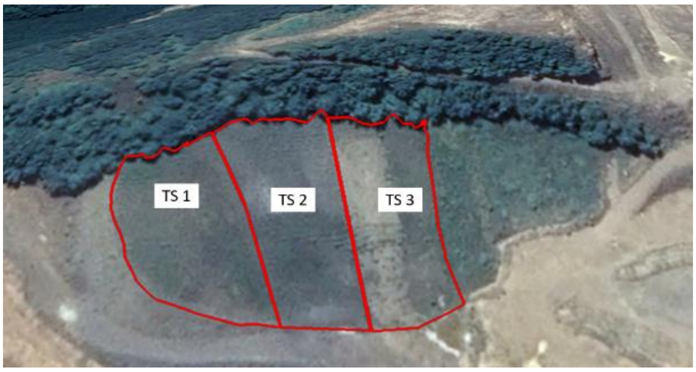


Fig. 1. The location of the study area in the recultivated terrain (the north is reversed for better visual clarity)

(**a**) (**b**)

Fig. 2. Study area in (a) 2010 and (b) 2019.

Methods

Satellite data processing

Remote sensing technology has rapidly developed, enabling many vegetation indices to be obtained through formula calculations based on image data, which has led to the widespread use of vegetation indices for vegetation assessment and monitoring. To monitor vegetation growth, the Normalized Difference Vegetation Index (NDVI), which reflects the characteristics of plant growth, plant cover, and biomass, is widely used. Several scientists have used this method to study the status of vegetation both locally and globally for a long time. As a measure of vegetation growth status, NDVI was used in this study. In accordance with relevant studies, this index can eliminate the influence of other factors (terrain, shade, and atmosphere) to a certain extent.

NDVI is a widely used vegetation index that is calculated by dividing the difference between the near-infrared and near-infrared bands by their sum, and the threshold is set at [-1,1]:

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{NIR} - \boldsymbol{R})}{(\boldsymbol{NIR} + \boldsymbol{R})}$$

where NDVI is the normalized difference vegetation index, NIR is the near-infrared band, and R is the visible red band. Generally speaking, when $-1 < \text{NDVI} < 0$, the land cover type is cloud, water, snow, etc., which are without vegetation cover; when NDVI = 0, the ground cover is rock or bare soil; when $0 < \text{NDVI} < 1$, the land is usually covered by vegetation. The larger the NDVI value, the better the vegetation condition. Based on the preprocessed remote sensing image, NDVI is calculated by the above formula (Verhulst & Govaerts, 2010).

To achieve the purpose of this study, the average values of the index were compared between three of the trial sites (the second and third of which are divided into limed and unlimed) and two reference areas. NDVI time-series were analyzed descriptively; no inferential tests were applied. Trends were evaluated by comparing annual peak NDVI values across years and sites.

Field survey

The study area was the subject of a field survey conducted in 2019. A morphological descripttion of the soils and a determination of the species composition of the trees were conducted during the survey.

Results

Characteristics of the embankment

In the field survey conducted, it was established that the trial sites in the reclaimed site have a primitive profile: OF (OFS) - OFS - S. Due to the altitude and the age of the recultivated terrain, the formed profile is to be expected.

Based on the depth of the soil profile, the studied soils can be classified as shallow (up to 30 cm) (Petrova, 2017) or weak (50 cm) (Donov, 1993). A soil profile was observed in the investigated soils of the order of 25 cm, with a formed surface layer (leaf litter) and a subsurface layer (a mixture of mining waste and selected materials for reclamation - soil, shale, other mining wastes).

TS 1 and TS 3 have dense grass covers, while TS 2 has grass cover below 50%. Apart from the main planting mix - black pine (*Pinus nigra* Arn.), white pine (*Pinus sylvestris* L.), common spruce (*Picea excelsa* Link.), common fir (*Abies alba* Mill.), common birch (*Betula pendula* Roth.), common sycamore (*Acer pseudoplatanus* L.), co-occupancy of pioneer species - *Betula pendula* Roth., *Salix caprea* L., *Populus tremula* L, *Salix purpurea* L., in some trial areas was observed.

The presence of dead forest litter is noticed depending on the species composition with which biological reclamation was carried out. The presence of moss is also observed in some of the test areas, which may be related to the pH value in the acidic region.

NDVI and related analyses

Trial site 1 (TS 1)

In TS 1 no liming activities were carried out in it. During the field survey, it was found that the area is covered with grass. The vegetation consists of black pine (*Pinus nigra* Arn) and white pine (*Pinus sylvestris* L.).

Fig. 3 illustrates the NDVI value. As can be seen from the graph, the maximum value of the index in each of the three years was established in May-June-July during the peak vegetation season. This index has a maximum average value of 0.497553258 in 2018, 0.588800629 in 2019, 0.548607221 in 2020, and 0.533911571 in 2021. The vegetation in the sample area has been moderately healthy during the years.

Fig. 3. Development of NDVI in TS 1.

Trial site 2 (TS 2)

There are two types of reclamation activities carried out on Trial site 2 - liming (TS 2.1) and non-liming (TS 2.2). During the field survey, it was established that the area is covered with grass. The vegetation consists of common birch (*Betula pendula* Roth.), common sycamore (*Acer pseudoplatanus* L.). There is almost no grass vegetation present in the sample area. We estimated that the sample area covered less than 50% of the area during our visit. Instead of weeding, mosses are observed. As a result of the acidic nature of the embankment (Petrov, 2019), this is to be expected.

Fig. 4 illustrates the NDVI value in TS 2. As can be seen from the graphs, similar to Trial area 1, the maximum value of the index in each of the three years was established in May-June-July during the peak vegetation season. This index in TS 2.1 (limed) has a maximum average value of 0.425633933 in 2018, 0.548203893 in 2019, 0.42839936 in 2020, 0.502932543 in 2021. The vegetation in the sample area has been moderately healthy during the years. The tendency to increase the value of the index compared to 2018 is reported. The NDVI in TS 2.2 (non-limed) has a maximum average value of 0.363416548 in 2018, 0.495860997 in 2019, 0.439252421 in 2020, 0.4689466 in 2021. The vegetation in the sample area has been moderately healthy during the years. The tendency to increase the value of the index compared to 2018 is reported.

It can be seen from the data presented that TS 2.1 (limed) have a higher NDVI, which indicates that liming improves biological reclamation. Additionally, both for the limed and non-limed sites, the general trend is to increase the value of the index every subsequent year, which indicates that the soil conditions are improving.

(**a**) (**b**)

Fig. 4. Development of NDVI in TS 2 (a) liming (TS 2.1), (b) non-liming (TS 2.2)

Trial site 3 (TS 3)

Additionally, Trial area 3 is divided into two groups according to the reclamation activities conducted - liming (TS 3.1) and non-liming (TS 3.2). During the field survey, it was found that the area is densely grassed. The vegetation consists of common spruce (*Picea excelsa* Link.) and common fir (*Abies alba* Mill.).

Fig. 5 illustrates the NDVI value. As can be seen from the graphs, similar to TS 1 and TS 2, the maximum value of the index in each of the three years was established in May-June-July during the peak vegetation season. This index in TS 3.1 (limed) has a maximum average value of 0.51931528 in 2018, 0.625668093 in 2019, 0.504542978 in 2020, 0.567366631 in 2021. The vegetation in the sample area has been moderately healthy during the years. This index in TS 3.2 (non-limed) has a maximum average value of 0.312718105 in 2018, 0.417241332 in 2019, 0.444669907 in 2020, 0.436635652 in 2021. The vegetation in the sample area has been moderately healthy during the years.

(**a**) (**b**)

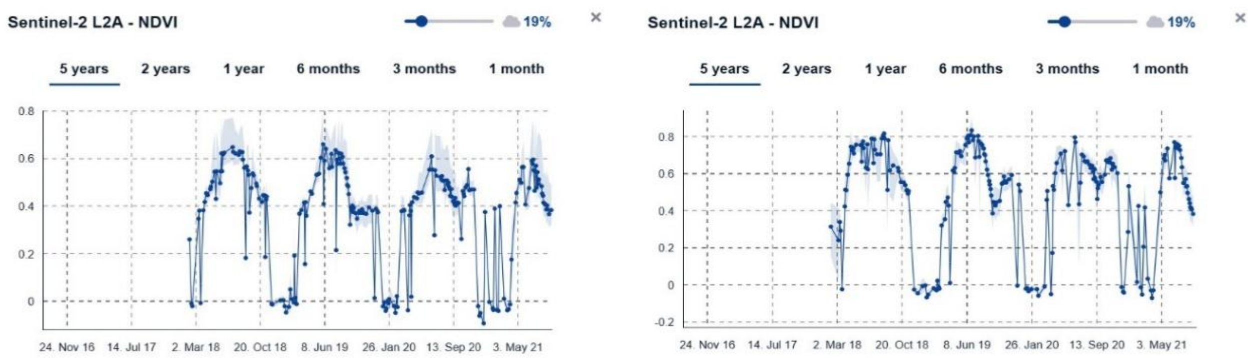
Fig. 5. Development of NDVI in TS 3 (a) liming (TS 3.1), (b) non-liming (TS 3.2).

Reference site

Two reference areas were chosen - first located 3.5 km from the study area (R1) and second one located near the reclaimed site and the active embankment (R2).

Fig. 6 presents data from the conducted analysis regarding the state of the vegetation. As can be seen from the graphs similar to other sites, the maximum value of the index in each of the three years was established in May-June-July during the peak vegetation season. This index in R1 has a maximum average value of 0.815975476 in 2018, 0.807026582 in 2019, 0.7689191 in 2020, 0.750267304 in 2021. The vegetation in the sample area has been healthy during the years. Maximum average value of index in R2 is 0.37019406 in 2018, 0.491878477 in 2019, 0.439252421 in 2020, and 0.4689466 in 2021. The vegetation in the sample area has been healthy over the years.

The reference site near the embankment has a lower NDVI value, which may be due to a variety of factors, including dust from the mine and the embankment, poor soil conditions, stony soil, and a lack of grass cover. There were no site visits to reference sites. The NDVI value at the peak of the vegetation at the second reference site is approximately 0.75-0.8, which is taken as the reference value for grass cover in this area to ensure greater representativeness of the results.



(**a**) (**b**)

Fig. 6. Development of NDVI in reference site (a) R1, (b) R2.

Comparative analysis

To evaluate the development of the vegetation, a comparison of the obtained NDVI indices for each site with the reference was made.

The data are presented in Fig. 7. As can be seen from the graph, for all the investigated sites, a maximum value of the NDVI index was recorded in 2019. The value of the index remains below that calculated in the reference area R1. It varies from 51% (TS 3.2) to 77% (TS 3.1) of the value of NDVI in R1. All sites, including reference sites, showed a decline in NDVI value after 2019, probably due to external factors, such as climatic variations, and therefore we do not consider restored soils to be responsible for the decline in NDVI. Additionally, the graph shows that the decrease of the index is much smoother in the reference areas, illustrating the importance of soils quality to the vegetation resistance to bad conditions.

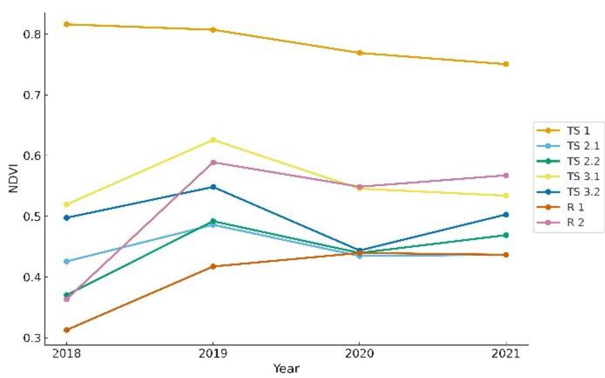


Fig. 7. Comparative analysis of maximum mean NDVI value.

The change in NDVI index at the peak of vegetation is presented in Fig. 8. As can be seen from the figure, the value of the index fluctuates from medium to high, with a tendency to increase over time. As can be observed from the sample area in 2018, lower values of the index dominated, and in single fields, values were ≤0.2. However, in 2020, the trend is to have a more even distribution of NDVI values; fields with NDVIs of ≤0.5 are most prevalent. One field in the southern part of the site has an NDVI of ≤0.6, likely as a result of shading caused by natural terrain and tall woody vegetation adjacent to the field.

(a) (b) (c)

Fig. 8. NDVI at the peak of vegetation (a) 2018, (b) 2019, (c) 2020

Discussion

The NDVI in TS 1 remains relatively constant and comparable despite the rise between 2018 and 2019. According to the comparison of the NDVI values, the limed areas of TS 2 and TS 3 have higher NDVI values. Liming results in better biological reclamation results as a result of this. As can be seen, both for the limed and non-limed sites, the index value has generally increased over time, indicating improvements in soil conditions and progress in restoration.

The trend over the years between the experimental sites and the reference sites is comparable when comparing the experimental sites with the reference sites. Lower NDVI values during the growing season in 2020 and 2021 compared to 2019 were observed at all sites. This indicates that this decline in NDVI is likely due to climatic conditions or other environmental factors. NIMH data shows 2019 was the warmest year since 1930. As a result of the higher temperatures and precipitation in winter and spring, the earliest occurrence of the phenological phases of budding and flowering was observed in cereal crops - as early as the first ten days of May. Usually this happens in the third ten days of May. This is probably the reason for the maximum NDVI results in the respective year.

For all the experimental sites (1, 2 and 3), higher NDVI values were observed in 2019 compared to 2018, while at the reference site (R1) these values were the same, which shows that the implemented reclamation and the planned land reclamation have a positive effect on restoring the plant cover.

The comparison between the reclaimed areas and the reference site shows a difference of up to 51 - 77% in the NDVI value. Despite the dense grass cover, up to about 80% for the limed sites and site 1, it can be seen that the grass vegetation health is adversely than the natural grass cover in the area. In comparison with the nearby reference area, the same trend is observed, to a lesser extent. This condition is probably due to the condition of the soils and their properties - poor in nutrients, worse mechanical properties, higher content of heavy metals and metalloids, which makes soil moisture fluctuations much larger than natural soils with a clearly defined soil profile.

Conclusion

The research finding shows that restoration processes are occurring on the reclaimed sites. Development of the vegetation indicates an ongoing soil-forming process.

Despite the significant grass cover of some of the terrains investigated, their condition is worse than the typical meadow in the area.

A clear connection is observed between the state of the vegetation, determined by NDVI, and melioration (liming). This dependence determines liming as the most essential melioration in the recultivation of territories disturbed by copper ore mining and characterized by low pH.

Another important finding is that using NDVI, it is possible to track the restoration processes on reclaimed sites in a reliable manner.

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