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Technique for Satellite Monitoring of Illegal Amber Mining Territories Based on Integrated Landsat and Sentinel Data Processing

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ABSTRACT

This paper is devoted to the use of multispectral satellite imagery for monitoring and effective control of illegal amber mining. The main problems that prevent implementation of these tasks are the existence of a large number of sand dumps in mining places that are different in origin and difficult to distinguish its origin; "amber rush" territorial distribution covers very large areas (near 14,000 sq km); part of mining sites are guarded by criminal and, as consequence, inaccessible for ground truth research. To solve these problems new monitoring technique is proposed. The technique based on fusion of free Landsat and Sentinel data and takes into account spectral and thermal differences between disturbed by illegal amber mining lands and surrounded landscapes. The results of technique application over Olevsk district of Zhytomyr region are demonstrated.

KeyWords. Remote sensing, illegal amber mining, spectral analysis, spectral libraries, satellite monitoring, surface temperature distribution.

Introduction. In recent years, the problem of illegal amber mining has become urgent in Ukraine, which has reached critical dimensions. Today unlawful amber extraction covers wide areas in the north-western part of the country, mainly within the Rivne and Zhytomyr regions. The artisanal mining with the aid of motor pumps leads to a number of negative environmental impacts, including the destruction of the vegetation and soil covers, root system of trees, the violation of reservoirs` hydrological regime on the adjacent territories, amplification of water and wind erosion, non-toxic land pollution. In addition to the above-mentioned environmental problems, the state suffers serious financial and economic losses and social tension level increases. Economic losses are considered in two aspects: first, the loss of state revenue due to non-compliance with taxes and customs duties, damage to forest, water and agriculture, and second, the need to attract budget funds for the reclamation of disturbed lands. The social consequences are depriving crime in the region and the high risk of conflicts between miners and local residents.

A lot of actions need to be done to mitigate this situation and one of them is establishment of disturbed land monitoring. The solution of this problem is possible by using multispectral satellite data which provide a number of advantages compared to traditional methods like field measurements and aerial survey. These advantages are possibility to swath wide areas, low cost, high responsiveness and researcher`s security.

Resent research analysis. At moment a lot of scientists all over the world have investigated the possibilities of remote sensing data implementation for geoecological monitoring of strip mining areas. Among them are Indian researchers M. Suresh and K. Jain worked on detection of illegal mining using satellite images, Russian scientists I. Zenkov at. al. studied open cast nickel mining, Chinese researcher F Xu, who used multitemporal satellite imagery for recognition of waste dumps in mining areas and many others.

But the problem of illegal amber mining is common for Ukraine only, so it was studied only by Ukrainian specialists before. The main achievements in this direction are highlighted in the studies of

specialists of Scientific Centre for Aerospace Research of the Earth of National Academy of science of Ukraine (Filipovich V), Institute of Telecommunications and Global Information Space (Ohariev V), National University of Water and Environmental Engineering (Prokopchuk A, Trohimets S, Yanchuk R) and others. In these research advantages of satellite multispectral imagery application for illegal amber mining detection based on texture, spectral and temperature features of sand dumps inside surrounding environmental objects were investigated. The formation dynamics of such deposits was determined by mapping disturbed lands for a long period of time using multitemporal satellite imagery. A mapping of state losses caused by illegal amber mining was assessed. But despite the existence of such studies, the problem of remote sensing data application for illegal amber mining monitoring areas is under investigation now.

The main purpose of the study is to develop the technique, which, on the one hand, would accurately map the areas of lands disturbed by illegal amber mining, and, on the other hand, promptly identify new mine sites to prevent unlawful extraction.

The implementation of these tasks is challenging due to the features of the study area geological structure and due to way of illegal extraction performance. Extractions are characterized by high intensity, spread and criminality. New mining pits appear regularly and are usually placed among forest and shrub thickets, have a small area and are often guarded by illegal combatants, which make impossible direct access for the researcher. Concerning geology, the main type of soils of the territory covered by the "amber rush" are sod-podzolic and sandy, with a small humus horizon thickness (up to 30 cm) that lie on the sandy substrate. As a result, sand dumps are not only formed by illegal subsurface mining, but also by other types of economic activities such as deforestation. This affects the interpretation accuracy of such areas using existing techniques based on image supervised classification. In their application, the main task of the researcher is to precisely determine the reference sites ("region of interest") that would have the signature of the search object with the maximum delectability among parts of environment. Very often similar in spectral features, but different in origin objects can designed as class after classification is performed and, consequently, results` accuracy is decreasing.

Efficient solution to this problem could be the use of high resolution satellite images (0.5-2.0 m.), but such data are commercial and its price varies between $ 15-30 per one km^2, while the total area of the territory covered by illegal amber extraction is about 14 thousand km^2 [3]. At high intensity of illegal extraction, monitoring should be performed on average once a month (in summer months more frequently, and in winter mining activity is practically strops). As a result, the cost of purchasing images may even exceed the state`s losses from illegal extraction.

To solve this problem, we propose a new technique based on integrated application of free-of-charge satellite image data taking into account thermal and spectral differences between disturbed by illegal amber mining lands and sand dumps formed by deforestation.

The research methodology consists of several stages. The source data are satellite imagery of the Landsat 8 OLI/TIRS та Sentinel-2 MSI. In the first stage, cloudless images of study area are selected, after which an atmospheric correction of selected data is performed if one not applied before. Primarily it concerns the part of available Sentinel-2 images, the maximum processing level of which is L1C (radiometric calibration and orthorectification is performed). Atmospheric correction of such data is carried out by the Sen2cor module integrated in the ESA/SNAP software (scihub.copernicus.eu/).As for Landsat 8 satellite data each scene is provided with atmospheric correction and available for downloading at USGS official site (eartheplorer.usgs.gov).

The second stage includes data classification and postclassification processing in order to detect sand dumps which spectral signatures are differ from the surrounding landscapes on the satellite image. As a result of classification, a small part of the dumps formed by deforestation and other types of economic activities can be recognized as disturbed by illegal amber mining lands. Thus on the third stage the surface temperature estimation in order to improve accuracy of these results is performed.

As a consequence of motor hydraulic pumps use, surface of disturbed by amber extraction lands is covered with moist sand dumps from different horizons and small diameter (less than one pixel on image) mining pits filled with water. Sometimes these dumps contain clay inclusions. All these factors affect on surface temperature distribution. Minerals have different normal heat capacity at constant pressure, for water it is 4.187 kJ/(kg*K), for clay 0.92 kJ/(kg*K),and for quartz is - 0.8 kJ/(kg*K).Minerals and mineral mixtures which heat capacity are high, heating and cooling slowly. It means that disturbed by amber mining lands will have lower temperature on daily images than sand dumps formed by deforestation (Fig. 1).

To perform surface temperature estimation pixel (T) of mapped area the inverse Planck radiation formula is used [5]:

$$T = \frac{c_2}{\lambda \ln\left(\frac{\varepsilon \cdot c_1}{\lambda^5 \cdot L_0} + 1\right)}, \quad (1)$$

where $c_1 = 1.191 \cdot 10^{-16}$ W per m^2, $c_2 = 1.439 \cdot 10^{-2}$ m·K –radiation constants ,ε –land surface emissivity, λ-electromagnetic radiation wavelength, L_0 - surface radiance.

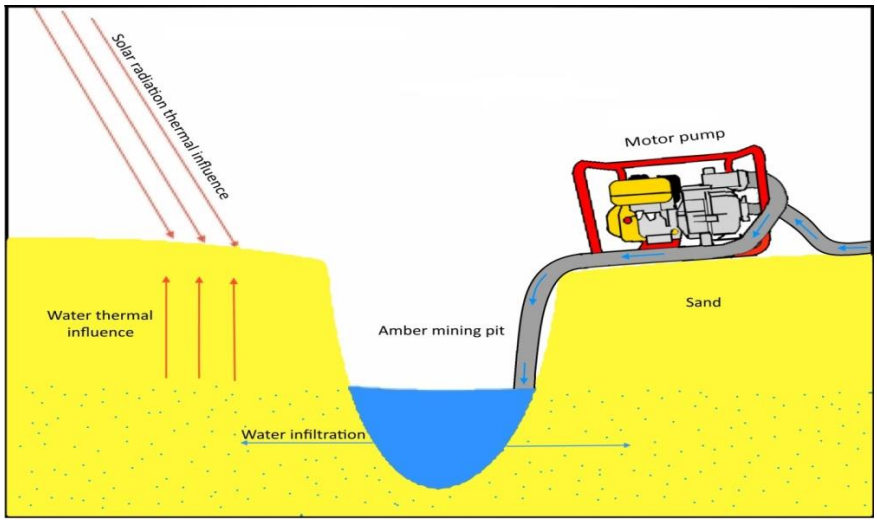

Fig. 1. Diagram of water influence on the temperature of sand dumps formed by illegal amber mining using hydraulic motor pumpsю

The source data for surface physical temperature estimation are long-wave infrared imagery. Used in our research the Landsat 8 TIRS sensor provides ones in two spectral bands: 10.60 - 11.19 μ m and 11.50 - 12.51 μm. These bands are acquired at 100 meter resolution, but are resampled up to 30 meter in delivered data product. Necessary for temperature estimation emissivity can be estimated from visible and near-infrared data by determination of emissivity and NDVI index ratio [5]. That means emissivity can be extracted from any satellite data contains red and NIR bands, so it is reasonable to fuse two types satellite dataset (red and NIR from first one and long-wave infrared from second one) in order to improve temperature accuracy and resolution of surface temperature distribution (Fig. 2)

Two masks of disturbed lands obtained as a result of classification and calculation of temperature are superimposed on each other and areas for conducting field research are determined.

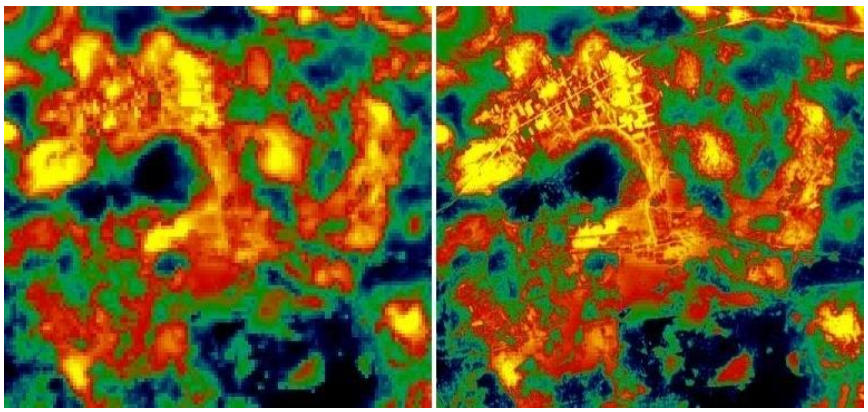

Fig. 2. Fragment of surface temperature distribution map. Outskirts of the Obysche village in Olevsk district Zhytomyr region. Estimated from Landsat 8 data (left) and Sentinel-2and Landsat 8 fused data (right).

The fourth stage includes field spectrometric measurements or laboratory studies of selected sand samples and subsequent processing. The Fieldspec-3 portable spectroradiometer was used for spectral measurements. It`s work spectral range is from 350 to 2500 nm with one nanometer sampling interval.

Spectral reflectance is unique for each type of surface. It is necessary to take into account their humidity, color, structure, layer depth in mining pits when sampling.

At the final stage, the digital processing of ground truth data obtained by the spectroradiometer using the WievSpecPro software is carried out and spectral library is formed. Then, a support vector machine method classification using created library is carried out. This allows to improve the results` accuracy for the study site and to identify small areas of disturbed lands to which researcher access is impossible. Raw spectral library must be recalculated according to the satellite sensor bands responses. The date of image acquisition selected for the classification and field measurement date must be the same, or it should be days with the same weather conditions with a small (up to several days) time interval. Since the spectral reflectance of the surface deposits can vary at different times, depending on the humidity or change of mining pit depth, it is necessary periodically to conduct ground spectrometry or sampling. That's why the classification by the spectral library should be considered as a component of the result`s verification.

Research results. The study site is situated between villages Obyshche-Sushchany-Shebedikha-Zamyslovichi of Olevsk district of Zhytomyr region within Klesivsko-Perzhanska amber-bearing zone. The total area of this territory is 195 km^2 (Fig. 3). The identification of sand dumps distribution areas was carried out by supervised classification of Sentinel-2A satellite multispectral data using the support vector machine method. As a result, several areas of disturbed lands were discovered, the largest of which are located southward of Obyshche village and northward of the Shebedikha village (Fig. 4).

Land surface temperature estimation has shown that several sites identified by classification as disturbed by illegal amber mining lands in fact, are sand dumps formed as a result of deforestation. These are, in particular, the areas on the northward and the eastward of the Obyshche village and on the westward of Shebedykha village (Fig. 5). The received results were confirmed at the stage of ground field research. The land surface temperature of these areas is, on average, 2-3 ºC higher than the land surface temperature of disturbed by unlawful amber extraction land. Spectral analysis of surface sediments samples, selected in field studies, was conducted in laboratory. Spectral library was formed from spectroradiometer measurements and recalculated according to wavelength and quantity of Sentinel-2 bands.

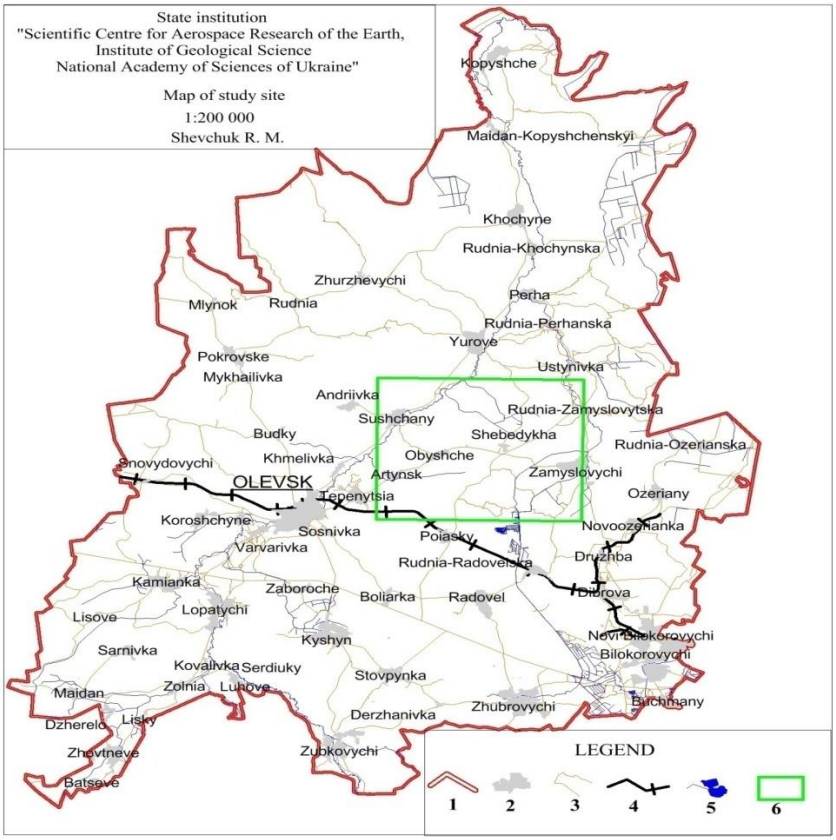

Fig. 3. Study area map. Legend: 1.Administrative boundaries of Olevsk district Zhytomyr region, 2. Settlements, 3. Roads, 4. Railways, 5.Reservoirs, 6. Study site boundaries.

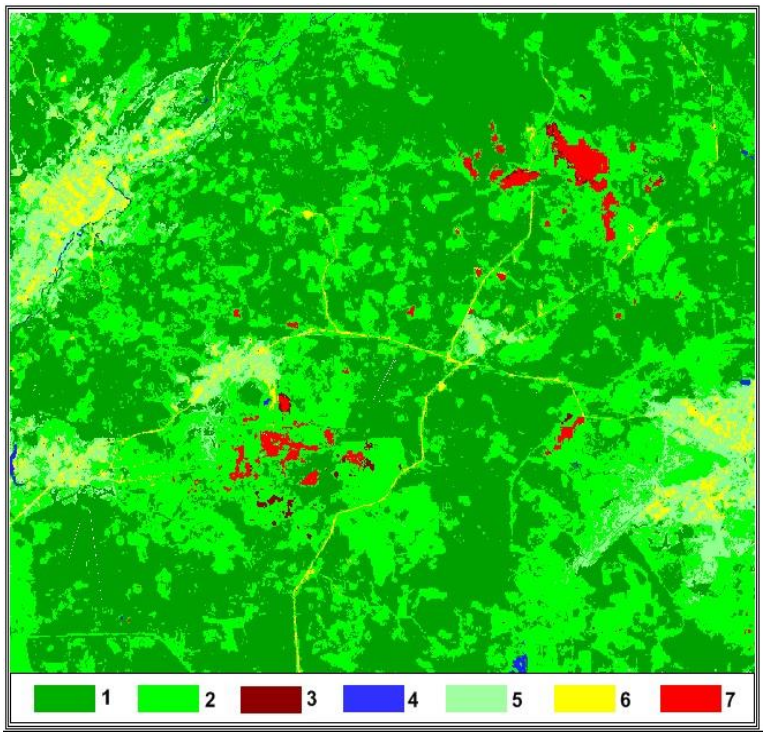

Fig. 4. Map of the identified areas of sand dumps of May 11, 2018.Result of supervised classification. Legend: 1. Forest. 2. Grassland and shrubs. 3. Bare soil. 4. Water. 5. Crop. 6. Rural buildings and roads. 7. Sand dumps.

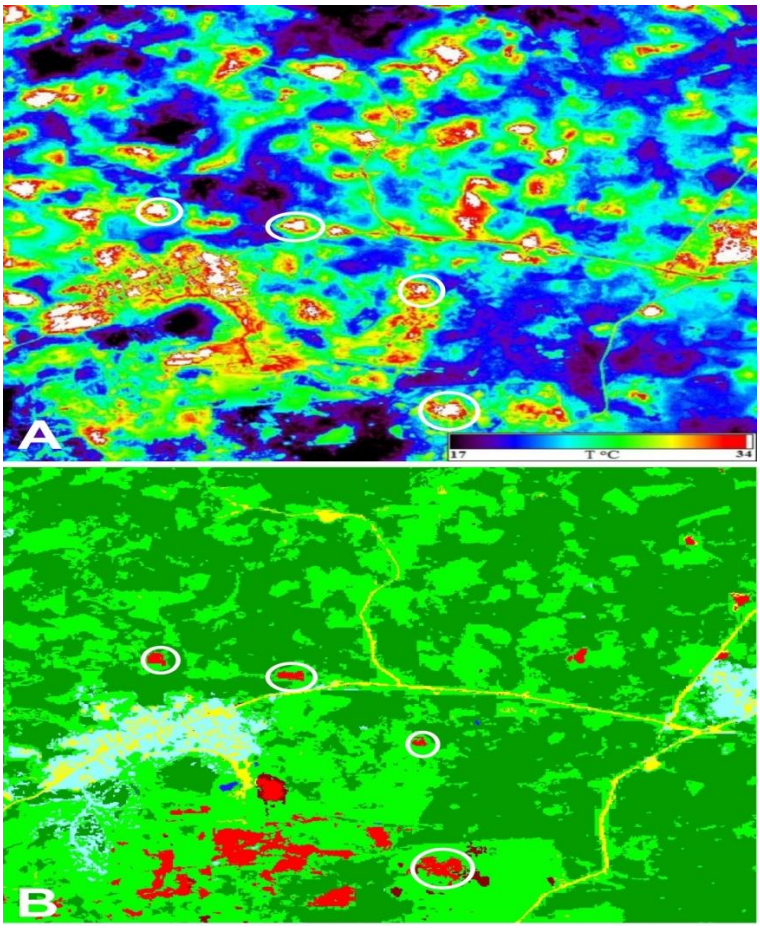

Fig. 5. Fragment of surface temperature distribution map (A), and map of disturbed land distribution (B). Circled areas are sand dumps formed by deforestation.

Then SVM-based supervised classification using the library was performed in order to improve result`s accuracy (Fig. 6). The total area of disturbed by amber extraction lands on the study site is 105.33 hectares. The use of spectral library allows accurately identify surfaces covered with dumps of mixed sand from different horizons without vegetation, but disturbed by illegal amber mining lands also include water channels, areas with fallen trees, areas covered with vegetation growing on sandy substratum where landscape self-renovation already has started. The proposed technique allow to perform area measurement with high accuracy, but accuracy is restricted by Sentinel-2 image resolution (10 m per pixel), so high resolution satellite data or aerial imagery need to be used while reclamation of actual amber mining sites is planned.

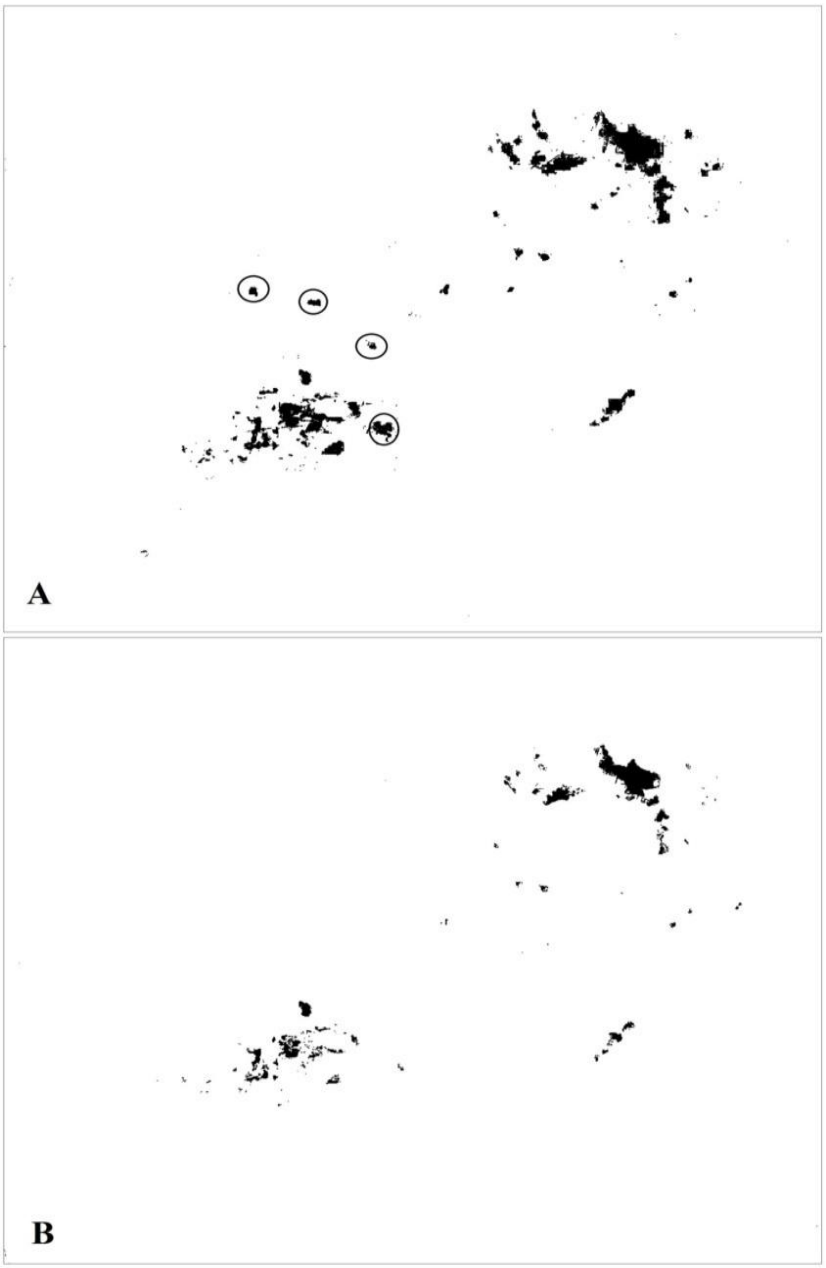

Fig. 6. Results of disturbed lands SVM-based classification. A. Based on ROI. B. Based on spectral library of sand samples. Circled areas are sand dumps formed by deforestation, first time identified on land surface temperature estimation stage.

Conclusions

The proposed technique is intended for monitoring the territories of illegal amber mining and based on open access Landsat and Sentinel multispectral satellite data fusion with ground-based spectrometry support. This technique allows timely and high accurate to identify new illegal amber mining areas and to distinguish them from sand dumps formed by other types of economic activity, which is relevant for assessing the current environmental condition of Zhytomyr Polesie. The results of the research showed that 105.33 hectares of study area lands were disturbed by illegal amber mining. The technique can be used by governmental and independent ecological organizations.

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ქარვის არალეგალური მოპოვების ტერიტორიების თანამგზავრული მონიტორინგის მეთოდიკა **Landsat** და **Sentinel** კომპლექსური მონაცემების გამოყენების საფუძველზე

რ. შევჩუკი

რეზიუმე

სტატია ეძღვნება თანამგზავრული გამოსახულებების გამოყენებას ქარვის არალეგალური მოპოვების მონიტორინგისა და ეფექტური კონტროლის განხორციელების მიზნით. ძირითადი პრობლემები, რომლებიც ხელს უშლიან ამ მიზნის მღწევას არიან სხვადასხვა წარმოშობის ქვიშის გროვების დიდი რაოდენობა, რომელთა წარმოშობის მიზეზები ძნელია განისაზღვროს; უზარმაზარი ტერიტორია(დაახლ. 14000 კმ^2) მოცულია „ქარვის ციებით"; გამომუშავებების

ნაწილს მფარველობენ კრიმინალური ელემენტები და როგორც ამის შედეგი, მიუწვდომელია მიწისპირა დაკვირვებისათვის. ამ პრობლემების გადასაჭრელად შემოთავაზებულია ახალი მეთოდიკა. ეს მეთოდიკა ემყარება Landsat და Sentinel ღია მონაცემების კომპლექსირებაზე და მხედველობაში იღებს ქარვის მოპოვებით დაზიანებულ და მის გარშემო მდებარე ლანდშაფტებს შორის სპექტრალურ და ტემპერატურულ სხვაობას. მეთოდიკის გამოყენების შედეგები ნაჩვენებია ჟიტომირის მხარის ოლევის რაიონის მაგალითზე.

Методика спутникового мониторинга территорий нелегальной добычи янтаря на основе применения комплексных данных Landsat и Sentinel

Р. М. Шевчук

Резюме

Статья посвящена применению спутниковых изображений в целях осуществления мониторинга и эффективного контроля над незаконной добычей янтаря. Основными проблемами, предотвращающими достижение таких целей, есть наличие большого количества разных по происхождению песчаных отвалов в местах ведения добычи, происхождение которых тяжело определить; огромная площадь охваченной «янтарной лихорадкой» территории (около 14,000 км^2); часть мест разработки охраняется криминальными элементами и, как следствие, недоступна для проведения наземных исследований. Для решения этих проблем была предложена новая методика. Методика базируется на комплексировании открытых спутниковых данных Landsat и Sentinel и принимает во внимание спектральные и температурные различия между нарушенными добычей янтаря землями и окружающими ландшафтами. Результаты применения методики показаны на примере Олевского района Житомирской области.