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Assessment of the state of phytocenoses of quarry-dump complexes by remote sensing

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Abstract. One of the types of anthropogenic activities that leads to negative environmental changes and biodiversity loss is the extraction of minerals within quarry-dump complexes, which requires measures to restore ecological balance following the completion of mining operations. The search for optimal methods to identify disturbed areas, monitor the condition and recovery dynamics of exhausted lands in the context of biodiversity conservation and restoration was the aim of the study, particularly when field research was inaccessible, and there was a need to observe multiple sites simultaneously. This paper presents the results of assessing vegetation cover within territories disturbed by mineral extraction using remote sensing techniques. Methods such as scientific analysis, synthesis, statistical data processing, and the transect method were employed. It has been determined that the analysis and monitoring of Normalised Difference Vegetation Index (NDVI) values, obtained via remote sensing, enable the assessment of the quality of reclamation measures, identification of high-productivity areas, and detection of problem zones for devising effective methods to improve the ecological condition of the studied site. Within the examined Andriikovetskyi quarry-dump complex, the successional stages exhibited heterogeneity, with some areas remaining open without vegetation cover and others characterised by early successional stages and sparse vegetation. The lowest NDVI values were recorded in 2019 and 2022, while between 2020-2021 and 2023-2024, an increase in biomass productivity was observed, with the extent of areas covered by dense and moderate vegetation growing. It was noted that

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this situation was caused by height differences, surface irregularities, water and wind erosion processes (due to the absence of reclamation measures), instability of the sandy substrate, and a low capacity to supply vegetation with sufficient moisture. The findings of the study highlighted the importance of reclamation measures for post-mining areas and provided practical recommendations for the necessary engineering and technical measures to restore the quarry-dump complex to conditions that are closer to natural ones, promoting the spread of zonal species and self-recovery processes

Keywords: disturbed areas; NDVI; mineral extraction; vegetation; habitat conditions; reclamation; monitoring

INTRODUCTION

Since the beginning of the 21st century, a negative trend of increasing anthropogenic impact on natural environmental components has been observed, particularly in the last decade. Anthropogenic influence contributes to the emergence of significant areas of unauthorised landfills, pollution of soils and water bodies, a decrease in soil fertility, and a reduction in productivity. Biodiversity loss, a crucial component of the environment, is also significant on a large scale.

As highlighted by M. Horun *et al*. (2019), a primary driver of rapid biodiversity loss is the "Great Acceleration", a period beginning in 1950 characterised by a surge in human activities. This era marks the onset of the Anthropocene, a new epoch where humanity has become the dominant force shaping climate change, biodiversity, and the environment through deforestation, soil degradation, agricultural expansion, land degradation, and landscape fragmentation. The existing network of protected areas is insufficient to safeguard species, habitats, and ecosystems. According to the State cadaster of territories and objects of the nature reserve fund (2024), as of 2023, the coverage of protected areas was 6.91%, significantly below the European average of 21%.

Reclamation activities are accompanied by monitoring of the restoration process of disturbed lands. Remote sensing systems, including aerial imagery and unmanned aerial vehicles (UAVs), are used to observe and predict changes in the state of the studied area under the influence of anthropogenic factors. As noted by N. Mironova & B. Artamonov (2020), these systems are used to address practical tasks related to spatially distributed data, which are employed to ensure the environmental safety of regions and their sustainable development. The authors highlight several advantages of remote sensing methods, including the ability to cover large areas, obtain information on multiple objects simultaneously, monitor areas in regions that are difficult to access for field observations, achieve a high degree of information generalisation, and transition from a discrete picture of the values of natural environment indicators at individual points within the study area to a continuous map of the spatial distribution of these indicators. According to Yu. Vikhot *et al*. (2022), the main disadvantages of using remote sensing methods include dependence on weather conditions (as satellite imaging cannot occur during cloudy or rainy weather). When employing unmanned aerial vehicles, research time is limited by weather conditions and the season, and GPS signals can be lost or degraded. Additionally, the cost of specialised software or sensors can be quite high.

In the context of monitoring post-mining areas, the obtained data can provide information on the structure and composition of the study area, the dynamics of changes in mining landscapes, and can be used to assess the effectiveness of reclamation stages (including agricultural and forest phytomelioration), the spread of hazardous phenomena or their consequences (landslides, erosion, fires), and the identification of critical conditions such as weed proliferation, vegetation thinning, changes in moisture content, and precipitation levels. Using remote sensing techniques and analysing satellite data, scientists R.M. Shevchuk (2019), V. Carabassa *et al*. (2021), and J.C. Padro *et al.* (2022) have highlighted the importance of conducting monitoring studies using remote sensing for mining sites, investigating their condition and changes, and identifying water erosion processes in disturbed areas through remote sensing.

According to data obtained by P. Prokop (2020), an assessment of long-term land use was conducted, identifying the main factors contributing to land degradation, such as deforestation, reduction of pastures, stability of arable land cultivation, population growth, expansion of water bodies, and mining activities. Researchers M.K. Firozjaei *et al*. (2021) evaluated the actual and potential impacts of mining on the biophysical characteristics of the Earth's surface. Monitoring the Normalised Difference Vegetation Index and other plant growth indicators using remote sensing (Earth observing system, n.d.; Crop monitoring, n.d.) can reveal critical conditions and phenomena after biological reclamation or during spontaneous recovery.

The study aimed to assess the condition of the phytocoenoses in the post-mining areas of the Andriikovetskyi quarry-dump complex by analysing Normalised Difference Vegetation Index values over a five-year period, obtained using remote sensing techniques. To achieve this aim, the following tasks were undertaken: identifying the main factors influencing vegetation recovery in the quarry-dump complex and characterising the structure of the mining-industrial landscape. The study also involved zoning the area according to prevalent vegetation types, outlining problematic zones within the quarry-dump complex and determining the causes of their emergence, as well as providing recommendations for further measures to optimise the ecological state of the studied area.

MATERIALS AND METHODS

To assess the condition of the phytocoenosis within the study, various methods were employed, including field methods (transect method, aerial photography, collection of herbarium samples), scientific methods (analysis, synthesis), and statistical methods (statistical analysis of collected data). Changes in the condition of disturbed areas were identified through monitoring the NDVI (Normalised Difference Vegetation Index), one of the most widely used indices for the quantitative assessment of vegetation cover. This index was used to analyse the characteristics of primary vegetation formation and the progression of successional stages for different vegetation types within the Andriikovetskyi quarry-dump complex. The NDVI data were systematised and analysed during the active vegetation period (March to October) from 2019 to 2023, based on the Crop Monitoring system using Sentinel-2 satellite data. The findings allowed conclusions to be drawn regarding the vegetation's projected cover.

The Andriikovetskyi sand quarry-dump complex is located near the village of Andriikivtsi in the Rozsoshanska rural territorial community of the Khmelnytskyi District in Khmelnytskyi Region. The designated study area of the quarry is 4.3 hectares. Extraction took place from 2006 to 2015, and the quarry is situated amid agricultural land where maize and sunflower are cultivated. The identification of the quarry-dump complex in the geospatial context was conducted using GPS coordinates. The results of monitoring topographical changes through UAV aerial photography led to the creation of an elevation change map, which depicts the lowest and highest points of the quarry and highlights its differences from the surrounding agricultural landscape. Based on the aerial photography, a map with a hypsometric profile was generated, which facilitated the description and identification of the main elements of the mining-industrial landscape structure. The progression of primary succession is influenced by factors such as the mechanical composition of the soil, the physical properties of the surface layer of sand, and the exposure of slopes and dumps, reflecting the edaphic conditions. The characteristics of the sandy substrate affect the distribution, anchoring, and germination of seeds, as well as the subsequent spread rate of species.

Based on archival data and Geoinform Ukraine (n.d.), the main characteristics of the substrate of the Andriikovetskyi sand quarry-dump complex were determined as of 2020 and 2022: physicomechanical properties, mineral composition, chemical composition, and fine-grained fraction. In terms of physicomechanical properties, the sandy substrate is characterised by a dense structure, with a bulk density ranging from 1.3 g/cm^3 to 1.41 g/cm^3 and an average true density of 2.63 g/cm^3. The proportion of fine-grained fractions of clay, silt, and mud varies from 2.4% to 19.9%. The primary mineral composition consists of quartz, with admixtures of potassium feldspar and glauconite. In terms of chemical composition, the sandy substrate contains SiO_2 (which predominates over other compounds, ranging from 81.99% to 86.03%), Al_2O_3 (alumina), and CaO (quicklime), each with contents exceeding 3%, as well as Fe_2O_3 and K_2O, both with contents greater than 1%, and TiO_2 and MgO, with contents up to 1%. Plant names are provided according to the International plant name index (n.d.) and the system by S. Mosyakin & M. Fedoronchuk (1999). Species with high invasive potential are indicated as per V. Protopopova *et al*. (2002). The description and identification of common species were conducted under laboratory conditions based on the collected herbarium material.

RESULTS AND DISCUSSION

Post-mining areas, once mineral extraction has ceased, exhibit a range of negative environmental impacts including degraded air quality, soil contamination, depletion of natural resources, reduced groundwater levels, and altered topography. In such areas, segetal and ruderal species, and highly invasive species rapidly proliferate, hindering zonal successional processes and contributing to the decline and loss of biodiversity in adjacent natural areas. Natural restoration can take decades or even centuries or may not occur at all, as devastated lands are low in productivity and have conditions that differ significantly from those of surrounding areas, preventing the colonisation and formation of species-rich zonal phytocoenoses.

It has been established that within the studied sand quarry-dump complex, self-restoration of the plant cover has occurred, accompanied by noticeable plant differentiation. The phytocoenosis significantly differs from those formed in undisturbed natural areas. One of the factors influencing species distribution within quarry-dump complexes is the heterogeneous conditions of the edaphotope. The results obtained from surveying the area using UAVs facilitated the construction of a height change map for the quarry-dump complex, as depicted in Figure 1.

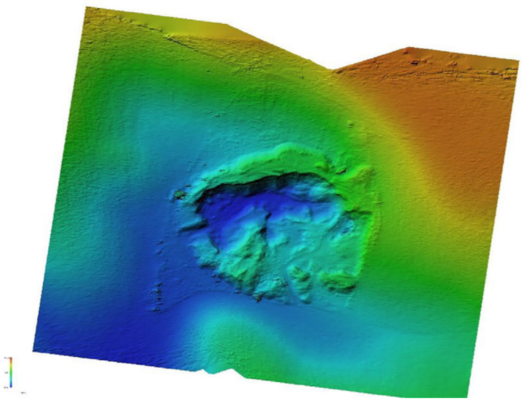

Figure 1. Height change map of the quarry-dump complex
Source: created by the authors

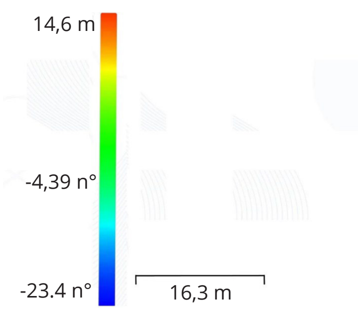

Figure 2. The scale of values for the measured contrasts
Source: created by the authors

Research findings have revealed that the anthropogenic conditions within the quarry-dump complex are characterised by significant elevation differences (the deepest point of the quarry is 328 meters above sea level, located in the northeastern part, while the highest point is 340 meters above sea level, with a height difference within the quarry ranging from 15 to 20 meters), the presence of large embankments in the southern and southwestern parts of the quarry, and steep, unvegetated sand walls and slopes (up to 80° in the northern part, up to 70° in the central, northwestern, and western parts, and more gentle, up to 40°, in the eastern and southeastern parts). The vegetation zoning of the quarrydump complex during the period from 2019 to 2023 and its current state (2024) are presented in Figure 3.

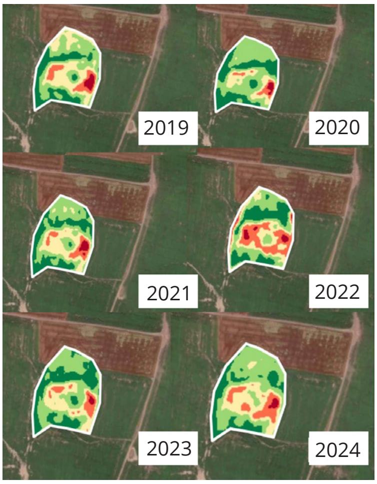

Figure 3. Zoning of the study area
Note: – dense vegetation; – moderate vegetation; – sparse vegetation; – bare soil.
Source: created by the authors

Based on *in situ* research, the primary structure of the mining landscape was determined, taking into account the aforementioned anthropogenic conditions: the quarry floor (bottom) where clay-rich rocks have partially surfaced; hilly areas; inclined surfaces; sandy-loamy dumps and sandy-loamy areas that were not involved in mineral extraction; ridge-like rock embankments, micro-hilly surface areas and escarpments, especially the escarpment of exposed rocks (mainly fine-grained sand), as well as low-lying areas and transitional areas with sufficient moisture. Since no reclamation measures have been carried out within this quarry, and the structure of the quarry-dump complex differs significantly from natural landscape conditions, the distribution of species and the course of successional stages are heterogeneous, with some areas lacking or virtually devoid of vegetation cover.

At the beginning of the study, a significant difference in the condition of the eastern part of the quarry and its internal slopes was observed, as they were subject to landslides and erosion, which was recorded in satellite images. Meanwhile, in the central and western parts of the quarry, the spread of woody shrub species and herbaceous plants was noted. By 2022-2023, zonal species had appeared in the species composition of the phytocoenosis. The presence of mesophytes and mesotrophs among the zonal species indicates soil-forming processes and access to the necessary nutrients. Woody shrub species are common in depressions with sufficient moisture, on the slopes of the northern part, while in the micro-hilly escarpments of the northwestern part, the distribution of herbaceous-grassy plant communities with solitary woody species was recorded. Within the asymmetrical hollows of the central part of the quarry, segetal and ruderal, and herbaceous vegetation predominates with a moderate projective cover.

Over the study period from 2019 to 2024, plant colonisation did not occur in certain areas, primarily the eastern part of the quarry and the internal slopes of the western, north-central, and north-eastern parts. However, the total area of land with absent or nearly absent vegetation cover decreased. Several monocarpic herbs appeared, dominated by the pioneer species *Tussilago farfara* L., which is characteristic of the initial stage of succession. A small number of polycarpic herbs, represented by species of the genus *Fabaceae*, were also present, which will positively impact the enrichment of the sandy substrate with nitrogen (Didur & Shevchuk, 2020). The largest area of land not covered by vegetation or with insignificant projective cover – 1.08 hectares, accounting for 25% of the total quarry area – was observed in 2022. The change in the area of vegetation-covered areas and areas with bare ground (sandy substrate) is presented in Table 1.

Table 1. Changes in the area of vegetation-covered territories

Year / Indicator	2019		2020		2021		2022		2023	
	Area, ha	In %	Area, ha	In %	Area, ha	In %	Area, ha	In %	Area, ha	In %
Dense vegetation	1.09	26	1.31	31	1.58	37	1.16	27	1.41	33
Dense vegetation	1.49	35	2.16	51	1.38	32	1.26	30	1.76	41

Table 1. Continued

Year Indicator	2019		2020		2021		2022		2023	
	Area, ha	In %	Area, ha	In %	Area, ha	In %	Area, ha	In %	Area, ha	In %
Moderate vegetation	1.22	28	0.56	13	0.97	23	0.77	18	0.79	18
Sparse vegetation	0.36	8	0.19	4	0.26	6	0.88	21	0.29	7
Bare soil	0.11	3	0.05	1	0.08	2	0.2	4	0.02	1

Source: calculated by the authors

Analysis of the retrospective data over a five-year period allows for the tracking of the dynamics of plant biomass development. The average NDVI values for the study period are depicted in Figure 3.

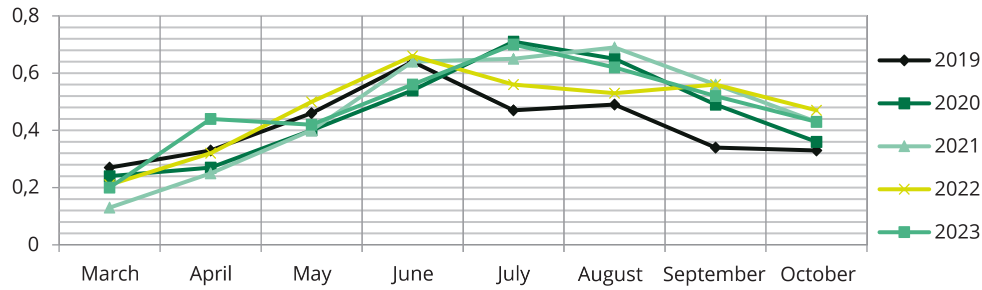

Figure 4. Average NDVI values during the active vegetation period 2019-2023
Source: developed by the authors based on the study

An increase in the NDVI was recorded from May to June, with peak values occurring in July. The lowest values were recorded in 2019, which is associated with the presence of larger areas not covered by vegetation and landslides on the slopes. The highest biomass productivity values were obtained in 2020-2021: in July-August 2020, the values reached 0.65-0.71; in 2021, 0.65-0.69. However, in 2022, a sharp decline in plant biomass productivity was recorded: during the period from July to August, values were within the range of 0.53-0.56. In 2023, the situation improved – NDVI values increased (0.62-0.7), as did the areas covered by dense vegetation (the area value in 2022 was 1.16 ha and 1.26 ha, in 2023 this value was 1.41 ha and 1.76 ha), however, despite the increase in productive areas, landslides continue in the eastern part of the quarry.

It has been established that within devastated lands, negative phenomena can occur, timely identification of which will allow for the implementation of preventive measures or measures to mitigate the consequences and continue the restoration of disturbed territories. The identification of these factors is carried out through thermal contrasts, which are recorded by infrared and thermal spectra. Scientist S. Alpert (2024) has substantiated that using the NDVI index, problem areas with probable oil pollution sites can be identified in this way. In the case of the study of the Andriikovetskyi quarry-dump complex, changes in spectra have allowed for the determination of a sharp decline in plant cover productivity, increasing the area of bare ground and sparse vegetation. After inspecting the territory of the sand quarry, it was found that the decrease in productivity was associated with the appearance of several fire outbreaks, caused by possible spontaneous combustion or arson of unauthorised landfills, which spread to adjacent territories.

The pyrogenic factor poses a significant threat and its monitoring is crucial not only in human-disturbed ecosystems but also in natural ones. Researchers Ye. Suetnov & A. Lazebna (2020) have determined that in areas where landfills are located, spontaneous combustion can occur due to the disposal of waste in unauthorised sites, the absence of proper waste disposal procedures, and the formation of biogas, the accumulation of which in large volumes can lead to massive fires. In the case of the studied quarry, the most likely cause of fires is the intentional burning of waste by humans for disposal purposes, as the size of the formed landfills and the insignificant composition of organic waste are insufficient for the accumulation of excessive amounts of biogas and its subsequent combustion. As noted by O. Mudrak & D. Andrusiak (2022), the impact of the anthropogenic factor is decisive in the occurrence of fires. Climatic conditions, highly flammable plants and their dry residues play a crucial role, as they can lead to the rapid spread of fires and increase the risk of emergencies that are no longer dependent on human factors. This is what happened within the Andriikovetskyi quarry – due to the burning of landfills, the fire spread to vegetation-covered areas, resulting in a massive wildfire of dead wood.

Large-scale mining sites such as peatlands are particularly susceptible to fires. According to research by L. Lischenko *et al*. (2022), seasons with the highest risk of fires and the primary risks associated with anthropogenic factors were identified: within the two study areas, fires most frequently occurred in autumn (September-October). In the Andriikovetskyi quarry, a massive fire broke out in July, during peak temperatures, confirming the influence of climatic conditions on the spread of fire in the study area. In some areas, the spread of segetal and ruderal vegetation was observed, including species such as *Elytrigia repens* (L.)P. Beauv, *Capsella bursa-pastoris* L., *Artemisia absinthium* L., *Cirsium vulgare* (Savi) Ten, *Tripleurospermum inodorum* (L.) Sch. Bip, *Erysimum cheiranthoides* L., *Chenopodium album* L., etc. Some species have a high invasive potential (*Solidago canadensis* L., *Stenactis annuua* L. Cass, *Acer negundo* L., *Amaranthus retroflexus* L.).

As of 2023, the hilly and sloping surfaces, the quarry floor, the rampart-like embankments, and the sandy-loamy surfaces are dominated by ruderal vegetation, herbaceous plants, grasses, and a small number of woody species. The inner slopes are characterised by the absence of phytocoenoses or are covered with sparse herbaceous vegetation and are subject to frequent landslides of sandy substrate. The eastern part of the quarry is characterised by the almost complete absence of vegetation, particularly within the sandy escarpment where unauthorised sand extraction occurs, and the surrounding area – the monolithic sandy bottom and individual sections of sandy-loamy spoil heaps. A small amount of herbaceous vegetation is represented by species such as *Astragalus onobrychis* L., *Tanacetum vulgare* L., *Pimpinella saxifraga* L., *Myosotis micrantha* Pall. ex Lehm, *Taraxacum officinale* Weber ex F.H. Wigg. s. l., is formed on the steep slopes of the quarry, with *Tussilago farfara* L. as the dominant species in the plant cover of this area. The process of quarry restoration is directly dependent on its location, the degree of disturbance, the formed edaphic conditions, the type of rock and its properties, as demonstrated by the results of the study conducted on different types of quarries.

The overall condition of the quarry and its vegetation cover has been assessed as satisfactory. Similar findings were reported by I. Vorovencii (2021), who investigated the state of areas following reclamation efforts, noting the establishment of spontaneous vegetation and forest regeneration over several years. The development of vegetation cover has also been deemed satisfactory within the titanium ore extraction site, as indicated by the results of an EIA conducted by B.V. Borysiuk *et al.* (2022). The identified biogeocenoses of forests, meadows, and wetlands are considered to be quite resilient and suitable for supporting plant and animal life. However, it has been noted that the forested areas are densely populated with underbrush, which may adversely affect the overall biogeocenosis of the forest. A similar negative factor has been identified in the studies of the Andriikovetskyi sand quarry-dump complex, where a significant number of segetal and ruderal species are prevalent, thereby impacting the formation of vegetation cover within the studied area and hindering the spread of zonal flora species.

Y. Wang *et al.* (2022), through NDVI analysis of a vacant lot with limestone soil, found that the ecological condition of the area was improving but only reached a moderate level of vegetation cover, indicating the need for additional reclamation measures. According to the obtained monitoring results, a general improvement in the situation has occurred within the Andriikovetskyi quarry-dump complex; however, the situation within the eastern part of the quarry remains unsatisfactory, requiring restoration work. When studying a limestone quarry in India, scientists V. Kumar &

K. Yarrakula (2022) analysed data from 1997 to 2017 and found an increase in built-up and agricultural areas, while natural water bodies and forest areas decreased. Within the studied Andriikovetskyi quarry, on the contrary, using the NDVI index, an increase in the total area covered by vegetation was determined (indicating a sequence of successional stages). However, destructive processes within the quarry do not cease, and areas of bare ground (sandy substrate) are still localised within the study object. A similar situation was found by scientists L. Suresh *et al.* (2021) in granite quarries: within the study area, areas were found where vegetation was destroyed and there are areas of bare substrate, although vegetation was preserved on most of the study area. Researchers A. Buczyńska *et al.* (2023) found, through an analysis of vegetation index values within brown coal extraction quarries, a general improvement in vegetation cover, except in a specific area in the north-west, where a decrease in the vegetation index was observed. Within the eastern part of the studied quarry-dump complex, a section with the worst vegetation cover indices was identified, significantly differing from the sections in the western, central, and southern parts.

In the studies conducted by S. Huang *et al.* (2021), the overall trend of using NDVI and the limitations of the method that may impact the assessment of vegetation cover were examined. The researchers noted that this vegetation index would continue to be the dominant index for vegetation studies; however, its effective application depends on the quality of the multispectral data obtained and its subsequent interpretation. Furthermore, the need for training users of NDVI was highlighted to minimise uncontrolled usage of the data acquired. An important factor identified for the accurate recording and interpretation of data is the influence of sensor and atmospheric effects. During the analysis of data from the Andriikovetskyi quarry-dump complex, the atmospheric effect was noted as the most frequently recurring factor that hampers proper registration of remote sensing data on certain days of the growing season.

Monitoring disturbed areas using remote sensing is more effective when combined with other research methods and measures that contribute to improving the restoration processes of devastated sites. Researchers V. Adjiski & V. Zubíček (2023) combined the Google Earth Engine (n.d.). computational platform with Landsat time series data, NDVI, the RandomForest (RF) algorithm, and LandTrendr to monitor the impact of mining, reclamation measures, and solar power plant activities at a coal mine from 1984 to 2021. In this study, remote sensing monitoring was combined with *in situ* research within the quarry, making it possible to identify the prerequisites and trends in changes in vegetation and landscapes in the study area, characterise the factors influencing the formation of vegetation cover at the time of the study, and forecast possible ways to implement conservation measures. The study has determined that the Andriikovetskyi quarry requires a mining engineering stage of reclamation (grading, slope stabilisation, formation of slopes, covering with a layer of fertile or potentially fertile soil, removal and disposal of waste) using environmentally friendly methods to bring the conditions of the quarry-dump complex closer to natural ones, which will contribute to accelerating zonal successional transformations.

CONCLUSIONS

Biodiversity is a crucial component of the natural environment, and its preservation is a prerequisite for the sustainable development of any region. Since 2014, the risk of its loss has increased, especially in heavily disturbed areas of mining landscapes, necessitating the adoption of new technologies for monitoring and observing the state of the environment. Monitoring the NDVI index has enabled the assessment of the condition of phytocoenoses in the studied areas and the timely identification of problem areas during reclamation or the monitoring of self-recovery of post-mining territories.

Remote sensing results and the transect method of the territory have confirmed that due to elevation differences, surface irregularities, frequent water and wind erosion processes (resulting from the lack of reclamation measures), instability of the sandy substrate, and its low ability to provide plants with the necessary amount of moisture, plant differentiation has formed within the quarry. Some areas within the eastern part of the quarry are not covered by vegetation, while the inner slopes of the western and central parts of the quarry are characterised by the course of primary successional stages, distinguished by sparse vegetation. In 2023, the total area of plots where primary colonisation by species did not occur decreased: the area of bare ground is 0.02 ha, which is 5.5 times less than the values recorded at the beginning of the study in 2019.

The sparse vegetation cover in transitional areas includes the appearance of ruderal and segetal species, and species with high invasive potential, such as *Solidago canadensis* L., *Stenactis annuua* L. Cass, *Acer negundo* L., and *Amaranthus retroflexus* L., which may hinder the spread of zonal species and the formation of stable phytocoenoses. Continued monitoring will allow tracking the dynamics of vegetation cover, and reducing the impact of negative processes in the edaphic environment through necessary engineering measures will ensure the formation of zonal natural flora. Measures aimed at the self-recovery of quarries and the formation of vegetation cover will contribute to the establishment of quarries as objects that will represent natural zonal flora in the context of biodiversity conservation and sustainable development. Further research aimed at finding and identifying similar objects in the geospatial realm, determining ways to improve the condition of disturbed areas, and ways of their further profitable use is promising.

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CONFLICT OF INTEREST

None.

REFERENCES

[1] Adjiski, V., & Zubíček, V. (2023). Continuous monitoring of the mining activities, restoration vegetation status and solar farm growth in coal mine region using remote sensing data. *Mining Revue*, 29(1), 26-41. doi: 10.2478/minrv-2023-0003.
[2] Alpert, S. (2024). Anapplication of the modern methods for satellite image processing for solution of problems of environmental monitoring. *Ukrainian Journal of Remote Sensing*, 11(2), 13-18. doi: 10.36023/ujrs.2024.11.2.260.
[3] Borysiuk, B., Hurelia, V., & Statnyk, I. (2022). Study of the influence of activities on flora during the construction and operation of the titanium ore quarry. *Herald of the National University of Water and Environmental Engineering: Agriculture Science*, 3(99), 15-24. doi: 10.31713/vs320222.
[4] Buczyńska, A., Blachowski, J., & Bugajska-Jędraszek, N. (2023). Analysis of post-mining vegetation development using remote sensing and spatial regression approach: A case study of former "Babina" mine (Western Poland). *Remote Sens*, 15(3), article number 719. doi: 10.3390/rs15030719.
[5] Carabassa, V., Montero, P., Alcañiz, J.M., & Padró, J.C. (2021). Soil erosion monitoring in quarry restoration using drones. *Minerals*, 11(9), article number 949. doi: 10.3390/min11090949.
[6] Crop monitoring. (n.d.). Retrieved from https://crop-monitoring.eos.com.
[7] Didur, I., & Shevchuk, V. (2020). Increasing soil fertility as a result of the accumulation of nitrogen by leguminous crops. *Agriculture and Forestry*, 16(1), 48-60. doi: 10.37128/2707-5826-2020-1-4.
[8] Earth observing system. (n.d.). Retrieved from https://eos.com/uk/products/crop-monitoring/key-functions/satellite-monitoring.
[9] Firozjaei, M.K., *et al*. (2021). A historical and future impact assessment of mining activities on surface biophysical characteristics change: A remote sensing-based approach. *Ecological Indicators*, 122, article number 107264. doi: 10.1016/j.ecolind.2020.107264.
[10] Geoinform Ukraine. (n.d.). Retrieved from http://geoinf.kiev.ua.
[11] Google Earth Engine. (n.d.). Retrieved from https://earthengine.google.com/.
[12] Horun, M., Pyrih, H., Faifura, V., & Fedirko, M. (2019). *Ecology*. Ternopil: Ternopil National Economic University.
[13] Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *Journal of Forestry Research*, 32, 1-6. doi: 10.1007/s11676-020-01155-1.
[14] International plant name index. (n.d.). Retrieved from https://www.ipni.org/.
[15] Kumar, V., & Yarrakula, K. (2022). Environmental impact assessment of limestone quarry using multispectral satellite imagery. *Earth Science Informatics*, 15, 1905-1923. doi: 10.1007/s12145-022-00845-0.

[16] Lischenko, L., Shevchuk, R., & Filipovych, V. (2022). The technique for satellite monitoring of peatlands in order to determinate their fire hazard and combustion risks. *Ukrainian Journal of Remote Sensing*, 9(1), 16-25. doi: 10.36023/ujrs.2022.9.1.210.

[17] Mironova, N., & Artamonov, B. (2020). The use of GIS technology in the study of mineral deposits of sedimentary origin of the Khmelnitskyi Region. *Herald of Khmelnytskyi National University: Technical Science*, 3(285), 7-11.

[18] Mosyakin, S., & Fedoronchuk, M. (Eds.). (1999). *Vascular plants of Ukraine: A nomenclatural checklist*. Kyiv: M.G. Kholodny Institute of Botany. doi: 10.13140/2.1.2985.0409.

[19] Mudrak, O., & Andrusiak, D. (2022). Influence of the pyrogenic factor on natural ecosystems of Podilski Tovtry National Nature Park. *Agroecology Journal*, 2, 124-138. doi: 10.33730/2077-4893.2.2022.263328.

[20] Padro, J.C., *et al*. (2022). Drone-based identification of erosive processes in open-pit mining restored areas. *Land*, 11(2), article number 212. doi: 10.3390/land11020212.

[21] Prokop, P. (2020). Remote sensing of severely degraded land: Detection of long-termland-use changes using high-resolution satellite images on the Meghalaya Plateau, northeast India. *Remote Sensing Applications: Society and Environment*, 20, article number 100432. doi: 10.1016/j.rsase.2020.100432.

[22] Protopopova, V., Mosyakin, S., & Shevera, M. (2002). *Phytoinvasions in Ukraine as a threat to biodiversity: Current state and tasks for future*. Kyiv: M.G. Kholodny Institute of Botany.

[23] Shevchuk, R.M. (2019). Monitoring of myliatyn Granular phosphorite quarry current state using remote sensing data. *Geological Journal*, 2(367), 73-78. doi: 10.30836/igs.1025-6814.2019.2.169937.

[24] State cadaster of territories and objects of the nature reserve fund. (2024). Retrieved from https://data.gov.ua/dataset/mepr_05.

[25] Suetnov, Ye., & Lazebna, A. (2020). Legal regulation of waste management: Analysis, problems and directions of solution. *Man and Environment*, 33, 102-108. doi: 10.26565/1992-4224-2020-33-09.

[26] Suresh, L., Jothibasu, A., & Anbazhagan, S. (2021). Assessment of land use and land cover changes in the granite mining area of Krishnagiri district, South India using remote sensing data. *Indian Journal of Natural Sciences*, 12(67), 32976-32988.

[27] Vikhot, Yu., Bubniak, I., Kril, S., & Fourman, V. (2022). Using unmanned aerial vehicles (UAV) for geophysical observations. *Herald of the Lviv University: Geology*, 36, 100-105. doi: 10.30970/vgl.36.08.

[28] Vorovencii, I. (2021). Changes detected in the extent of surface mining and reclamation using multitemporal Landsat imagery: A case study of Jiu Valley, Romania. *Environmental Monitoring and Assessment*, 193(30). doi: 10.1007/s10661-020-08834-w.

[29] Wang, Y., Qiao, L.F., Yao, Z.Y., Qi, A.G., & Zhang, Y.C. (2022). Analysis of the change in vegetation coverage of chalk soil wasteland during the growing season based on UAV sequence image. *Applied Ecology & Environmental Research*, 20(4), 3311-3322. doi: 10.15666/aeer/2004_33113322.

Оцінка стану фітоценозів кар’єрно-відвальних комплексів засобами дистанційного зондування

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Анотація. Одним із видів антропогенної діяльності людини, який спричиняє негативні зміни природних умов середовища та втрату біорізноманіття, є видобування корисних копалин у межах кар’єрно-відвальних комплексів, які потребують заходів з відновлення екологічної рівноваги після завершення видобувних робіт. Пошук оптимальних методів для виявлення порушених ділянок, моніторингу стану та динаміки відновлення відпрацьованих земель у контексті збереження та відновлення біорізноманіття, становив мету дослідження, особливо в умовах недоступності для проведення натурних досліджень та за необхідності спостереження за кількома об’єктами одночасно. В статті представлено результати оцінки стану рослинного покриву в межах порушених видобуванням корисних копалин територій за допомогою засобів дистанційного зондування Землі. Застосовано такі методи як наукові (аналіз, синтез), статистична обробка даних, маршрутний метод. Визначено, що аналіз та моніторинг значень нормалізованого диференційного вегетаційного індексу (NDVI), отриманих засобами дистанційного зондування Землі, дає змогу оцінити якість проведених заходів із рекультивації, визначити високопродуктивні ділянки та виявити проблемні зони для пошуку ефективних методів покращення екологічного стану досліджуваної ділянки. В межах досліджуваного Андрійковецького кар’єрно-відвального комплексу відзначено неоднорідність перебігу сукцесійних стадій, на території локалізовані відкриті ділянки без рослинного покриву та ділянки, які характеризуються перебігом первинних сукцесійних стадій та розрідженою рослинністю. Зафіксовано найнижчі показники NDVI в 2019 та в 2022 роках, у період з 2020 по 2021 рр. та з 2023 по 2024 роки відбулось збільшення продуктивності біомаси, площа ділянок із густою та помірною рослинністю збільшилась. Відзначено, що дана ситуація спричинена наявністю перепадів висот, нерівностей поверхні, процесами водної і вітрової ерозії (що є наслідком відсутності рекультиваційних заходів), нестабільністю піщаного субстрату та низькою здатністю до забезпечення рослин необхідною кількістю вологи. Результатами проведеного дослідження підкреслено важливість рекультиваційних заходів пост-майнінгових територій та надано практичні рекомендації щодо проведення необхідних інженерно-технічних заходів для наближення умов кар’єрно-відвального комплексу до природних, що сприятиме поширенню зональних видів та процесам самовідновлення

Ключові слова: порушені території; NDVI; видобування корисних копалин; рослинність; умови місцезростань; рекультивація; моніторинг