UDC 332.3:528.88

IDENTIFICATION AND MONITORING OF THE STATE OF ILLEGAL AMBER MINING LANDS

R. Yanchuk, *PhD, Head of Geodesy and Cartography Department,*
E-mail: r.m.yanchuk@nuwm.edu.ua
O. Dmytriv, *PhD, Associate Professor of Geodesy and Cartography Department,*
E-mail: o.p.dmytriv@nuwm.edu.ua
S. Ostapchuk, *PhD, Associate Professor of Geodesy and Cartography Department,*
E-mail: s.m.ostapchuk@nuwm.edu.ua
A. Prokopchuk, *Senior Lecturer of Geodesy and Cartography Department,*
E-mail: a.v.prokopchuk@nuwm.edu.ua
S. Trokhymets, *Senior Lecturer of Geodesy and Cartography Department,*
E-mail: s.m.trokhymets@nuwm.edu.ua
O. Yanchuk, *PhD, Associate Professor of Geodesy and Cartography Department,*
E-mail: o.e.yanchuk@nuwm.edu.ua
National University of Water and Environmental Engineering

Abstract. *The negative consequences of illegal amber mining in Ukraine are analyzed. Emphasis is placed on the urgent need for a reliable assessment of the extent of illegal mining, determining the area of such sites and the necessary amount of their further reclamation.*

As part of scientific and technical research commissioned by the Ministry of Education and Science of Ukraine "Development of a system for identification and monitoring of lands damaged by amber mining" in the northwestern part of Ukrainian Polissya selected 5 test plots of 100 km^2 with the highest distribution of disturbed lands. The test areas have clear features and a significant area of merged contours.

An integrated approach has been proposed for the identification and monitoring of such areas, which involves the use of multi-zone satellite images, mapping from unmanned aerial vehicles, and ground geodetic measurements. A methodology for

such research has been developed. To automate the work on the basis of the free open source program QGIS 3.4.2, the structure was substantiated and a modular geographic information system was developed. Verification of the areas of disturbed lands on the basis of satellite survey materials and field geodetic measurements has been performed. Some results of researches of the sites of the broken earths in the Sarny area of the Rivne area which testify to efficiency of the offered technique are resulted.

Key words: *amber, disturbed lands, monitoring, satellite images, ground geodetic surveys.*

Formulation of the problem.

Illegal amber mining in Ukraine began in the late 1980s, but it has become widespread and threatening in the last 15-20 years. Volumes of amber production are quite large. Even according to modest estimates, they reach from 150 to 300 tons per year. Nobody knows the real volumes. The most attractive areas for the extraction of "sun stone" are the northern districts of Rivne and Zhytomyr regions. Nobody knows the real volumes. The most attractive areas for the extraction of "sun stone" are the northern districts of Rivne and Zhytomyr regions. Industrial deposits of amber are associated here mainly with humus quartz sands of the intermountain world of the Lower Oligocene, which lie in layers at a depth of 2.5 to 10 m from the surface and have a total thickness of 0.5-5.0 m. The content of amber in them is from several to several hundred grams per cubic meter. The price of amber depends on its quality and in Ukraine on the "black market", as a rule, ranges from 300 to 3 000 conventional units (euros) per kilogram. The approximate total annual income is up to 300 million euros [1].

This is a huge temptation for illegal miners. Despite the fact that world prices for the mineral have been falling recently and the state is more actively combating its illegal extraction, amber fever in these regions is still not happening. And this has caused a number of negative consequences, among which are:

- ecological (destruction of vegetation and fertile soil layer, violation of the relief structure, change of microclimate, deterioration of hydrological regime, water pollution, etc.);
- economic (non-receipt of taxes and rents and, as a consequence, loss of cash to state and local budgets, the need to eliminate the consequences of illegal diligence, losses of agricultural, forestry, tourism and other industries);
- social (criminalization of the territory, decline in the capacity of government agencies, involvement in the amber mining of adolescents);
- political (for example, a decrease in confidence in the Ukrainian state as a reliable partner in the field of international environmental law).

Given the above, it is clear and urgent to identify and monitor lands damaged by illegal amber mining, which would allow to assess the extent of illegal mining, determine the area of such sites and the necessary volume of their further reclamation.

Analysis of recent research and publications.

The study of theoretical and applied issues on this topic has not gone unnoticed by domestic and foreign scientists and practitioners. Such investigations have been covered in relevant publications [2-8].

The importance of issues of rational use of natural resource potential is reflected in legislative documents, such as [9].

The aim of the study.

Theoretical developments and proposed methods for determining natural resource losses on lands of illegal amber mining need their practical implementation and improvement, as there is currently no clear algorithm for their implementation. Such studies commissioned by the Ministry of Education and Science of Ukraine were performed at the National University of Water Management and Nature Management within the scientific and technical theme "Development of a system for identification and monitoring of lands damaged by amber mining" (agreement №DZ / 46-2018).

Materials and methods of research.

Based on multispectral images of satellite systems used as input data, developed methods of geoinformation data analysis, providing functions for unambiguous identification of target areas with the definition of their location (location), geometric dimensions (areas), land composition, forests, arable land, etc. .) at a particular point in time. Theoretical assumptions about the composition, scope and possible interaction of geographic information system modules are confirmed by field verification using classical methods of geospatial data collection.

Presenting main material.

Illegal amber mining has taken place and is currently carried out differently in the north-western Ukrainian Polissya. It has certain peculiarities related to somewhat different natural conditions of the territory, different time and method of extraction, different activity of criminal armed groups, reaction to their actions of the local population and authorities, etc. This requires the use of different approaches and materials to accomplish the task. In this regard, 5 arrays of test plots with an area of 100 km^2 were selected, with the most widespread distribution of disturbed lands in Rivne and Zhytomyr regions. The test areas have clear features and a significant area of merged contours. For the identification and monitoring of sites it was decided to use an integrated approach, which provides:

1) use of materials from different time space images, namely multi-zone satellite images WordlView-2, WordlView-3, Pleiades-1, Spot-6/7 (provided by the remote sensing distributor in Ukraine LLC "TVIS UKRAINE" on a commercial basis), Planet Scope (after registration are provided free of charge for a period of 14 days with a limit of 500 km2) and Sentinel-2A / 2B (available on the website of the European Space Agency ESA in free access). This makes it possible in in-house conditions with high reliability and sufficient accuracy due to the textural, spectral and temperature differences of sand dumps from the surrounding environment to identify areas of illegal mining and realistically assess the scale of the environmental disaster;

2) faster and more accurate mapping with the help of unmanned aerial photography systems (provided that the risk of UAV loss due to criminal actions of miners is

minimized). To perform the work, a multi-engine unmanned aerial vehicle PHANTOM 4 Professional from DJI was used;

3) terrestrial geodetic measurements using electronic total stations (mostly indoors and in wooded areas) or satellite receivers (outdoors) to verify remote sensing materials under the condition of free and secure access to observation points. The first case used an electronic total station Leica TCR 405 Ultra, the second - a rover RTK receiver based on a multi-frequency GPS receiver Leica 1200 and antenna geodetic accuracy class Leica AX1202 GG.

When conducting research, especially at the initial stage, it was decided to pay the greatest attention to satellite imagery materials, which in addition to the above advantages, are characterized by global coverage (in our case this is important because natural obstacles and human factors can hinder access to the right places) , relatively high frequency of survey (it is possible to analyze the dynamics of landscape changes), the presence of proven processing algorithms, etc. Due to the fact that amber is mined in different ways and in slightly different natural conditions, and the disturbed areas are partially covered with different vegetation, for correct decoding you need to use different types of space imagery (different in resolution, set of spectral channels, date of removal).

Here are some research results on the array №3, which is located in the western part of the Sarny district of Rivne region. Illegal extraction of amber from sand deposits is carried out here, mainly in two ways: mechanical (excavation) and hydraulic (hydraulic pump). The consequences of such actions on the ground are shown in Fig. 1, 2. The methods are used depending on a combination of a number of factors, the determinants of which are the depth of amber-bearing rocks and the level of groundwater. In addition to the two main methods, the option of combined extraction is used, when hydraulic wells are drilled in the trenches.

Fig. 1. Location of excavations on the territory of the array №3.

Fig. 2. The results of hydrowashing in the array №3.

Images from the Spot-6 and Sentinel-2 spacecraft were taken as input materials for the study of the array №3 (Fig. 3, Tables 1, 2).

Fig. 3. Scheme of the array zone №3.

Table 1. **Specification of Spot-6 satellite data of the №3 array zone.**

Spacecraft	Spot-6 (AIRBUS, France)
Order type	Archival photography
Scene ID	DS_SPOT6_201610140904152_FR1_FR1_FR1_FR1_E026N52_03008
Cloudiness	0%
The angle of deviation from the nadir	22,4°
Channels	PSM 4-bands: R,G,B,NIR
Spatial resolution of the product	1,5 m/pixel
Radiometric resolution	16 bit/pixel
Data format	GeoTIFF
Binding accuracy without anchor points	10,0 m CE90
Coordinates of the shooting center	51° 34′ 34″ N 26° 29′ 47″ E
Shooting area	100,00 sq. km
Projection, ellipsoid	UTM Zone 35

Table 2. **Specification of satellite data Sentinel-2 area of the array №3.**

Spacecraft	Sentinel-2B (AIRBUS, France)
Order type	Archival photography

Scene ID		S2B_MSIL1C_20180429T092029_N0206_R093_T35UMT_20180429T112810.SAFE	
Cloudiness		0%	
Channels	Spatial resolution of the product	R,G,B,NIR 4 Vegetation red edge 2 SWIR Coastal aerosol Water vapour SWIR - Cirrus	10 m/pixel 20 m/pixel 20 m/pixel 60 m/pixel 60 m/pixel 60 m/pixel
Radiometric resolution		11 bit/pixel	
Data format		GeoTIFF	
Binding accuracy without anchor points		20,0 m CE90	
Shooting area		100,00 sq. km	
Projection, ellipsoid		UTM Zone 35	

In the south-western part of the massif there is a test area, which is provided with images from the spacecraft WordlView-2 and Planet Scope (Fig. 4, Table 3)

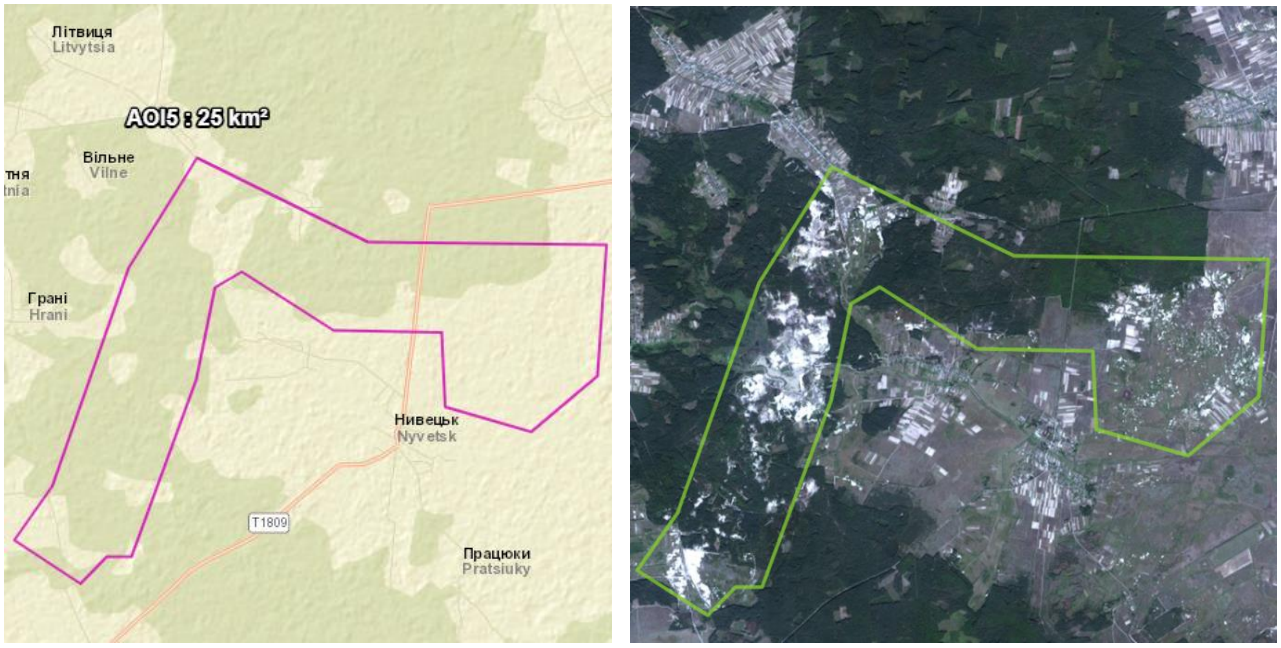

Fig. 4. Scheme of the test area of the array №3.

Table 3. **Specification of satellite data WorldView-2 and Planet Scope of the test area of the array №3.**

Spacecraft	WorldView-2 (Digital Globe Inc., USA)	Planet Scope (Planet Labs, Inc., USA)

Order type	Archival photography	
Scene ID	103001005CA03500	20180503_084125_1012_3B_AnalyticMS 20180503_084126_1012_3B_AnalyticMS 20180503_084127_1012_3B_AnalyticMS
Cloudiness	0%	0%
The angle of deviation from the nadir	17,8°	
Channels	Panhromatic MS:R,G,B,NIR, coastal, yelow, red edge, NIR-2	PSM 4-bands: R,G,B,NIR
Spatial resolution of the product	0,5 m/pixel (P) 2.0 m/pixel (MS)	3,0 m/pixel
Radiometric resolution	16 bit/pixel	
Data format	GeoTIFF	
Binding accuracy without anchor points	4,5 m CE90	
Coordinates of the shooting center	51° 32′ 34″ N 26° 23′ 36″ E	
Shooting area	25,00 sq. km	
Projection, ellipsoid	UTM Zone 35	

Remote sensing data processing includes standard steps. It is clear that the practical implementation of these stages depends on the hardware and software used. The generalized procedure for processing remote sensing data is:

1) data preparation (formation of geospatial data base, unification of data formats);
2) pre-processing of data (geometric correction, atmospheric correction, radiometric correction and calibration);
3) thematic data processing (preparation of composite and index images, classification, map algebra, statistical information);

4) analysis of the obtained results (research of time series of data, support of further decisions).

The presence of open heaps of sand and pits in the immediate vicinity of space images is the main feature of places of illegal amber mining. Such locations are distinguished by a characteristic spectral image, fine-grained image texture and temperature contrast with the surrounding vegetation. Taking this into account, the method of identification and further mapping of illegal mining sites is based on sequential analysis of multispectral space data on inherent spectral features and assessment of ground temperature increase in disturbed areas (according to Landsat 8 / TIRS analysis of recovered temperatures).

To reliably determine such areas, the analysis of hyperspectral remote images of the HIPERION sensor of the EO-1 satellite is performed. The obtained results provide an opportunity to form a complete spectral image of the desired object and its identification in the space image.

In order to increase the amount of input data, in addition to standard images and heat maps, index images and the results of the analysis of the main components are used. Partially simplified procedure for determining the area can be presented as:

1) pre-treatment;
2) determination of surface temperature, construction of composites and index maps, analysis of main components, analysis of spectral characteristics of the object;
3) construction of reference sites, creation of signatures, analysis of signatures;
4) classification, masking, determination of areas;
5) analysis of changes.

QGIS 3.4.2 was used as the basic desktop GIS. The processing of space images was performed using standard QGIS modules and developed appropriate applications. GDAL (Geospatial Data Abstraction Library) resources, additional GRASS GIS and GIS SAGA modules were used to increase the system's capabilities.

The result of such work is an array of integer ridges, the cells of which carry relevant information about the affiliation of the pixels to the disturbed lands. Having

different distribution of input data, it is further possible to determine the dynamics of changes in the areas of illegal amber mining.

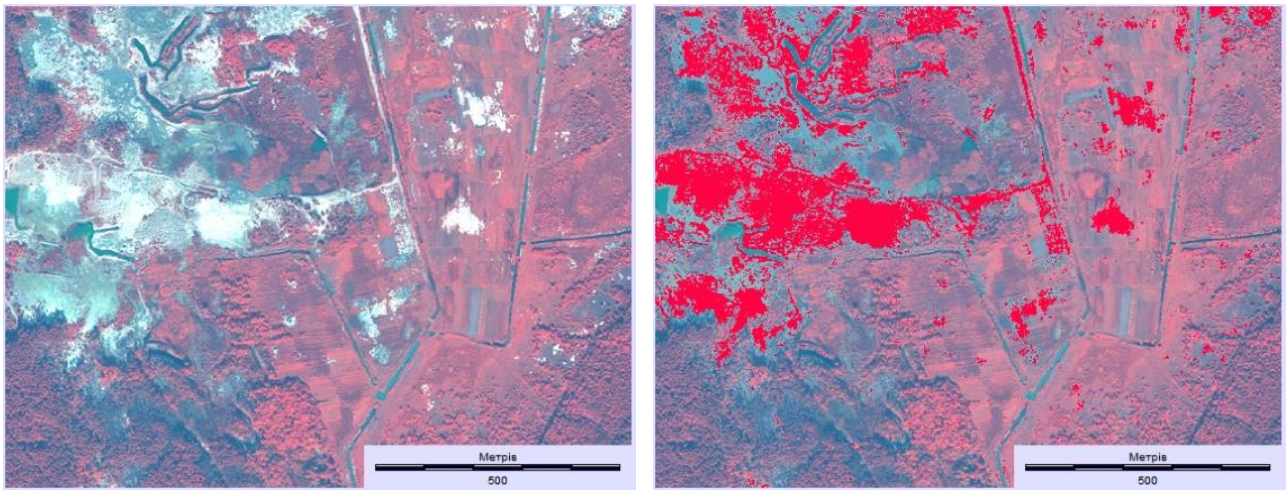

Fig. 5. The results of classification according to WV-2.

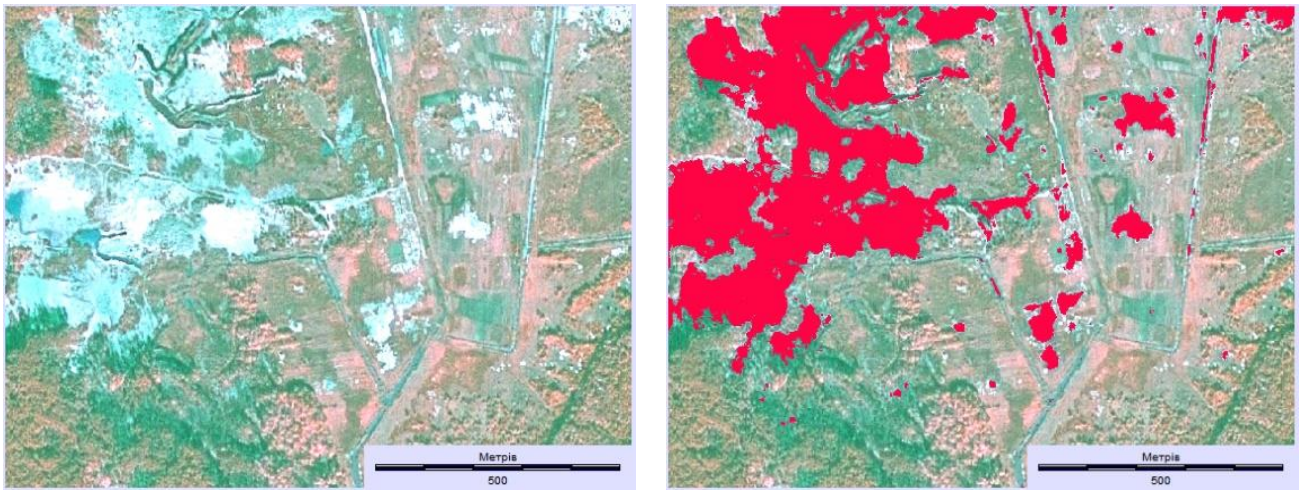

Fig. 6. Classification results according to SPOT-6.

In fig. 5 and 6 present the results of automated determination of disturbed lands on the part of the test area of the array №3. The areas of the identified plots were 211 and 237 ha, respectively. The difference in areas is caused by different time distribution of data and differences in their spatial separation.

For the purpose of field verification of the method of identification of disturbed lands based on the materials of satellite survey systems for the array №3, the target area was selected, where field field surveys and measurements were performed. The territory of the target area is provided with a picture from the KompSAT-3 spacecraft as of July 29, 2019. The area of disturbed lands, determined automatically by the space picture, was 31,93 hectares. The area of disturbed lands according to land

surveying was 35,06 hectares. The area of disturbed lands according to land surveying was 35,06 hectares. Thus, the difference between the areas determined by different methods is 3,13 hectares. This is 8,9% of the area determined by ground survey. In this case, the automated mode did not identify part of the disturbed land, overgrown with grass, shrubs and trees, which was the reason for this difference.

Conclusions.

A method for identifying and monitoring the state of lands of illegal amber mining with the help of remote materials from various space imaging systems has been developed. Data of satellite systems WordlView-2/3, Pleiades-1, Spot-6/7, Planet Scope, Sentinel-2A/2B were used as input parameters.

To automate the work, the structure is substantiated and a modular geographic information system is developed. A free open source program QGIS 3.4.2 was used as the basic shell of the geographic information system.

Verification of the obtained areas of disturbed lands on the basis of satellite survey materials and field geodetic measurements was carried out.

Approbation of the proposed method on certain areas of disturbed lands in Sarny district of Rivne region has been performed.

The results of the study can be used to make appropriate management decisions to eliminate the negative consequences of the phenomenon.

References

1. Hryshko L. (2016). "Burshtynova lykhomanka" zahrozhuie Ukraini ekolohichnoiu katastrofoiu. URL: https: //p.dw.com/p/112rk.
2. Filipovych V.Ie., Krylova H.B., Lubskyi M.S. (2015). Metodyka poshuku ta lokalizatsii dilianok nezakonnoho vydobutku burshtynu za materialamy bahatozonalnoi kosmichnoi ziomky. *Suchasni informatsiini tekhnolohii upravlinnia ekolohichnoiu bezpekoiu, pryrodokorystuvanniam, zakhodamy v nadzvychainykh sytuatsiiakh:* zb. nauk. pr. 14-yi Mizhn. nauk.-prakt. konf. , Kyiv (Pushcha-Vodytsia). S. 181-198.
3. Godert W. J. van Lynden, Stephan Mantel (2001). The role of GIS and remote sensing in land degradation assessment and conservation mapping: some user

experiences and expectations. *International Journal of Applied Earth Observation and Geoinformation*, Elsevier, Vol. 3, Issue 1, pp. 61–68. www.doi.org/10.1016/S0303-2434(01)85022-4.

4. Hadeel A., Xiaoling Chen, Mushtak Jabbar (2011). Remote sensing and GIS application in the detection of environmental degradation indicators. *Geospatial Information Science,* Vol. 14, Issue 1, pp. 39–47. www.doi.org/10.1007/s11806-011-0441-z.
5. Maslei V.N., Mozghovoi D.K., Belousov K.H. et al. (2016). Metodyka otsenky posledstvyi dobychy yantaria po mnohospektralnym sputnykovym snymkam. *Kosmichna nauka i tekhnolohiia*. T. 22. №6. S. 26-36.
6. Metodyka vyznachennia rozmiriv vidshkoduvannia zbytkiv, zapodiianykh derzhavi vnaslidok samovilnoho korystuvannia nadramy: nakaz Ministerstva ekolohii ta pryrodnykh resursiv Ukrainy № 303 vid 29.08.2011 r. URL: https: // zakon.rada.gov.ua/laws/show/z1097-11.
7. Shevchuk R.M. (2017). Veryfikatsiia rezultativ suputnykovoho monitorynhu terytorii nelehalnoho vydobutku burshtynu. *Ekolohichna bezpeka ta pryrodokorystuvannia.* № 3-4 (24). S. 133-137.
8. Yanchuk R., Dmytriv O., Trokhymets S. et al. (2020). Rozroblennia metodyky rozrakhunku kilkisnykh ta yakisnykh vtrat pryrodno-resursnoho potentsialu porushenykh zemel vnaslidok nezakonnoho vydobutku burshtynu. *Suchasni dosiahnennia heodezychnoi nauky ta vyrobnytstva:* zb. nauk. pr. Lviv: vyd.-vo Lvivskoi politekhniky, vyp. II (40). S. 93-101.
9. Zakon Ukrainy "Pro osnovni zasady (stratehiiu) derzhavnoi ekolohichnoi polityky Ukrainy na period do 2030 roku" vid 28 liutoho 2019 roku, №2697-VII.

Янчук Р.М., Дмитрів О.П., Остапчук С.М., Прокопчук А.В., Трохимець С.М., Янчук О.Є.

ІДЕНТИФІКАЦІЯ ТА МОНІТОРИНГ СТАНУ ЗЕМЕЛЬ НЕЛЕГАЛЬНОГО ВИДОБУТКУ БУРШТИНУ

Проаналізовано негативні наслідки нелегального видобутку буртину в Україні. Наголошено на актуальній потребі достовірної оцінки масштабів нелегального старательства, визначенні площ таких ділянок та необхідних обсягах їх подальшої рекультивації.

У рамках виконання науково-технічних досліджень на замовлення Міністерства освіти і науки України «Розроблення системи ідентифікації та моніторингу земель, порушених внаслідок видобування буртину» у північно-західній частині Українського Полісся відібрано 5 масивів тестових ділянок площами по 100 км^2 з найбільшим поширенням порушених земель. Тестові ділянки мають чітко виражені ознаки та значну площу злитих контурів.

Для ідентифікації та моніторингу таких територій запропоновано комплексний підхід, який передбачає використання багатозональних супутникових знімків, картографування з безпілотних літальних апаратів, наземні геодезичні вимірювання. Розроблено методику таких досліджень. Для автоматизації робіт на базі безкоштовної програми з відкритим кодом QGIS 3.4.2 обґрунтовано структуру та розроблено модульну геоінформаційну систему. Виконано верифікацію площ порушених земель за матеріалами супутникових знімань і польовими геодезичними вимірюваннями. Наведено окремі результати досліджень ділянок порушених земель у Сарненському районі Рівненської області, які засвідчують дієвість запропонованої методики.

Ключові слова: *буртин, порушені землі, моніторинг, супутникові знімки, наземні геодезичні знімання.*