UDC 332.32

METHODOLOGY OF GEOINFORMATION MODELING OF AREAS AFFECTED BY AMBER MINING

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Abstract. *The article considers modern possibilities of geoinformation technologies for geospatial modeling of areas affected by amber mining in Ukraine on the example of Rivne Region. The purpose of the study is to present a methodology for decoding satellite image materials for geoinformation modeling of the areas affected by amber mining. The use of actual materials of remote sensing of modern satellite systems in combination with geospatial models during land monitoring is analyzed. It was found that the calculation of the NDVI makes it possible to identify the contours of affected areas more clearly. An approach for assessing soil cover moisture content based on the use of norm-difference water indices is presented. It is noted that the assessment of soil moisture is one of the elements of thematic processing of satellite images which makes it possible to identify the areas where amber mining by hydraulic method was carried out. It is offered to consider the method of geoinformation modeling of areas affected by amber mining as a method of practical implementation of determining affected lands using remote sensing images, due to the regularities and features of spectral analysis of a photo image. The use of the methodology is presented on a specific example, namely on state-owned lands of Dubrovytsia Forestry of Rivne Region. The methodology will provide a technical*

basis for the decisions on the identification of affected land plots and their further monitoring. In addition, the methodology offered in the article will help to determine the directions of land reclamation and groups of affected lands.

Keywords: *affected lands, amber mining, multispectral satellite images, remote sensing.*

Relevance. The level of forest cover and the quality of forests largely determine the state of the country's natural environment. However, today in Ukraine, forest vegetation is intensively exploited. It is dying of industrial emissions and fires, careless allocation of land for mining and merciless extraction of minerals, amber, in particular. These problems are particularly acute in the north-western regions of the Polissia. As of 2017 [1], according to the Main Department of the State Service of Ukraine for Geodesy, Cartography and Cadastre (Derzhheokadastr) in Rivne Region, there are about 4.16 thousand hectares of forestry land affected by illegal amber mining. It is 92% of the total amount of state-owned land affected by illegal amber mining, or 73% of the total land of the region of state and private ownership affected by illegal amber mining. Due to the rapid spread of the areas of affected land and the scale of these processes, there is a need for constant monitoring and research of the dynamics of changes on these areas.

Analysis of recent research and publications. It should be noted that the main researches on the locations of lands affected by amber mining at the regional and local levels are presented in the scientific works of V. Ye. Filipovych and R. M. Shevchuk [2]. The results of processing and analysis of multispectral satellite images of average difference to assess the dynamics and consequences of illegal amber mining in Ukraine can be found in the works of A. V. Prokopchuk, R. M. Yanchuk, S. M. Trokhymets, V. M. Maslei, D. K. Mozhovyi, K. H. Bilousov, V. S. Khoroshylov, O. S. Bushanska, M. H. Halych [3]. The work of Ye. A. Ivanov includes an analysis of the ecological situation in the areas of illegal amber mining and a cartographic model of anthropogenic transformation of the natural environment in the territorial units of Rivne Region as a result of unauthorized mining [4]. Attention should be paid to the researches of the scientists of Zhejiang University and

China University of Mining and Technology, namely their methodology for determining the calendar date of land cover disturbance during mining. However, scientific developments are fragmentary in nature. This is due to the coverage of only certain elements and partial consideration of the problem of studying the dynamics of changes in the area of affected territories. The method of geoinformation modeling of areas affected by the amber mining remains out of consideration.

Purpose of study. To present the methodology for decoding satellite survey materials for geoinformation modeling of lands affected by amber mining.

Materials and methods of research. This scientific study was conducted based on remote sensing data obtained from various survey systems, such as Landsat 4-5 TM (2010-2013), Landsat 8 (2014-2021), Sentinel-2 (2015-2021), cartographic materials of forest plantation estimate survey of State Enterprise "Dubrovytsia Forestry" (https://www.lisproekt.gov.ua) and digital archive of the ESRI base map WayBack.maptiles.arcgis.com with a time frame of 2010-2021, connected to the WMTS server. The materials of the list of forestry lands, namely lands affected by amber mining that need reclamation [5] was the information base. Among the main research methods were modeling, comparison and generalization, analysis and synthesis.

Research results and discussion. Amber mining was performed mainly manually by quarry and hydro-mechanical methods and did not provide for compliance with environmental protection measures and labor protection standards. When using the quarry method of mining, the pits with a length of 1 to 6 m, pipes with a diameter of 6 to 8 m are formed, so the integrity of geological formations is destroyed and shaft-like rock mass emissions are formed around the objects. The use of the hydro-mechanical method leads to the formation of funnel-shaped recesses of various diameters (0.4-1.0 m, > 1 m) in the soil, subsidence of soil and rocks.

Land massifs damaged by amber mining are characterized primarily by the lack of soil and vegetation cover, and on their surface you can often find rocks that were previously located under the ground cover, so in the image synthesized from spectral channels, their photographic tone differs from surrounding landscapes. Therefore, the

spectral characteristics are the main parameters on the basis of which decoding is carried out, which serves as the basis for the use of remote sensing images and geospatial modeling during land monitoring [2].

Accordingly, the method of geoinformation modeling of areas affected by amber mining should be considered as a method of practical implementation of determining affected lands using remote sensing images, due to the regularities and features of spectral analysis of a photo image. This technique involves a number of stages and steps, shown in Figure 1.

According to the methodology, three zonal images are selected for the analysis of color composite remote sensing images, each of which is considered as the red, green and blue components of the RGB space. At the same time, the use of various channel combinations allows you to create color images that emphasize certain features of objects. In our case, these are Landsat 4-5 TM B05-04-03, Landsat 8 B06-B05-B04, Sentinel-2 B11-B08-B04.

Classification is one of the components of forming cartographic models of forests. Classification is a procedure for computer decryption of images, which consists in automatic division of all pixels of the image into groups (classes) corresponding to different objects [6]. Training samples of the main types of land cover were classified using the additional Spatial Analyst Module using the reference vector method in ArcGIS Pro 2.8 software.

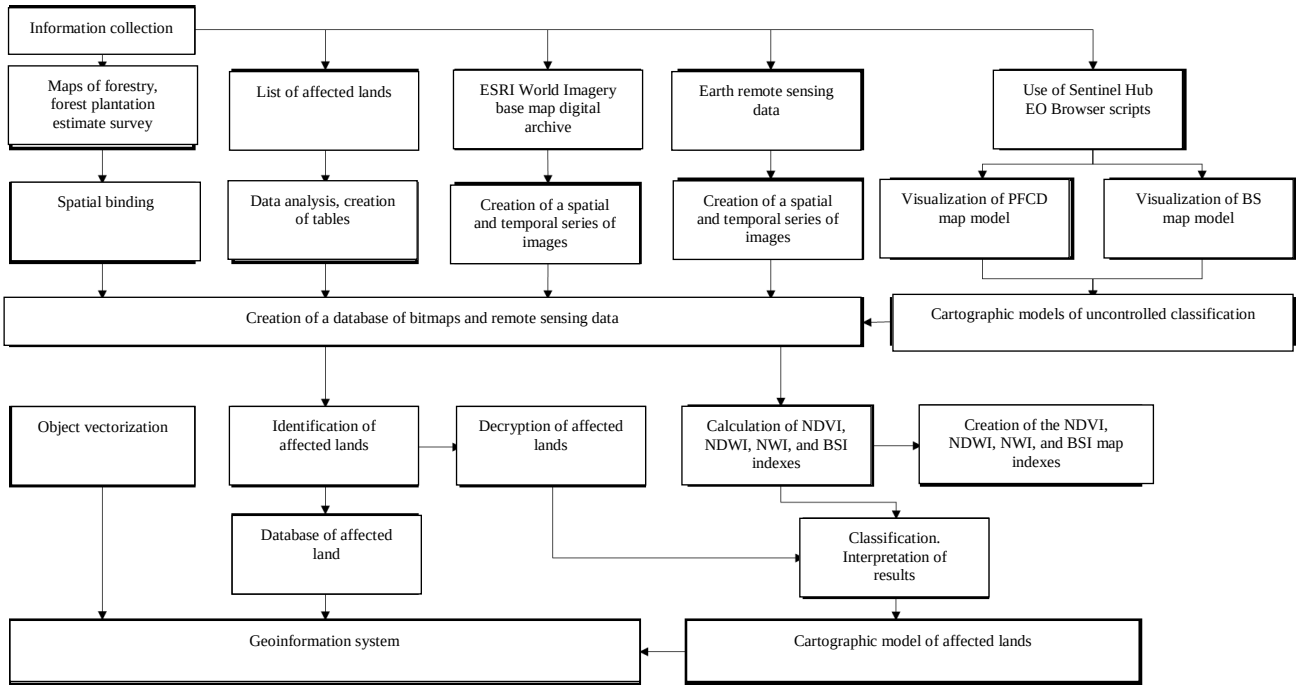

Figure 1. Flowchart of the methodology of geoinformation monitoring of affected lands

The surface of affected massifs is almost completely devoid of vegetation, so the use of vegetation indices under certain conditions allows us to identify the contours of disturbed lands more clearly, and therefore increase the decoding accuracy. The calculation of the NDVI (Normalized Difference Vegetation Index) shows the best result during decoding [6].

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

where, *NIR* – near infrared*; RED* - red spectrum range. Normalized differential vegetation index is one of the most common vegetation indices for performing tasks related to the quantitative assessment of vegetation cover. It is highly sensitive to changes in vegetation cover.

That is, high photosynthetic activity, associated with dense vegetation, leads to slight reflection in the red part of the spectrum and more significant reflection in the infrared part. The ratio of these indicators to each other makes it possible to clearly separate vegetation from other natural objects and perform their analysis. NDVI indicators of plowed fields, deforestation in autumn and spring are close to the indicators of the surface of disturbed amber mining lands, which actually makes its calculation unsuitable for detecting the contours of quarries and dumps [2].

Soil moisture assessment is one of the elements of thematic processing of satellite images, which allows you to identify areas where amber mining was performed using motor pumps (hydraulic mining method).

Soil moisture is the content of some water in its cracks and pores. Water contained in the soil under natural conditions is called natural soil moisture (W).Most often, soil moisture is represented as the ratio of the weight of water (q_b),in the rock to the weight of dry rock (q_c) (weight moisture) as a percentage [7] (2):

$$W=\frac{q_b}{q_c} \quad (2)$$

Using calculation methods, it is possible to determine the foci of waterlogging and excessive moisture content of the soil cover in the area with open soil cover and "pitted" structure. Decoding of satellite images for humidity assessment was based on a priori analysis using some landscape components that are detected in satellite images: vegetation, terrain, and hydro network [2].

An approach to the assessment of soil moisture, which is based on the use of normative-difference water indices, is proposed. In this study, existing water indices sensitive to soil moisture were considered and applied, namely the Normalized Difference Water Index proposed by B. Gao [8]:

$$NDWI = \frac{NIR-SWIR}{NIR+SWIR} \quad (3)$$

To differentiate the types of soil cover, the bare soil index (BSI) was used, which was offered and used in the works of Can Trong Nguyen, Amnat Chidthaisong, Phan Kieu Diem and Lian-Zhi Huo [9]

$$BSI = \frac{((SWIR2+Red)-(NIR+Blue))}{((SWIR2+R)+(NIR+B))} \quad (4)$$

The modified bare soil index makes it possible to classify bare soil from clearings, built-up areas, and other types of land cover [9].

Verification of the proposed method of geoinformation modeling of areas disturbed as a result of amber mining was carried out on state-owned lands of Dubrovytsia forestry in Rivne region. As a result of the research, 5 main types of land cover were selected: coniferous forest, broad-leaved forest, young forest, clearings,

affected land. Based on the classification, cartographic models for monitoring disturbed land as a result of amber mining were created, which are shown in Figure 2.

Based on the results of cartographic models analysis, it can be concluded that in some areas of forest districts the vegetation is being restored, but at the same time new disturbed forest areas are emerging.

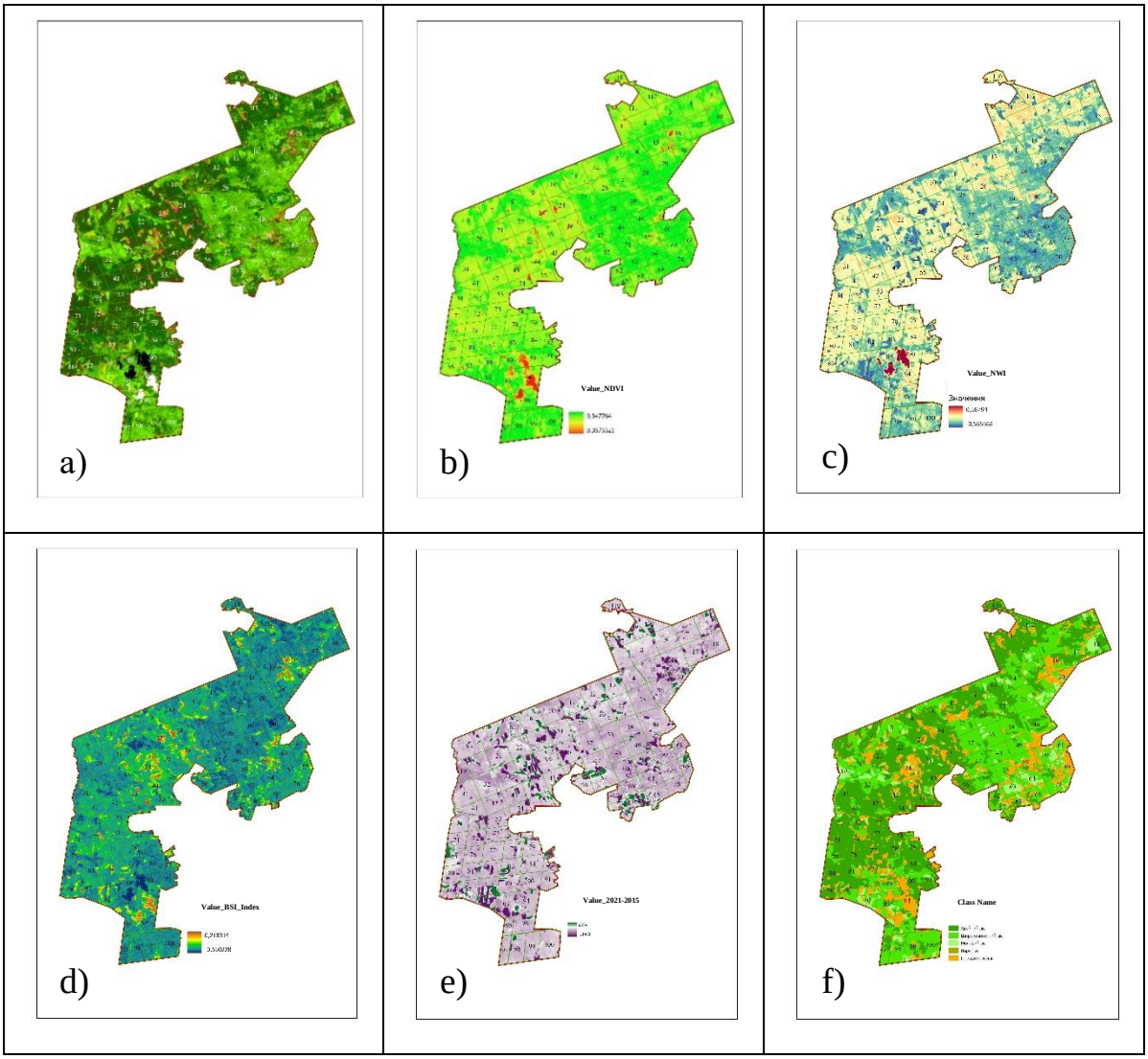

Figure 2. Cartographic models for monitoring lands affected by illegal amber mining:

a) Sentinel-2B.01.08.2021 space snapshot; b) NDVI cartographic model; c) NWI cartographic model; d) BSI cartographic model; e) cartographic model for analyzing changes in soil and vegetation cover during the period of 2021-2015; f) cartographic model for classifying lands affected by illegal amber mining

According to the results of geoinformation monitoring in Dubrovytsia Forestry, the areas of disturbed lands are located in

3,5,13,16,18,30,48,50,59,61,63,65,67,69,98, 100 forest blocks and cover the area of 837.46 hectares, which is 11% of the total area of the Forestry in Figure 3.

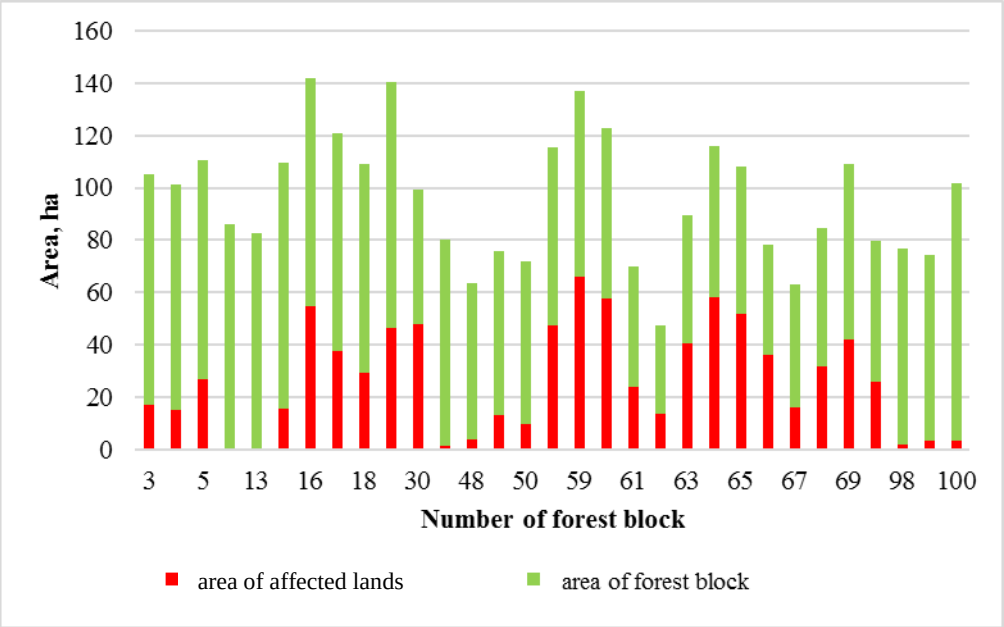

Figure 3. Ratio of the total area of forest blocks to the affected Dubrovytsia Forestry

It should be noted that according to the Order of the State Forestry Agency of Ukraine No. 138 [5] dated 21 April 2017, the Register includes 2046 land plots with a total area of affected lands of 4385.45 hectares.

State Enterprise "Dubrovytsia Forestry" includes 9 forest divisions: Chermenske Forest Division, Ozertsi Forest Division, Dubrovytsia Forest Division, Tryputnianske Forest Division, Berezhnytsia Forest Division, Litvytske Forest Division, Budymlianske Forest Division, Lisove Forest Division and Perebrodivske Forest Division. It was established that the area of affected land is 2539.56 hectares, which is 5.14% of the total area of State Enterprise "Dubrovytsia Forestry" in Figure 4.

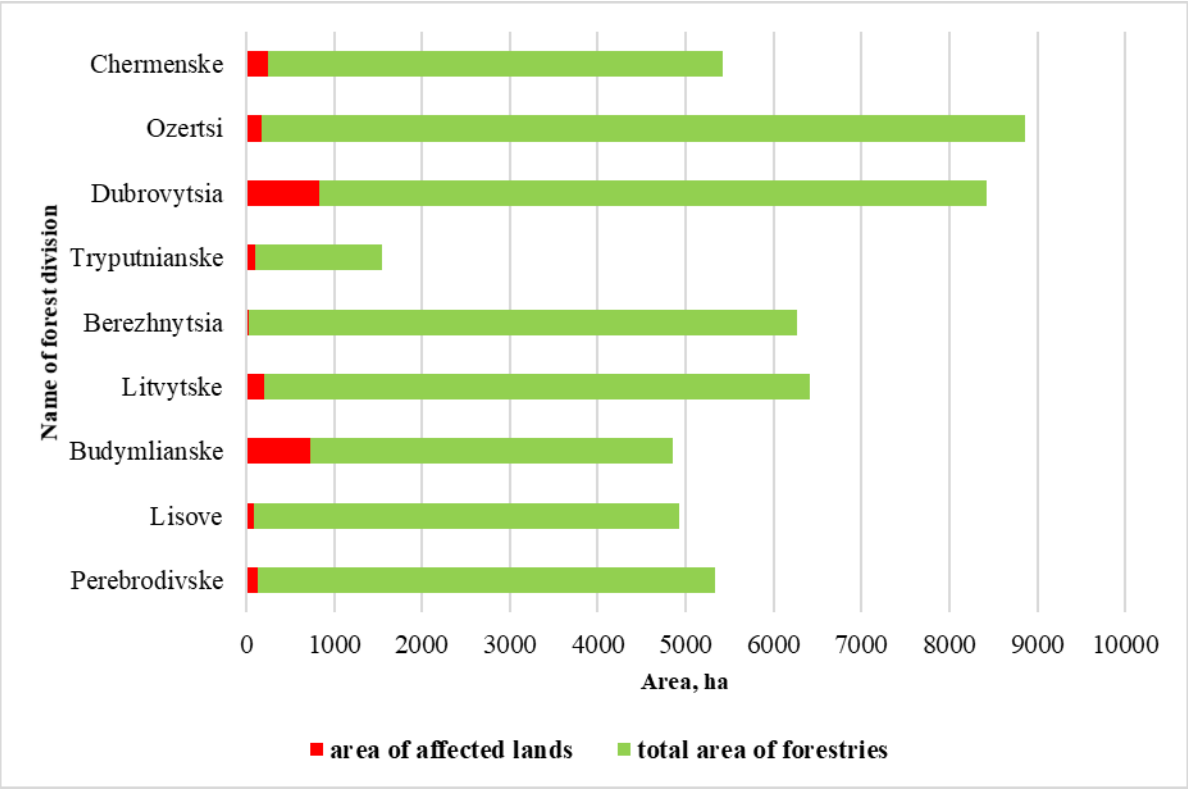

Figure 4. Ratio of the total area to the affected area of State Enterprise "Dubrovytsia Forestry"

Conclusions and prospects. The current state of natural environment of the north-western part of the Ukrainian Polissia is characterized by huge changes in agricultural landscapes. Lands affected by amber mining are permanently withdrawn from economic circulation, because the restoration of these lands is often neglected, or reclamation measures are carried out very often. Over the past 10 years, the quantitative indicator of the area of reclaimed land in the region ranges from 0 to 0.1 thousand hectares [10]. This shows that insufficient attention is paid to the reclamation of affected lands.

The article considers modern possibilities of geospatial modeling of areas affected by amber mining on the example of Rivne region. This study offers a method for deciphering satellite survey materials for geoinformation modeling of the territories with the lands affected by amber mining. The use of actual materials of remote sensing of modern satellite systems in combination with geospatial models during land monitoring is analyzed. It was found that the calculation of the NDVI makes it possible to identify the contours of affected areas more clearly. An approach

for assessing soil cover moisture content based on the use of Norm-difference water indices is presented. It is noted that the assessment of soil moisture is one of the elements of thematic processing of satellite images which makes it possible to identify the areas where amber mining by hydraulic method was carried out. The use of the methodology was tested on state-owned lands of Dubrovytsia Forestry of Rivne Region. The methodology will provide a technical basis for decisions on the identification of affected land plots and their further monitoring. In addition, the methodology offered in the article will help to determine the directions of land reclamation and groups of affected lands.

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МЕТОДИКА ГЕОІНФОРМАЦІЙНОГО МОДЕЛЮВАННЯ ДІЛЯНОК, ПОРУШЕНИХ ВНАСЛІДОК ВИДОБУВАННЯ БУРШТИНУ

У статті розглянуто сучасні можливості використання геоінформаційних технологій геопросторового моделювання ділянок,

порушених внаслідок видобування бурштину в Україні на прикладі Рівненської області. Метою дослідження є представлення методики дешифрування матеріалів супутникових знімань з метою геоінформаційного моделювання територій порушених земель унаслідок видобутку бурштину. Проаналізовано можливості застосування актуальних матеріалів дистанційного зондування сучасних супутникових систем в поєднанні з геопросторовими моделями під час проведення моніторингу земель. Досліджено, що розрахунок вегетаційного індексу NDVI дозволяє більш чітко виділити контури порушених земель. Представлено підхід для оцінювання зволоженості ґрунтового покриву, що базується на застосуванні нормово-різницевих водних індексів. Відзначено, що оцінка вологості ґрунтів являється одним із елементів тематичної обробки космічних знімків, яка дозволяє виявити ділянки на яких проводився видобуток бурштину за допомогою гідротехнічного способу. Запропоновано розглядати методику геоінформаційного моделювання ділянок, порушених внаслідок видобування бурштину як спосіб практичної реалізації визначення порушених земель за допомогою зображень ДЗЗ, зумовленого закономірностями та особливостями спектрального аналізу фотозображення. Використання методики представлено на конкретному прикладі, а саме на землях державної власності Дубровицького лісництва Рівненської області. Методика забезпечить технічне підґрунтя прийняття рішень щодо встановлення порушених земельних ділянок і їхнього подальшого моніторингу. Крім того запропонована в статті методика, допоможе встановити напрями рекультивації земель та групи порушених земель.

Ключові слова: *порушені землі, видобуток бурштину, мультиспектральні супутникові знімки, дистанційне зондування.*