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REMOTE MONITORING OF LANDS, SOIL COVER OF WHICH IS DISTURBED AS A RESULT OF ARBITRARY AMBER MINING

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Illegal amber mining has become an environmental disaster in Rivne region. In particular, since 2014, amber has been illegally mined in the Varas district of the Rivne region, near the village of Zelene. Local residents are witnessing the destruction of the ecological and recreational value of forests, which until recently were places for them to rest, pick mushrooms, berries, etc. In order to extract amber, forests are cut down, the unique ecosystem is destroyed, the soil cover is disturbed, the water regime of the soil is changed, etc. Thus, "amber fever" causes significant damage to land resources. Land disturbance due to amber mining has caused significant economic losses and irreversible environmental changes. This research topic is timely, relevant and important from the point of view of ensuring the sustainable development of territories. The purpose of this study is to monitor lands whose soil cover has been disturbed as a result of unauthorized amber mining by means of remote land sensing (RLS) and geospatial analysis. RLS methods in combination with field observations of the research object confirm the obtained results. As a result of the illegal mining of amber within the experimental area of 40 hectares, a violation of the soil cover in the amount of 46.25% of the total area was found. The scientific work has a valuable practical result and makes it possible to remotely determine the location, time periods and extent of land cover violations caused by arbitrary amber mining with high accuracy using space

cameras. Such a research area is representative, and the research results can be used to develop recommendations and strategies for environmental protection and sustainable development of territories.

Key words: *amber mining; soil cover disturbance; monitoring of land resources; geospatial analysis; retrospective analysis; illegal mining; consequences of amber mining; lands, soil cover of wich is disturbed.*

Relevance. Amber was formed in the Rivne region about 40 million years ago. Rivne amber consists of 3-8% succinic acid, has a peculiar greenish tint and is more "pliable" in processing. Its main deposits are: Klesivske (Klesiv) and Dubrovytske (Dubrovytsia). Industrial extraction of amber began only in 1993, until the 1990s, all developments were carried out in an artisanal way. The first large producer was the state enterprise "Ukrburshtyn" (SE "Burshtyn of Ukraine") under the Ministry of Finance of Ukraine. On average, 1 to 3 tons of "sunstone" were mined. Historical information about the work of the enterprise is collected in the Amber Museum, located in the Rivne Building of Scientists [1].

Starting from 2014 and until now, illegal extraction of amber has been carried out in the territories of the Rivne region [2], which has led to the emergence of an ecological disaster zone [3]. Unlicensed amber mining on the territory of the Rivne region has been repeatedly highlighted in the mass media, which indicates significant areas with mutilated land cover and the scale of both economic and ecological damage caused. According to experts' estimates, the total amount of arbitrary mining in the north-west of Ukraine reaches from 120 to 300 tons of amber per year, which in monetary equivalent on the shadow market corresponds to about 300 million dollars [3].

However, the economic and ecological damage caused to the natural environment is even greater. Amber lies under a centuries-old forest, so in order to get it, treasure hunters cut down and uproot valuable trees. Next, the "solar stone" is mined with the

help of motor pumps, and in this way, in the area cleared from the forest, pits with a depth of up to 20 meters are washed with water. It is the currents of water that bring the amber to the surface, where it falls into the hands of illegal amber traders.

From 2020, the places of legal amber mines will be transformed into tourist facilities in some places. After the extraction of amber and valuable rocks, granite quarries manage to become tourist attractive [4].

Since 2014, illegal amber mining has been taking place in the Varas district of the Rivne region, in particular near the village of Zelene, turning picturesque areas into ecological disaster zones. Land disturbance due to amber mining has caused significant economic and environmental damage. Ensuring the sustainable development of territories in the areas of amber mining is an important problem that requires a complex scientific and management approach as a basis for preserving land resources from their further degradation.

Analysis of recent research and publications. Scientists A.G. Martin and O.I. Kachanovskyi studied the environmental and economic prerequisites for amber extraction in Ukraine [5]. The issue of identification of disturbed lands as a result of amber extraction using multispectral imagery and geoinformation modelling of damaged land plots is addressed by such scientists as Kachanovskyi O.I., Martyn A.G., Bulakevych S.V. [6,7].

Determination of damage caused to land resources is described in the article by Kachanovskyi O.I. [8]. Klymenko V.O.'s dissertation research is devoted to the issue of assessing the impact of unauthorised amber mining [9].

Environmental issues related to amber extraction are covered by Bartmansky M., Malimon S. [10], and the impact of amber extraction on the environment is covered by Kachanovsky O. I. [11]. Kachanovskyi O. I., Zalizko I., Kyiko N. [12] assessed the losses of forest landscapes. In addition to the actual assessment of damage, the work of Filipovych V. E. [13] is devoted to the issue of operational control of the spread of illegal amber mining based on multi-zone satellite imagery.

The analysis of publications shows the importance and relevance of remote monitoring of lands disturbed as a result of arbitrary amber mining, which is confirmed by a large number of scientific publications on this issue in various fields. Thus, the issue of reclamation of land disturbed as a result of illegal amber mining was studied by Butenko E., Khomych A. and Prokhorenko V. [14].

The purpose of this study: To carry out remote monitoring based on geospatial analysis of lands disturbed by illegal amber mining.

Materials and methods of the study: In this paper, we used four-spectral satellite imagery obtained through the resources of Planet Labs PBC (planet.com), to which the company granted the right to use for educational and scientific purposes. Images of the study area were selected for the period from 2016 to 2023 with a resolution of 3 m/pixel. Research methods are remote (RLS and geospatial analysis) and ground observations.

The object of observation was selected as a result of ground observations. Using the free-access software tool Google Earth Pro, the boundary of the study site was outlined with a perimeter of ≈2500 m, sides of ≈650 x 650 m, and an area of 40 ha, located northwest of the village of Zelene, Varasky district, Rivne region (Fig.1).

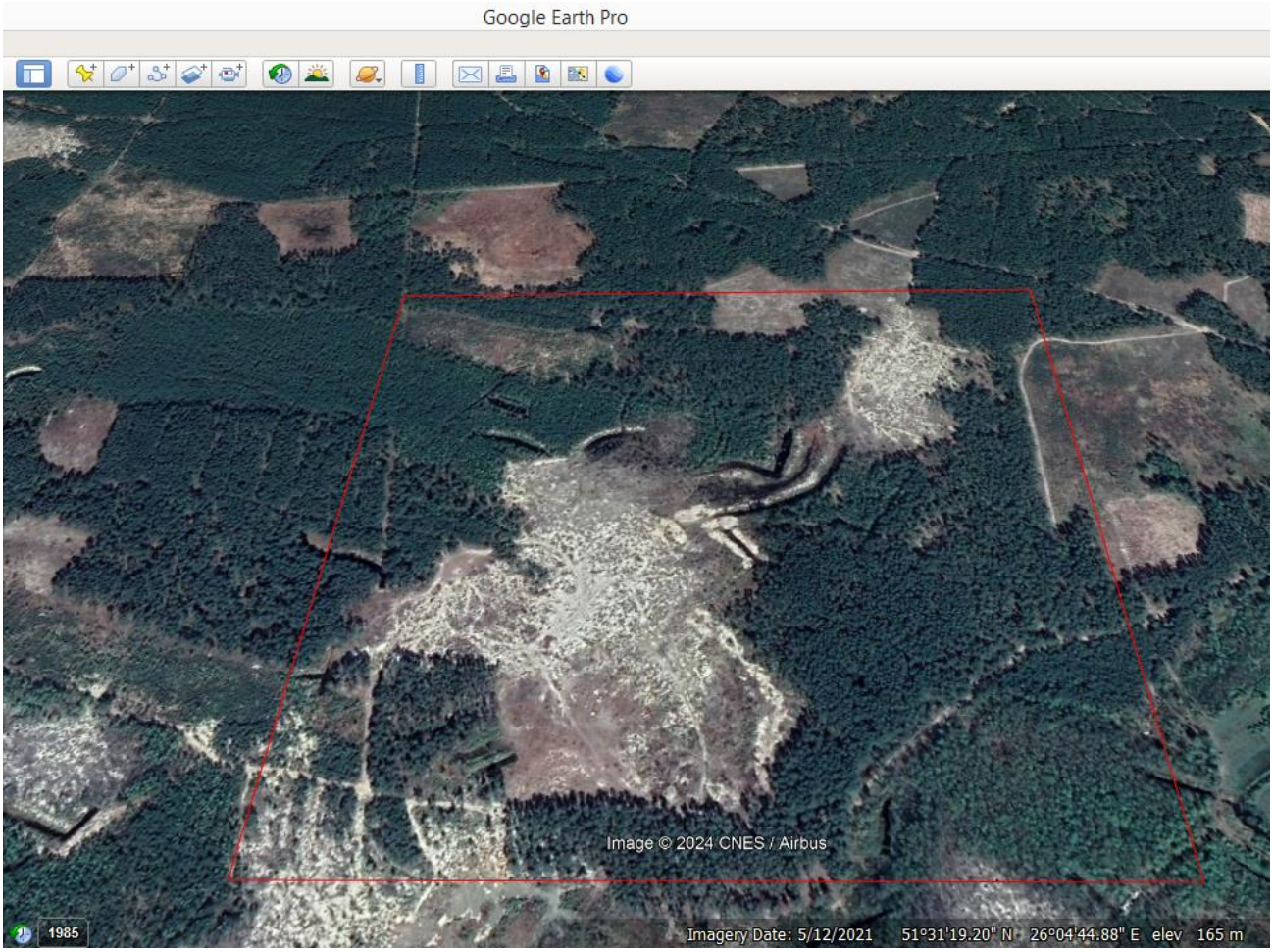


Fig. 1. Survey map of the experimental site in Google Earth Pro, 05.12.2021

An indicator of the change in soil cover as a result of illegal amber mining is the change in vegetation cover. That is why the images were chosen in the warm season, when green vegetation can best be identified, excluding images that were taken in high humidity and cloudy conditions. Thus, the initial data were taken in the June-July period (the exception was the photograph taken in March 2017, which first recorded minor ground cover violations in the experimental area). According to space photographs with a resolution of 3 m/pixel taken in the same period of the year starting from 2016, we can observe how areas of amber mining were formed and expanded from a solid covered forest (Fig. 2-9).

Fig. 2. Satellite image of 03.07.2016[1]

Fig. 3. Satellite image of 27.03.2017

Fig. 4. Satellite image of 18.06.2018

Fig. 5. Satellite image of 14.06.2019

[1] Image source https://www.planet.com/ as part of Planet's Education and Research (E&R) Programme

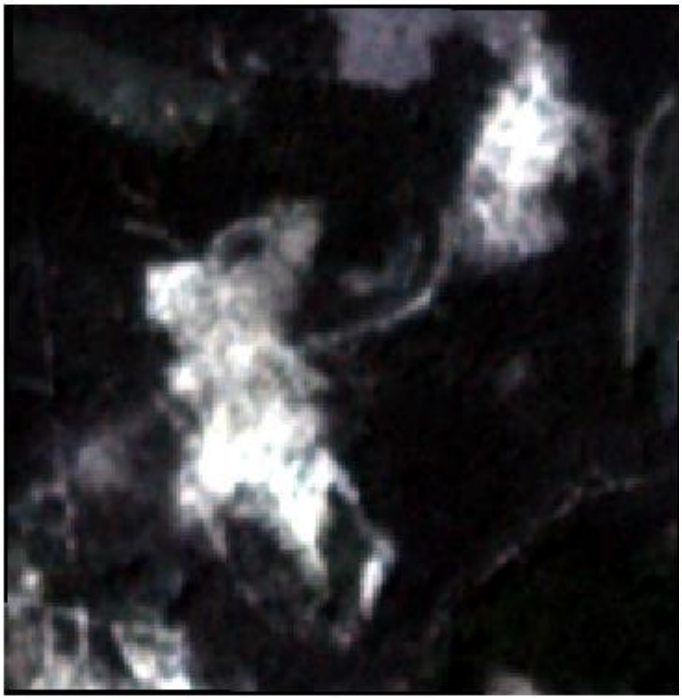


Fig. 6. Satellite image of 19.06.2020

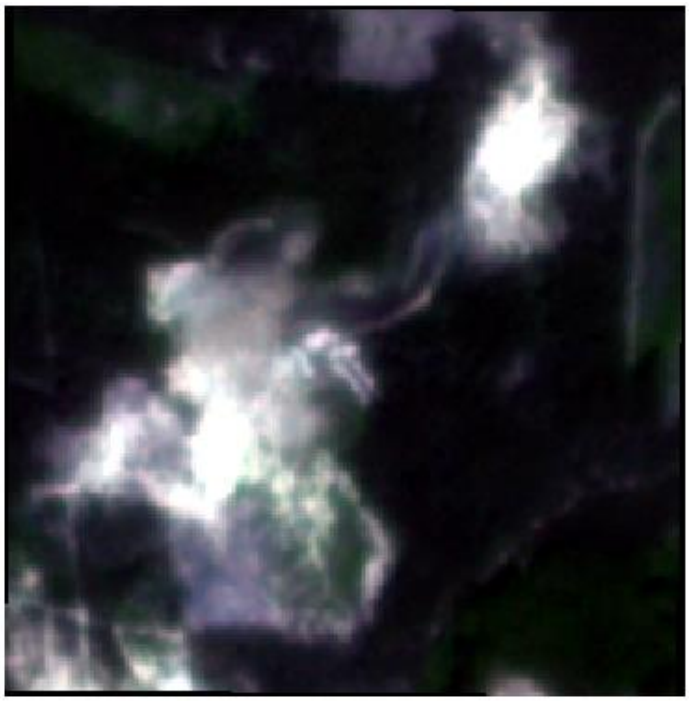


Fig. 7. Satellite image of 19.06.2021

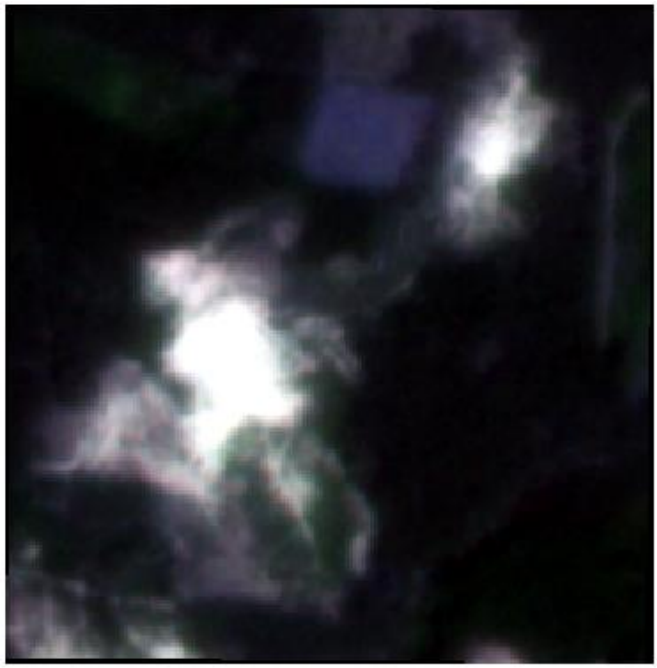


Fig. 8. Satellite image of 30.06.2022

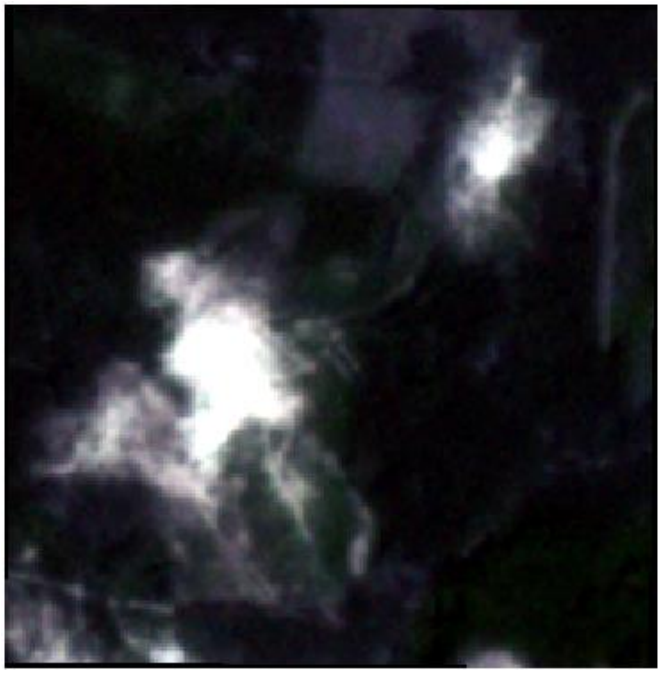


Fig. 9. Satellite image of 24.06.2023

The satellite imagery was processed using the licensed IDRISI SELVA software using machine learning (supervised classification). Each satellite image was analysed individually according to the algorithm:

1. spectral analysis, selection of the best combination for forest cover study;

2. visual analysis, decoding of cover types;

3. selection and vectorisation of reference plots;

4. assessment of signature quality;

5. construction of thematic maps by various statistical methods;

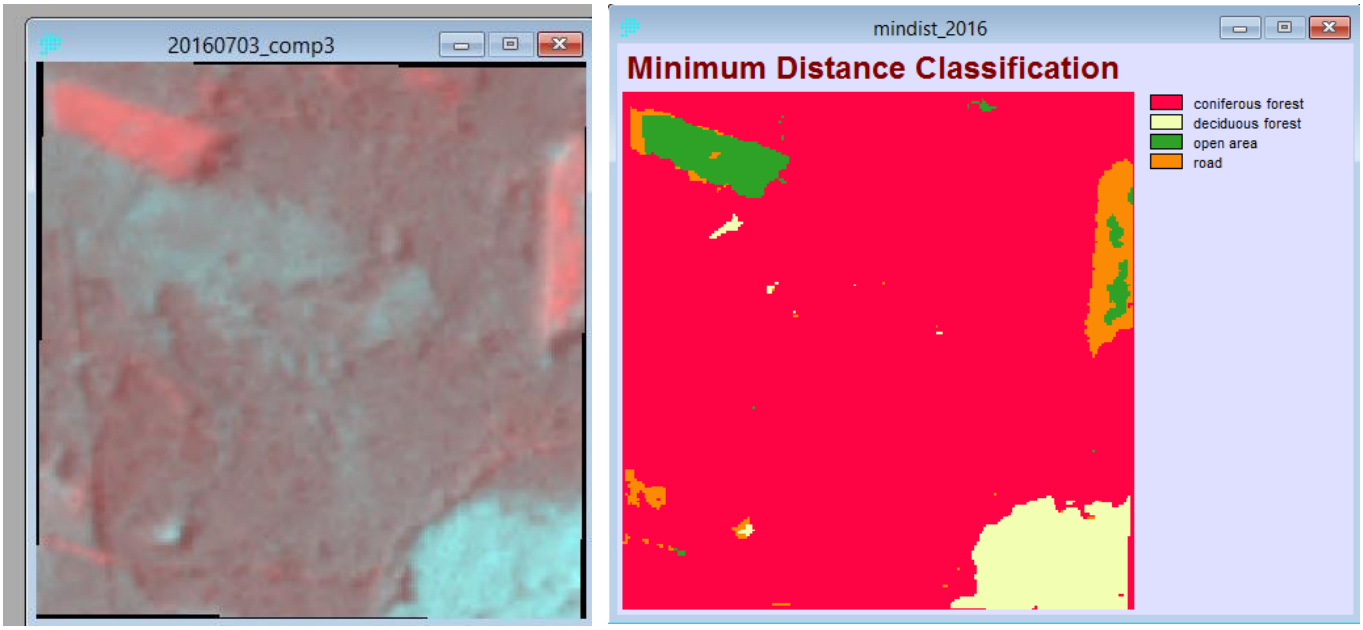
6. analysis and selection of the best result.

The monitoring of disturbed lands due to amber extraction was supposed to be carried out in forest areas during the period when all vegetation is green. In order to classify the types of cover in such conditions, it was most appropriate to use ‘artificial colours’, namely a combination of 4 (red), 3 (green), 2 (blue) spectral channels. The 4-3-2 combination shows:

- green vegetation - in shades of red;
- urban buildings - in green-blue;
- soil - from dark to light brown;
- ice, snow and clouds - white or light blue;
- coniferous forests - dark red or even brown compared to deciduous forests.

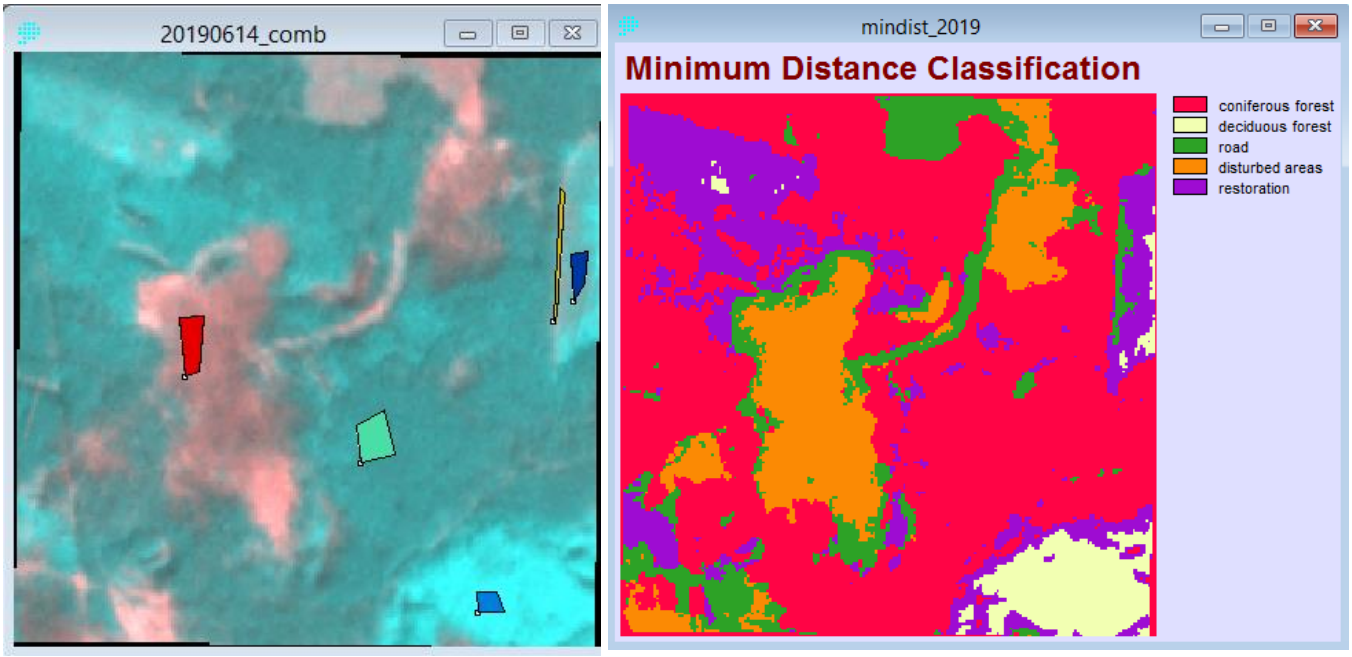
In general, saturated shades of red indicate healthy deciduous vegetation, while lighter shades indicate herbaceous or shrubby vegetation (Figs. 10a, 11a).

For further analysis, the selected thematic maps were constructed by the method of controlled classification using the minimum spectral distance method, as they best corresponded to the original space photographs (Figs. 10b, 11b). Geospatial analysis was carried out using a boolean operation, assigning the value of 1 to the forest cover "coniferous forest". The areas of land that lost forest vegetation cover were determined for a period of 1 year, using the Image Calculator function, Logical expression type. And with the help of the AREA function, we obtained the absolute areas of land that ceased to correspond to forest for the corresponding period (Table 1).



a b

Fig. 10. Classification of sattellite photo 03/07/2016: combination of "artificial colors" (a), thematic map by the method of the smallest spectral distance (b)



a b

Fig. 10. Classification of sattellite photo 14/06/2019: combination of "artificial colors" (a), thematic map by the method of the smallest spectral distance (b)

Table 1.

Results of determining changes in soil cover, ha

2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023
9,08	**5,18**	**4,93**	**1,75**	**6,58**	**3,01**	**0,72**

A geospatial analysis of land cover changes and a comparison of its condition in 2016 with that in 2023 gives us absolute results of changes in forest area of only 18.50 hectares. The reasons for this are both the natural restoration of soil cover (shrub growth), the re-engagement of previously disturbed lands in mining, and the errors of remote sensing methods. Nevertheless, with a total area of 40 hectares, we can confidently state that 46.25% of its territory, which was covered by forest in 2016, had disturbed soil cover. Thus, the environment has suffered an extremely large negative impact as a result of illegal amber mining (Fig. 12).

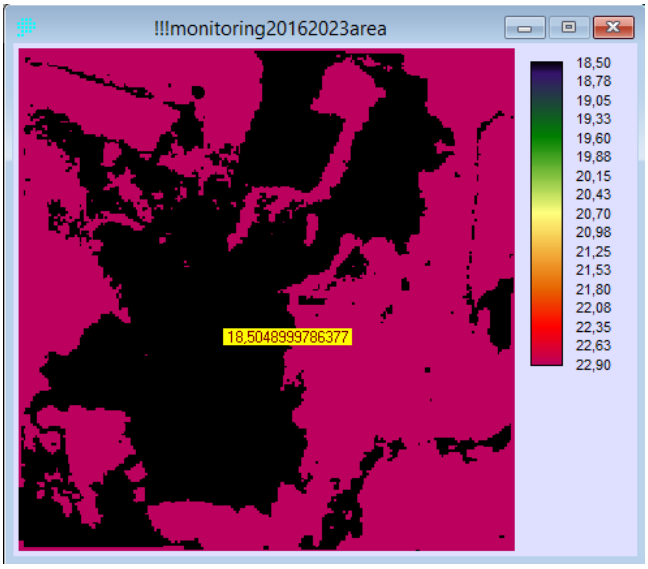


Figure 12. Changes in forest area due to amber extraction in 2016 to 2023 and field surveys

Trends in the area of disturbed land are shown in the graph (Fig. 13). The most significant changes in soil cover occurred between 2016 and 2019.

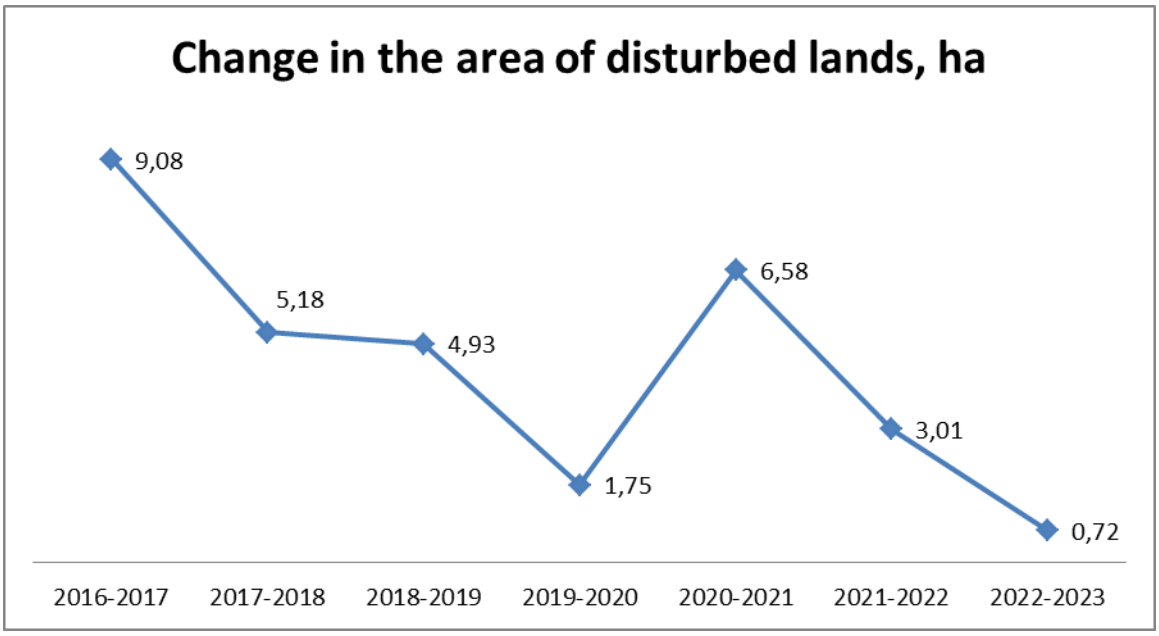


Figure 13. Change in the area of disturbed land in the study area between 2016 and 2023

In 2020, another area to the north-east of the first area of illegal mining underwent significant changes. As of 2023, we see a tendency to stop changes in soil cover (Fig. 14).

Figure 14. Location of disturbed lands in 2020-2022

Research results and their discussion. Based on the results of the study, a student research paper was written, which took 3rd place in the first round of the All-Ukrainian competition of student research papers in the speciality ‘Geodesy and Land Management’

Conclusions and perspectives. Remote monitoring of land resources based on satellite images is, although not absolutely accurate, the least expensive way to track changes in soil cover and detect negative impacts on the surrounding natural environment.

According to the research, as a result of illegal amber mining within the experimental area of 40 hectares, located near the village of Zelene, Varas district, Rivne region, we found a violation of the soil cover amounting to 46.25% of its total area. Such arbitrary actions caused comprehensive damages, including:

- violation of the stability of the natural environment as a result of changes in the structure of land by cutting down the forest, washing out the top layer of soil under water pressure, changing the relief, waterlogging;

- non-receipt of revenues to the budget from the extraction of minerals that are the property of the Ukrainian people;

- loss of ecological and recreational value of the territory.

Therefore, the experimental area within the boundaries of the Volodymyretsk territorial community of the Rivne region is a representative example of the impact of illegal amber mining on the state of the environment. The use of GIS analysis makes it possible to accurately determine the impact zones. The results of the research can be used to develop recommendations and strategies for the protection of nature and sustainable development of areas with amber mining potential.

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ДИСТАНЦІЙНИЙ МОНІТОРИНГ ЗЕМЕЛЬ, ГРУНТОВИЙ ПОКРИВ ЯКИХ ПОРУШЕНИЙ ВНАСЛІДОК СВАВІЛЬНОГО ВИДОБУВАННЯ БУРШТИНУ

На Рівненщині екологічним лихом стало незаконне видобування бурштину. Зокрема, з 2014 року на території Вараського району Рівненської області, поблизу села Зелене досі ведеться нелегальний видобуток бурштину. Місцеві жителі є свідками того як знищується екологічна та рекреаційна цінність лісів, які ще донедавна були для них місцями відпочинку, збирання грибів, ягід тощо. Щоб добути бурштин здійснюється вирубка лісів, руйнування унікальної екосистеми, порушення грунтового покриву, зміна водного режиму грунту тощо. Таким чином «бурштинова лихоманка» завдає значної шкоди земельним ресурсам. Порушення земель внаслідок видобутку бурштину завдало значних економічних збитків і безповоротних екологічних змін навколишнього середовища. Дана тема дослідження є своєчасною, актуальною та важливою з точки зору забезпечення сталого розвитку територій. Метою даного дослідження є моніторинг земель, грунтовий покрив яких порушений внаслідок самовільного видобування бурштину засобами дистанційного зондування земель (ДЗЗ) і геопросторового аналізу. Методи ДЗЗ у поєднанні з натурними спостереженнями об'єкту дослідження підтверджують отримані результати. Внаслідок нелегального видобутку бурштину в межах дослідної ділянки площею 40 га виявлено порушення грунтового покриву обсягом 46,25 % від загальної площі. Наукова робота має

цінний практичний результат та дозволяє з високою точністю використовуючи космознімки дистанційно визначити локацію, часові періоди та обсяги порушень грунтового покриву земель, зумовлені свавільним видобуванням бурштину. Така дослідна ділянка є репрезентативною, а результати дослідження можуть бути використані для розробки рекомендацій та стратегій захисту навколишнього природного середовища та сталого розвитку територій.

Ключові слова: *видобування бурштину; видобуток бурштину; порушення грунтового покриву; моніторинг земель; ДЗЗ; геопросторовий аналіз; незаконне видобування; земель, грунтовий покрив яких порушений.*