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ASSESSMENT OF COAL MINING IMPACT ON THE GEOECOLOGICAL TRANSFORMATION OF THE EMERALD NETWORK ECOSYSTEM

Purpose. Geoecological assessment of impact on the ecosystem transformation of a part of Emerald Network object "Samarskyi Lis – UA0000212" caused by coal mining at the section of "Ternivska" mine (Dnipropetrovsk region, Ukraine) using the methods of remote sensing of the Earth in conditions of limited access to the study object due to the state of martial law in Ukraine.

Methodology. A complex of standardized field, paper, laboratory and statistical research methods was used. When studying aquatic vegetation, generally accepted methods for describing the species and coenotic composition of vegetation and hydrobotanical mapping were used. The study on soil vegetation was carried out with the selection and description of the main phytocenoses, features of their composition and distribution on the territory. Floristic studies were carried out according to the method for collecting herbarium material. Field routes were carried out on the land surface along the mining of the coal bed with the recording of destructive changes in the landscape (falls, top-soil breaks, sufosis manifestations, cracks, lowering of the relief) and plant groups – the colour and condition of tree, shrub and grass vegetation. In order to compare visual observation data and obtain representative and reliable research results, the facility was monitored additionally using modern geoinformation systems. A satellite observation tool was used; it allowed searching, processing, and obtaining information from satellite data according to various indexes: WRI, NDWI, MNDWI, NDSI.

Findings. Negative consequences of the impact of the coal mine "Ternivska" on the geological and ecological transformation of the Emerald network ecosystem "Samarskyi Lis – UA0000212" have been established. It has been proven that long-term underflooding and flooding of lands leads to a change in the species composition of the forest stand, the death of the understory and grass layer, and the complete destruction of the existing plant and animal communities. In flooded areas of oak forests and pine plantations, forest species die out and wetland plant species spread. Over three years (2020–2023), the area of visible and established flooding according to remote sensing data has increased from 1 to 6 hectares, respectively.

Originality. Dynamics of the process of the land surface subsidence and protected area flooding has been established according to the data of open-source geoinformation systems and the comparison of various satellite data indexes (WRI, NDWI, MNDWI, NDSI). Gradual changes in the species composition of the forest stand, the death of the understory and the grass layer were revealed. It has been confirmed that long-term flooding leads to the complete destruction of existing plant and animal communities, the destruction of compound complexes of soil mesofauna makes development impossible for the terrestrial invertebrate species that lived in these biotopes before their destruction, including species from the Red List of Ukraine and protected by the Berne Convention.

Practical value. In the conditions of limited access for conducting direct geodetic and engineering-geological studies, the methodology of using modern GIS by combining various spectral channels (indexes) is substantiated to determine and study the dynamics of the underflooding (flooding) process in the territory. In combination with traditional field geobotanical research, the results of monitoring observations of the coal mining activity and its impact on the geoecological transformation of the ecosystem of the Emerald Network object are presented for the first time in the region. The negative impact of mining activity on natural conservation areas, which leads to the death and gradual change in the species composition of plants, has been determined.

Keywords: *geoecological transformation, underflooding, flooding, natural landscape, Emerald territory, coal mining*

Introduction. The mining industry is one of the largest polluters. Its impact on various components of nature becomes obvious as the earth's surface is damaged, polluting substances and greenhouse gases are emitted into the atmosphere, and land and water resources are contaminated [1, 2]. The impact of mining operations is particularly dangerous within protected and conservation areas. One of the examples of negative anthropogenic impact on such objects (Fig. 1) is coal mining of Ternivska mine of the Shahtoupravlinnia Pavlohradske Structural Subdivision, located in the West Donbas (Pavlohradskyi district, Dnipropetrovsk region, Ukraine). Underground development of the coal deposit poses a threat to a part of the territory of the Samarskyi Lis – UA0000212 Emerald Network [3, 4].

The project [5] provides for the development of coal reserves in the Ternivska-Pivdenna section of Ternivska mine

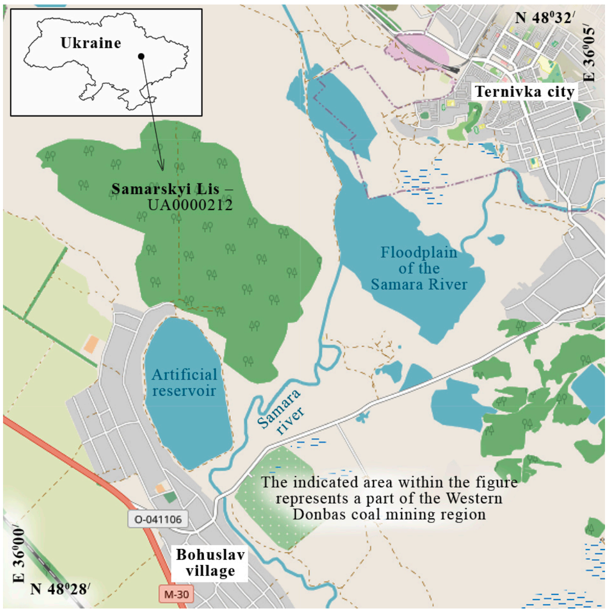


Fig. 1. Samarskyi Lis – UA0000212 Study Object Location Map

during 2020–2025 with a production of about 3.7 million tons of coal. At the same time, the length of the longwall is 200–255 m, and the length of the extraction pillars is 2,100–2,400 m. In the Ternivska-Pivdenna section, a system of extraction of a seam in long pillars along its length has been adopted. The roof management method involves a full collapse in increments of 0.8 m. In 2020, the first longwall was set in operation in the Ternivska-Pivdenna section. It is planned to discharge mine waters into the surface hydrographic network of the Samara River. The projected maximum mine water inflow for the extraction period is 745 m^3/hour.

The extraction of the coal seam involves disturbance of the natural equilibrium and stability of the rock mass [6, 7], as well as water inflow to the mine openings due to the discharge of aquifers. If the mine drainage plants stop and mine water is not pumped out, it will gradually flood the mine openings, due to man-made rock jointing, the groundwater levels in the carbon deposits will rise [5].

Given the long-term operation of the field, some areas of the daylight surface have already subsided considerably, compared to the initial (natural) state. Therefore, the possibility of saturation and flooding of the territory due to the mine' anthropogenic impact is not out of the question. Pumping out and discharging highly mineralized mine water can lead to a deterioration in the quality of water resources [8] and adversely affects the biota [9]. Mine water has a modified chemical composition and contains dissolved methane [10].

Negative geoecological transformation of natural landscapes of a part of the Samarskyi Lis – UA0000212 Emerald Network object during the operation of the mine, primarily related to the earth's surface undermining, changing the hydrogeological regime of the mine field and adjacent territories. It is estimated that the ground surface will subside to 0.94 m, and the total area affected by the Ternivska-Pivdenna seam extraction is 340 hectares [5]. As a result of the possible subsidence of the surface, the saturation and flooding of areas of 90 hectares is expected. In the area of possible impact, there are about 25 hectares of forest plantations of the Pavlohrad Forestry.

In 2022–2023, under the conditions of military activities, the scientists' access to the part of the Samarskyi Lis – UA0000212 Emerald Network object was limited. Therefore, the object was monitored using modern geoinformation systems for remote sensing of the Earth.

Thus, the *purpose of the research* is the post-project monitoring of the environmental impact of the planned operation of Ternivska mine within the Samarskyi Lis – UA0000212 Emerald Network object using satellite remote sensing data. To achieve this goal, the following *tasks* were completed:

1) the project of the planned operation of Ternivska mine was considered and evaluated and its hypothetical impact on part of the Samarskyi Lis – UA0000212 Emerald Network was identified;

2) during 2020–2022, field studies were carried out and the species composition of flora and fauna listed in the Red Data Book of Ukraine was identified;

3) the changes in the biotopes, stations, landscapes and habitats of various species of animals and plants to be protected in the object of the Samarskyi Lis – UA0000212 Emerald Network were defined;

4) the dynamics and boundaries of flooding (inundation) of the territory of the planned operation of Ternivska mine within the object under study according to the remote sensing data were assessed;

5) the results of field and laboratory studies were analysed and compared with the project data, which made it possible to fairly assess and propose reasonable recommendations for further scientific research on the protection of natural conservation areas.

Materials and methods. *The study object* is the site of the Samarskyi Lis – UA0000212 Emerald network, which is exposed to negative geo-ecological impact as a result of the planned operation of Ternivska coal mine in Pavlohrad district of Dnipropetrovsk region. The research at this facility was carried out in the spring-autumn periods of 2020–2022. A set of standardized [11] field, paper and laboratory methods was used – botanical, zoological, landscape, cartographic, geoinformation and statistical data processing methods. When studying the vegetation of reservoirs, generally accepted methods for describing the species and coenotic composition of vegetation, hydrobotanical mapping, etc. were used. The study on vegetation was carried through identification and description of the main phytocoenoses, features of their composition, and distribution across the territory. Plant names are given according to the modern botanical nomenclature [12]. Besides, routes were made on the ground surface along the coal seam entry in order to locate destructive changes in the landscape (sinkholes, turf ruptures, suffusion processes, cracks, etc.) of the Samarskyi Lis – UA0000212 Emerald Network. Particular attention was paid to natural topographic lows, the colour and condition of trees, shrubs and grass were registered.

To compare the data of visual observations and obtain representative and reliable research results, the object was additionally monitored using modern geoinformation systems. A satellite surveillance tool was used that allows searching, processing and receiving information from satellite data – *EOSDA LandViewer* [13, 14]. Various indices were used to detect water bodies according to remote sensing data [15]: Water Ratio Index (WRI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Normalized Difference Snow Index (NDSI).

In particular, for the optical range of electromagnetic waves for Landsat 7 satellite images, the Water Ratio Index (WRI) is calculated by the formula [15]

$$WRI = (GREEN + RED)/(NIR + SWIR2). \qquad (1)$$

It is used to assess the moisture content in the vegetation cover. If the index value is above 1, the objects of study are water surfaces or objects that retain moisture.

The Normalized Difference Snow Index (NDSI) and Normalized Difference Moisture Index (NDMI) were used during the previous stage of processing to ensure better interpretation of remote sensing images. The results were processed and analysed using statistical methods [16] and Microsoft and STATISTICA 10.0 application packages.

Results and discussion. *Vegetation studies.* In the Samarskyi Lis – UA0000212 Emerald Network object (within the territories and water areas of the planned operation of Ternivska mine), the following natural habitats have been identified in accordance with Resolution 4 of the Bern Convention [17]: *C1.67 Turlough and lake-bottom meadows, C3.5133 Wet ground dwarf herb communities, E1.2F Pannonic sand steppes, E3.4 Moist or wet eutrophic and mesotrophic grassland, G1.36 Ponto-Sarmatic mixed Populus riverine forests, G3.4232 Sarmatic steppe Pinus sylvestris forests, X35 Inland Sand Dunes*.

The flora of the region under study includes representatives of extrazonal and intrazonal plant communities. This is the Samara riverside, its floodplain and a significant part of the arena. In the floodplain, there are drying temporary reservoirs, where common reed *Phragmites australis*, great reedmace (bulrush) *Typha latifolia* and slender Tufted-sedge *Carex acuta* predominate in the vegetation cover. In the floodplain meadows, plant communities dominated by *Elytrigia repens* and *Poa trivialis* are developed. Deciduous forests of the floodplain area are represented by elm and black maple forests, and aspen groves. Shrub groups are formed by *Amorphafruticosa*, *Acer tataricum*, *Salix rosmarinifolia* thickets. The vegetation of the sands is represented by Scots pine *Pinus sylvestris* plantations with large areas of the sandy steppe, dominated by *Festuca beckeri* and *Koeleria sabuletorum*.

Table 1 provides a list of species of environmental importance both at the regional (national) and international levels.

Table 1

List of plant species subject to special protection and included in national and international lists of protected species*

No	Species	A	B	C	D	E
		Status***				
1	*Equisetum arvense* L.**	–	–	–	LC	–
2	*Agropyron dasyanthum* Ledeb.	–	–		–	CR
3	*Senecio borysthenicus* (D&c.) Andrz.	–	–	3	CR	–
4	*Stipa borysthenica Klokov ex Prokudin***	2	–	2	–	–
5	*Tragopogon ucrainicus* Artemcz.	–	–	3	CR	–
6	*Epipactis palustris* (L.)Crantz**	3	–	3	–	–
7	*Vincetoxicum rossicum* (Kleop.) Barbar.**	–	–	3	CR	CR
8	*Ornithogalum boucheanum* (Kunth) Asch.**	2	–	3	–	–
9	*Pulsatilla pratensis* (L.) Mill. s.l.**	2	–	3	–	–
10	*Tulipa quercetorum* Klokovet Zoz**	3	–	3	–	–
11	*Viola lavrenkoana* Klokov	–	–	–	CR	–
12	*Allium savranicum* Besser	2	–	3	–	–
13	*Jurinea cyanoides* (L.) Rchb.	–	D	–	LC	–
14	*Lactuca serriola* Torner	–	–	–	LC	–
15	*Lotus corniculatus* L.	–	–	–	LC	–
16	*Medicago lupulina* L.	–	–	–	LC	–
17	*Melilotus albus* Medik.	–	–	–	LC	–
18	*Melilotus officinalis* (L.) Pall.	–	–	–	LC	–
19	*Securigera varia* (L.) Lassen	–	–	–	LC	–
20	*Trifolium arvense* L.	–	–	–	LC	–
21	*Trifolium hybridum* L.**	–	–	–	LC	–
22	*Trifolium repens* L.**	–	–	–	LC	–
23	*Acorus calamus* L.**	–	–	3	–	–
24	*Allium paniculatum* L.	–	–	0	–	–
25	*Allium rotundum* L.	–	–	3	–	–
26	*Convallaria majalis* L.**	–	–	3	–	–
27	*Polygonatum odoratum* (Mill.) Druce	–	–	3	–	–
28	*Muscari neglectum* Guss. Ex Ten.**	–	–	2	–	–
29	*Ornithogallum kochii* Pare**	–	–	3	–	–
30	*Scilla siberica* Haw.**	–	–	3	–	–
31	*Wolffia arrhiza* (L.) Horkel ex Wimmer**	–	–	3	–	–
32	*Gagea lutea* (L.) Ker.-Gawl*	–	–	3	–	–
33	*Asarum europaeum* L.**	–	–	3	–	–
34	*Corydalis solida* (L.) Clairv**	–	–	3	–	–
35	*Corydalis cava* (L.) Schweigg. et Korte**	–	–	2	–	–
36	*Gentiana pneumonanthe* L.**	–	–	2	–	–
37	*Chamaerion angustifolium* (L.) Holub**	–	–	3	–	–
38	*Ranunculus lingua* L.**	–	–	3	–	–
39	*Ranunculus auricomus* L.**	–	–	2	–	–
40	*Padus avium* Mill.**	–	–	0	–	–
41	*Salix caprea* L.**	–	–	3	–	–
42	Sempervivum ruthenicum Schnittsp. & C. B. Lehm.	–	–	3	–	–

End of Table 1

Note: * Abbreviations: A – Red Data Book of Ukraine, B – Berne Convention, C – Regional Rare Species, D – European Red List, E – International Union for Conservation of Nature.

** Species likely to be found in these habitats.

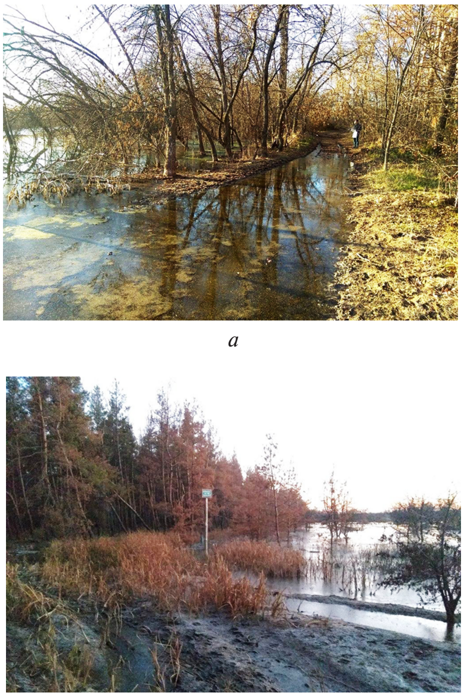
*** Status: depending on the state and degree of threat of extinction of species of fauna and flora included: extinct *0* – species for which there is no up-to-date information after repeated searches in their typical locations or in other known and possible habitats, there has been no information about their existence in the wild for about 50 years; endangered *1* – species that are in danger of extinction in natural environment and the preservation of which is unlikely with the ongoing action of factors that negatively affect the state of populations; vulnerable *2* – species that in the near future can be classified as endangered if the action of factors that negatively affect the state of populations continues; rare *3* – species whose populations are small and are not currently referred to the "endangered" or "vulnerable" categories, although they are at risk; insufficiently studied (unrated); Critically Endangered – CR, Least Concern – LC, Data Deficient – D

The study on the state of vegetation at the site of the planned operation at the Ternivska-Pivdenna site of Ternivska mine showed the availability of 233 species of higher vascular plants (168 genera, 62 families). *Five* plants listed in the Red Data Book of Ukraine are protected [18]: *Allium savranicum* Besser, feather grass *Stipa borysthenica* Klok. ex Prokud., *Pulsatilla nigricans* Storck, *Tulipa quercetorum* Klok. et Zoz, *Ornithogalum boucheanum* (Kunth) Aschers.

Hydrogeological impact on the ecosystem. Since the spring of 2021, the forest and meadow ecosystems have transformed due to a change in the hydrological regime in some areas of the Samara Forest, which are within the area of planned operation of Ternivska mine. Due to flooding of vast forest areas, death and loss of forest stand have been observed (Fig. 2).

The undergrowth and herbaceous tier have also died. There is a threat to the habitats of plants listed in the Red Data Book of Ukraine: *Tulipa quercetorum* Klok, et Zoz, *Ornithogalum boucheanum* (Kunth) Aschers. In the flooded areas of oak forests and pine stands, forest species are lost, and wetland plant species spread: *Lemna minor* L., *Juncus gerardii* Loisel., *Persicaria maculosa* Gray, *Persicaria hydropiper* (L.) Delarbre, *Carex acuta* L., *Scirpoides holoschoenus* (L.) Sojak (Table 2). In meadow ecosystems, dominant plants die: *Poa trivialis*, while marsh and wetland plant species spread: *Juncus gerardii* Loisel., *Persicaria maculosa* Gray, *Persicaria hydropiper* (L.) Delarbre, *Carex acuta*, *Scirpoides holoschoenus* (L.) Sojak.

In meadows that are not flooded, such species as *Limonium gmelinii* (Willd.) Kuntze, *Puccinelia distans* (Jacq.) Parl. have significantly increased in number, which indicates an increase in the level of soil salinity.



a

b

Fig. 2. Flooding of forests (a) and consequences of anthropogenic impact (b) on the ecosystem of the Samara Forest

Table 2

Plant species that undergo anthropogenic impact on flooded areas of the Samara Forest within the area of the planned operation of Ternivska mine

Forest species that die in flooded areas	
1	*Betula pendula* Roth.
2	*Quercus robur* L.
3	*Ulmus laevis* Pall.
4	*Acer tataricum* L.
5	*Acer platanoides* L.
6	*Acer campestre* L.
7	*Pinus sylvestris* L.
8	*Convallaria majalis* L.
9	*Salix acutifolia* Willd.
10	*Populus tremula* L.
11	*Urtica dioica* L.
12	*Polygonatum multiflorum* (L.) All.
13	*Geum urbanum* L.
14	*Sambucus nigra* L.
15	*Crataegus monogyna* Jacq.
16	*Lonicera tatarica* L.
17	*Frangula alnus* Mill.
Wetland species found in flooded forest areas	
1	*Lemna minor* L.
2	*Juncus gerardii* Loisel.
3	*Persicaria hydropiper* (L.) Delarbre
4	*Persicaria maculosa* Gray
5	*Scirpoides holoschoenus* (L.) Sojak

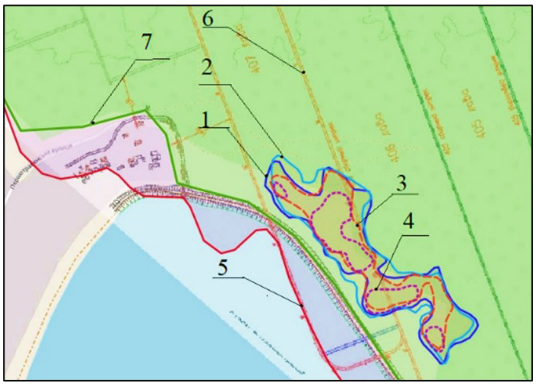


Fig. 3. Summary results of monitoring (according to the NDSI+WRI) of flooded area of the UA0000212 object:

1 – flooding as of May 18, 2023; 2 – flooding as of April 16, 2023; 3 – flooding as of July 02, 2022; 4 – flooding as of October 06, 2022; 5 – edge of shaft bench; 6 – modular gate entry; 7 – border of the Samarskyi Lis – UA0000212 Emerald Network object

It should be noted that the origin of changes in the hydrological regime of part of the study area (long-lasting flooding) is insufficiently studied, given the limited access to this area due to hostilities in the country. Obviously, flooding cannot be the result of powerful spring showers, but is caused by a constant backwater effect.

Monitoring studies of 2020 did not find such flooding in this area, while the data of observations of April-August 2021 indicate the presence of long-existing reservoirs up to 20 cm deep, persisting during the season.

A comprehensive analysis of remote sensing data made it possible to separate the flooded area of the Samarskyi Lis – UA0000212 Emerald Network from the dry land (Fig. 3) and estimate the flooded area (Table 3).

Analysis of the data obtained shows that flooding is most likely due to the flow of water from an artificial lake to the forest, since the water level in the lake is higher than the forest ground level. The forest and meadows are located in the regulated floodplain of the Samara River, the water level in which is also below the lake surface level. It should be noted that seasonal fluctuations in levels have always been observed in the Samara River, and the lake surface level has changed very slightly. At the same time, confirmation of this logical judgement is possible provided that geodetic and supportive specialized engineering and geological studies are carried out.

Thus, the preservation of the diversity of the gene pool of the planet living creatures today is becoming one of the main tasks of mankind. The protection of rare plants and animals is only possible within the framework of preservation of their habitats; therefore, the Convention on the Conservation of European Wildlife and Natural Habitats is an important tool to maintain biological and landscape diversity on the European continent [19]. Ukraine, as a Party to the Convention,

Table 3

Trend in the process of soil subsidence and flooding of the study area according to remote sensing indices

Date	Site number in Fig. 3	Flood area, ha
May 18, 2023	1	6.0
April 16, 2023	2	6.2
October 06, 2022	4	2.1
July 02, 2022	3	3.8
July 15, 2021	initial stage (not indicated in Fig. 3)	1.2

fulfils the obligations to create the Emerald Network [20], which is one of the main tools for the conservation of species and habitats specified by the Berne Convention. For Ukraine, the creation and development of the Emerald Network is an important part of the European integration process – the country's preparation for the introduction of European environmental laws.

Today, the Emerald Network in Ukraine should occupy at least 20 % of the area of the country, but this figure has not reached even 10 % [2]. Ukraine-EU Association Agreement signed in 2014 stipulates that the legislation of Ukraine must be approximated to the legislation of the European Union. It should be noted that Ukraine also undertook to complete the design of the Emerald Network and implement effective management and protection measures of Areas of Special Conservation Interest (ASCI) by September 1, 2021.

That is why the Emerald Network in Ukraine must develop, and its area including habitats, diverse flora and fauna must be protected. The negative impact on the areas of special conservation interest must be minimized, preventing any further degradation of any parts of the Emerald Network. In the long term, it is the ASCI that will have undeniable value and benefit for humans as ecosystem services rather than short-term mining activities in these areas. The development of recreation and tourism of protected areas in the future will have stable financial revenues to the budget of individual communities and the country as a whole.

The study and further consolidation of the Emerald Network boundaries is one of the promising tasks of post-war development and reconstruction of Ukraine.

Conclusions. Monitoring studies of the effects of coal mining activities of Ternivska mine during the new seam excavation indicate a negative impact on the ecosystem of Samarskyi Lis – UA0000212 Emerald Network. The most negative evidence of anthropogenic impact is saturation and flooding of large areas due to ground subsidence under coal mines. Field studies have established a significant number of rare and endangered plant species that are of scientific interest for conservation at the national and international levels. 233 species of higher vascular plants (168 genera, 62 families) were studied, among which five plants listed in the Red Data Book of Ukraine are protected.

According to remote sensing data and comparison of various satellite data indices (WRI, NDWI, MNDWI, NDSI), the dynamics of the process of ground subsidence and flooding of the protected area has been determined. It has been established that long-term (several years) saturation and flooding of surface leads to a gradual change in the species composition of the forest stand, the death of undergrowth and herbaceous layer. In the flooded areas of oak forests and pine stands, forest species disappear, and wetland plant species spread. Long-term flooding leads to the complete destruction of existing plant and animal communities, the destruction of complexes of soil mesofauna, makes the development impossible for terrestrial invertebrates that lived in these biotopes before their destruction, including species listed in the Red Data Book of Ukraine and protected by the Bern Convention.

In-depth studies with a reliable assessment of the negative impact of coal mining activities, as well as the development of predictive models for the transformation of the ecosystem of the Samarskyi Lis – UA0000212 Emerald Network require detailed geodetic survey and supportive specialized research, which is currently impossible under martial law in Ukraine and the limited access to the object of research.

The obtained research results are important evidence of the need to constantly review the projects of planned activities of mining enterprises regarding their impact on the environment during the entire period of operation and closure of mines.

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Оцінка впливу видобутку вугілля на геоекологічну трансформацію екосистеми Смарагдової мережі

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Мета. Геоекологічна оцінка впливу на трансформацію екосистеми частини об'єкту Смарагдової мережі «Samarskyi Lis – UA0000212» наслідків видобутку кам'яного вугілля на ділянці шахти «Тернівська» (Дніпропетровська область, Україна) із застосуванням методів дистанційного зондування Землі в умовах обмеженості доступу до об'єкту досліджень через воєнний стан в Україні.

Методика. Використано комплекс стандартизованих польових, камеральних, лабораторних і статистичних методів досліджень. При вивченні водної рослинності використовували загальноприйняті методи опису видового й ценотичного складу рослинності та гідроботанічного картування. Дослідження ґрунтової рослинності виконано із виділенням і описом основних фітоценозів, особливостей їхнього складу, розподілу на території. Флористичні дослідження проводили за методикою зібрання гербарного матеріалу. Здійснені польові маршрути на поверхні землі вздовж виробки вугільного пласта з фіксацією деструктивних змін ландшафту (провали, розриви дерну, суфозійні прояви, тріщини, пониженням рельєфу) та рослинних угрупувань – забарвлення та стан деревної, чагарникової та трав'яної рослинності. Для співставлення даних візуальних спостережень і отримання репрезентативних і достовірних результатів досліджень, додатково виконано моніторинг об'єкту за допомогою сучасних геоінформаційних систем. Використано інструмент супутникового спостереження, що дає змогу здійснювати пошук, обробку та отримання інформації із супутникових даних за різноманітними індексами: WRI, NDWI, MNDWI, NDSI.

Результати. Встановлені негативні наслідки впливу діяльності вуглевидобувної шахти «Тернівська» на геологічну та екологічну трансформацію екосистеми Смарагдової мережі «Samarskyi Lis – UA0000212». Доведено, що тривале підтоплення й затоплення ландшафтів призводить до зміни видового складу деревостану, загибелі підліску та трав'янистого ярусу, повного руйнування існуючих рослинних і тваринних угрупувань. На затоплених ділянках дібров і соснових насаджень випадають лісові види й поширюються водно-болотні види рослин. За три роки (2020–2023) площа видимого та встановленого за даними дистанційного зондування затоплення збільшилась із 1 до 6 га відповідно.

Наукова новизна. За даними геоінформаційних систем із відкритим кодом і співставлення різних індексів супутникових даних (WRI, NDWI, MNDWI, NDSI) встановлена динаміка процесу осідання земної поверхні й затоплення заповідної території. Виявлені поступові зміни видового складу деревостану, загибелі підліску та трав'янистого ярусу. Підтверджено, що довгострокове підтоплення призводить до повного руйнування існуючих рослинних і тваринних угрупувань, нищення складних комплексів ґрунтової мезофауни, унеможливлює розвиток наземних видів безхребетних, що мешкали в даних біотопах до їх руйнування, у тому числі видів, що занесені до Червоної книги України та охороняються Бернською конвенцією.

Практична значимість. В умовах обмеженого доступу для проведення прямих геодезичних і інженерно-геологічних досліджень обґрунтована методика застосування сучасних ГІС шляхом комбінації різних спектральних каналів (індексів) для визначення й вивчення динаміки процесу підтоплення (затоплення) території. У поєднанні з традиційними польовими геоботанічними дослідженнями вперше для регіону представлені результати моніторингових спостережень планованої діяльності вуглевидобувної шахти на геоекологічну трансформацію екосистеми об'єкту Смарагдової мережі. Визначено негативний вплив гірничопромислової діяльності на природоохоронні території, що призводить до загибелі та поступової зміни видового складу рослин.

Ключові слова: *геоекологічна трансформація, підтоплення, затоплення, природний ландшафт, територія Emerald, видобуток вугілля*

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