ENVIRONMENTAL SAFETY, LABOUR PROTECTION

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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 “Samarin 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 phytocoenoses, 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, suffosion 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 “Samarin Lis – UA0000212” have been established. It has been proven that long-term underwater flooding 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

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The study object was monitored using modern geoinformation systems for remote sensing of the Earth. The object was limited. Therefore, the scientists’ access to the part of the Samarskyi Lis – 25 hectares of forest plantations of the Pavlohrad Forestry was restricted. Water surfaces or objects that retain moisture. If the index value is above 1, the objects of study are determined according to the 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 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 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]

\[ WRI = \frac{\text{GREEN} + \text{RED}}{\text{NIR} + \text{SWIR2}}. \]  

(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 Turloogh 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 Eltygriva 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, and Salix caprea L.***

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 savanicum Besser, feather grass Slipa borysytchenica Klok. ex Prokud., Pulsatilla nigricans Storck, Tulipa quercetorum Klok. et Zot., 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 Zot. and 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, Puccinellia distans (Jacq.) Parl. have significantly increased in number, which indicates an increase in the level of soil salinity.
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 2

<table>
<thead>
<tr>
<th>Forest species that die in flooded areas</th>
<th>Wetland species found in flooded forest areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Betula pendula Roth.</td>
<td>1. Lemna minor L.</td>
</tr>
<tr>
<td>3. Ulmus laevis Pall.</td>
<td>3. Persicaria hydropiper (L.) Delarbre</td>
</tr>
<tr>
<td>4. Acer tataricum L.</td>
<td>4. Persicaria maculosa Gray</td>
</tr>
<tr>
<td>5. Acer platanoides L.</td>
<td>5. Scirpoides holoschoenus (L.) Sojak</td>
</tr>
<tr>
<td>6. Acer campestre L.</td>
<td></td>
</tr>
<tr>
<td>7. Pinus sylvestris L.</td>
<td></td>
</tr>
<tr>
<td>8. Convallaria majalis L.</td>
<td></td>
</tr>
<tr>
<td>10. Populus tremula L.</td>
<td></td>
</tr>
<tr>
<td>11. Urtica dioica L.</td>
<td></td>
</tr>
<tr>
<td>12. Polygonatum multiflorum (L.) All.</td>
<td></td>
</tr>
<tr>
<td>13. Geum urbanum L.</td>
<td></td>
</tr>
<tr>
<td>14. Sambucus nigra L.</td>
<td></td>
</tr>
<tr>
<td>15. Crataegus monogyna Jacq.</td>
<td></td>
</tr>
<tr>
<td>16. Lonicera tatarica L.</td>
<td></td>
</tr>
<tr>
<td>17. Frangula alnus Mill.</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Date</th>
<th>Site number in Fig. 3</th>
<th>Flood area, ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 18, 2023</td>
<td>1</td>
<td>6.0</td>
</tr>
<tr>
<td>April 16, 2023</td>
<td>2</td>
<td>6.2</td>
</tr>
<tr>
<td>October 06, 2022</td>
<td>4</td>
<td>2.1</td>
</tr>
<tr>
<td>July 02, 2022</td>
<td>3</td>
<td>3.8</td>
</tr>
<tr>
<td>July 15, 2021</td>
<td>initial stage (not indicated in Fig. 3)</td>
<td>1.2</td>
</tr>
</tbody>
</table>
fulfills 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% [21]. 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, which 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 objects 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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References.
Оцінка впливу видобутку вугілля на геоекологічну трансформацію екосистеми Смарагдової мережі

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Мета. Геоекологічна оцінка впливу на трансформацію 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 обмежені 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 фиксацією деструктивних змін ландшафту (провали, розриви дерну, суфозійні прояви, тріщини, пониження рельєфу) та рослинних угрупувань – забарвлення та стан деревної, чагарникової та трав'яної рослинності. Для співставлення даних візуальних спостережень і отриманих 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 супутникних даних за різноманітними індексами: WRI, NDWI, MNDWI, NDSI.

Результати. Встановлені негативні наслідки впливу діяльності вуглевидобувної шахти «Тернівська» на геоекологічну трансформацію екосистеми Смарагдової мережі «Samarskyi Lis – UA0000212». Водні ділянки залізничного шляху, рубежів ґрунту, залізничних перетинів, утворених на рівні рельєфу, втратили свою просторову структурну характеристику, що призводить до значного зменшення поширення певних видів рослин. У зоні дії вуглеобробних процесів змінюються видовий склад рослинності, а також структура гідроботанічного комплексу. На загальних ділянках ділянок виходу шахтних діячей відбувається зміна видового складу рослинності, а також інтенсивність рослинності, що призводить до значного зменшення поширення певних видів рослин. У зоні дії вуглеобробних процесів змінюються видовий склад рослинності, а також структура гідроботанічного комплексу. У зоні дії вуглеобробних процесів змінюються видовий склад рослинності, а також структура гідроботанічного комплексу. У зоні дії вуглеобробних процесів змінюються видовий склад рослинності, а також структура гідроботанічного комплексу.

Наукова новизна. За даними геоінформаційних систем із відкритим кодом і співставлення даних супутниковых даних (WRI, NDWI, MNDWI, NDSI) встановлено динаміка процесу осідання земної поверхні й затоплення заповідної території. Виявлено поступові зміни видового складу дерева, гідроботанічного складу, а також структури гідроботанічного комплексу. Використання сучасних ГІС для визначення, вивчення і прогнозування динаміки процесу підтоплення (затоплення) території може бути використано для прогнозування загрози для природоохоронних територій.

Практична значимість. В рамках обмеженого доступу для проведення прямих геодезичних і інженерно-геологічних досліджень обґрунтована методика застосування сучасних ГІС технологій для визначення, вивчення і прогнозування динаміки процесу підтоплення (затоплення) територій. У рамках досліджень використано сучасні геоінформаційні системи, які дозволяють здійснювати широкий спектр досліджень геоекологічного стану територій.

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

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