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MONITORING OF GEODYNAMIC PROCESSES IN THE TYSA RIVER BASIN USING AUTEL EVO II PRO RTK UAV

The aim of this work. This article is devoted to the study of geodynamic processes in the Tysza River basin within the Transcarpathian region with an analysis of geodetic observations obtained over the past decade. Method. Karst monitoring began with the identification of the most dangerous areas of the earth's surface that are subject to vertical displacements. After the detection of the most dangerous areas the local geodetic monitoring was carried out at facilities within the urban settlement to prevent possible accidents: Solotvyno, Dilove and Bila Tserkva. A collection of archival aerial photography was also used to develop a methodology for identifying changes in landscapes and landforms under the influence of geodynamic processes. Results. UAVs were used to remove karsts. On the basis of digital aerial photography data were created: orthophotos and digital terrain models. Digital aerial photography was carried out in accordance with the requirements of regulatory documents. To determine the dynamics of landslides and karst the digital aerial photography must be repeated several times at certain intervals. Aerial photography work was carried out in two stages in 2020 and 2021 Contour points were selected for identification marks. They are recognized on aerial photography and the terrain with an accuracy of at least 0.1 mm on the scale of the created plan. Mathematical processing of geodetic GPS measurements was performed using Trimble Geomatics Office software. After photogrammetric processing, the quality control of the obtained results was performed and digital surface models using DEM and TIN methods. Orthophotomaps on a scale of 1:1000 were made from raster images of aerial photographs, taking into account the created digital terrain model. There is a need for monitoring work to update information on the state of modern karst formations and areas with exogenous processes in Solotvyno and Bila Tserkva, Tyachiv district and the village Dilove, Rakhiv district, Transcarpathian region. The technology of topographic and geodetic works with the use of UAVs and GPS measurements in mountainous areas has been developed and tested. The results of aerial photography were used to visualize the study objects and to convey information regarding the deformation processes to local governments. For processes of natural or man-made nature (displacement, landslides, karst) requires the development of individual approaches to the use of UAVs. With the mass use of UAV images, a data bank is formed, which cannot be obtained by other methods. The study made it possible to create the method of complex determination of movements in exogenous and technogenic areas in mountainous areas with the use of the latest technologies. It allows quick establishing a plan-altitude basis of the required accuracy in the reference coordinate system in solving a number of applied geodesy problems using satellite technologies and UAVs for observations by objects.

Key words: digital aerial photogrammetry; digital surface models; deformations monitoring; unmanned aerial vehicle; orthophotoplan.

Introduction

In recent decades, environmental disasters have become more frequent in the Carpathian region. Territories with observed deformations of the earth's surface (geotectonic movements, landslides) are found in relatively densely populated areas, in industrial, agricultural, and urban recreation areas, as well as in landscapes with different levels of nature protection [Kalynych et al., 2013[. Any surface movement through dangerous processes can destroy structures of various types on the earth's surface, threaten human life and property, and seriously affect the environment. The main destructive force of these processes is groundwater. In particular, the level of groundwater in the Transcarpathian lowland from the late 60s of the last century to the early 90s decreased by about 2 m. In addition, both the average annual air temperature and the amount of total precipitation have increased since the mid-80s. This tendency, to some extent, is a consequence of climate change.

According to the State Geological Service, more than 26.0 thousand surface and underground karst manifestations have been recorded within the territory of Ukraine. In the areas of mining operations and intense technogenic load, the development of technogenic karst continues, sometimes with catastrophic manifestations of the process [Information Yearbook, 2020].

This process has received particular development in the areas of salt mineral extraction [Solotvynske, Kalushske, Novo-Karfagenske, etc.] within the Transcarpathian, Ivano-Frankivsk, Lviv and Donetsk regions.

The Solotvyno rock salt deposit is located in the southeastern part of the Tyachiv district of the Transcarpathian region. To protect the mine workings, drainage was installed to intercept the supra-salt waters. Nevertheless, in adits and pits, frequent falls were recorded, blocking the self-flow of tree waters. These fallouts were not eliminated in time due to the underfunding of the Solotvino salt mine. Artificial dams were formed, which created a backwater of supra-salt waters and their accelerated infiltration into the salt massif along weakened zones, primarily in the Chornyy Mochar region. This led to the catastrophic consequences that are observed at the field today. Violation of the natural regime of supra-salt waters established in geological time led to the activation of salt dissolution. The presence of an extensive system of drainage workings at the base of the Quaternary deposits and in the upper part of the salt body created zones of underground discharge. It also expanded the zone of active water exchange to easily soluble rock salt and became the main reason for the intensive use of the territory. The flooding of mines No. 7 and No. 8 (Figs. 1, 2) resulted in appearing new karst channel formations, the waterproof cover (canopy) destruction and the formation of dips through which atmospheric water flows. The technogenically activated karst within the Solotvyno deposit caused radical relief changes of the earth's surface, an increase in the runoff coefficient, and changes in the places of groundwater recharge and discharge (Dyakiv, 2012).

Fig. 1. Flooded mine No. 7

Fig. 2. Flooded mine No. 8

The aim of this work

This article is devoted to the study of geodynamic processes (landslides, subsidence, karst) of the earth's surface in the Tysza River basin within the Transcarpathian region with an analysis of geodetic observations obtained over the past decade.

Research methodology

The study area has all the reasons for the appearance and wide development of deformation displacements of the earth's surface. They include the high steepness of the slopes causes gravitational asymmetry; water saturation of the subsoil and a high level of the groundwater table; global warming, leading to waterlogging of clay material and its fluidity; alternation of dry periods with torrential precipitation. In addition, the territory is affected by both deep-focus earthquakes (Vrancea zones in Romania) and local earthquakes. Anthropogenic activity enhances these processes. *Most of all, the relief changes caused by the technogenically activated salt karst within the Solotvino deposit are striking. It is still not known exactly what caused the deformations of the earth's surface: whether they are associated with salt karst, or caused by heavy rains, causing groundwater to rise, or caused by the action of tectonic plates. Over the past twenty years, no types of karstomonitoring have been carried out at the object under study, only the already existing catastrophic manifestations are recorded!*

The natural disasters cause enormous damage to the environment and the economy of the country. Their prevention is possible only if the rational use of natural resources and the creation of a common system of measures to prevent the emergence of new zones of natural disasters. Karstomonitoring as the basis for the optimal development of karst territories is one of the main methods of anti-karst protection. It is understood as, first of all, monitoring the state of the territory, conditions and main factors of karst formation and dangerous karst manifestations. It also includes collection, analysis, processing, storage and dissemination of data, and timely warning (forecast) of possible critical situations.

The results of the analysis of the geological natural environment features of the Solotvyno village allowed identifying zones of catastrophic and potentially dangerous manifestations of karst-sufusion processes within the eastern part of the salt stock. They include the mine field areas of mines No. 7, 8 and the territory of "Chornyy Mochar", characterized by the formation of countless dips, as well as vertical and horizontal surface deformations (the rock mass shear zone). The territory is complicated by uneven local precipitation, salinization, flooding, waterlogging, and prone to soil erosion, with a significant unpredictable threat of their negative manifestations.

An integrated digital geological model of the Solotvyno structure was proposed in [Shehunova et al., 2019]. Adaptive methods of detecting environmental changes using multispectral space images of the Earth, combined with classical geodetic methods of observation, will help to determine the location of these critical parameters. Therefore, the creation of a system of remote monitoring of the territory of Solotvyno and adjacent territories is a priority today. Attention should also be paid to the hydrogeological studies of the Solotvyno area, including the Tysza River.

Geodetic support of the object of study

We studied the information for the survey area on providing the territory with planned high-altitude geodetic networks, topographic maps and digital aerial survey from the works of previous years. Its aim was to determine and justify the composition and scope of the projected topographic and geodetic works, define the methods and technologies for their implementation, calculate the accuracy and minimize the cost of work.

Their quantitative and qualitative parameters and characteristics were studied for compliance with current regulatory requirements and to establish the possibility and expediency of their use.

The collection and analysis of survey materials of past years was carried out in the State Cartographic and Geodetic Fund, and in other organizations that have topographic and geodetic materials. Table 1 presents overview information about the existing work area, topographic and geodetic, cartographic and aerial photography materials

Table 1

Overview data on the main cartographic, aerial topographic and auxiliary materials previously created for the area of work [Technical report, 2010]

Item No	Type of materials and characteristics	Performer of works, year of completion, other data	Location plans and maps, Technical progress reports, etc.
	A) Topographic maps and plans and orthophotomaps		
1	Topographic maps at scales 1:10,000, 1:25,000 1:50,000, 1:100,000, 1:200,000 on paper and in raster form	Enterprises of the USSR GUGK, Ukrgeodezkartografii, State Service of Ukraine for Geodesy, Cartography and Land Management From the 1960s until now	1. State Cartgeofund of Ukraine 2. Enterprises – performers of topographic and geodetic works
2	Raster copies of maps at a scale of 1:100,000	Internet	1. Internet
3	Basic digital vector map of Ukraine (combined from scales 1:100,000, 1:200,000)	Research Institute of Geodesy and Cartography 2006–2007	1. Research Institute of Geodesy and Cartography
4	Digital – cadastral maps and orthophotomaps with a scale accuracy of 1:2 000, 1:10 000	Created under the World Bank Project	1. State GeoCadastre of Ukraine and its territorial bodies. 2. Public cadastral map of Ukraine
5	Topographic plans 1:500, 1:2000 and 1:5000	Topographic and geodetic specialized enterprises, design and survey companies and entrepreneurs. Created as orders – in different years	1. Performers of topographic and geodetic works
6	Digital topographic plans and orthophotomaps in scale 1:2000	SE “Zakarpatgeodezcentre”	1. SE "Zakarpatgeodezcentre"

A collection of archival aerial photographs was used to test the method of detecting changes in landscapes and landforms under the influence of geodynamic processes (Figs. 3–7). A simple look at pictures of different ages in the same area suggests that even in such a short period of time, landscape changes can be very significant.

After identifying the most dangerous areas to prevent possible accidents, the local geodetic monitoring was conducted at sites within the village Solotvino, the village of Dilove and the village of Bila Tserkva (Figs. 3–9), using materials of digital aerial photography, topographic surveying and satellite imagery.

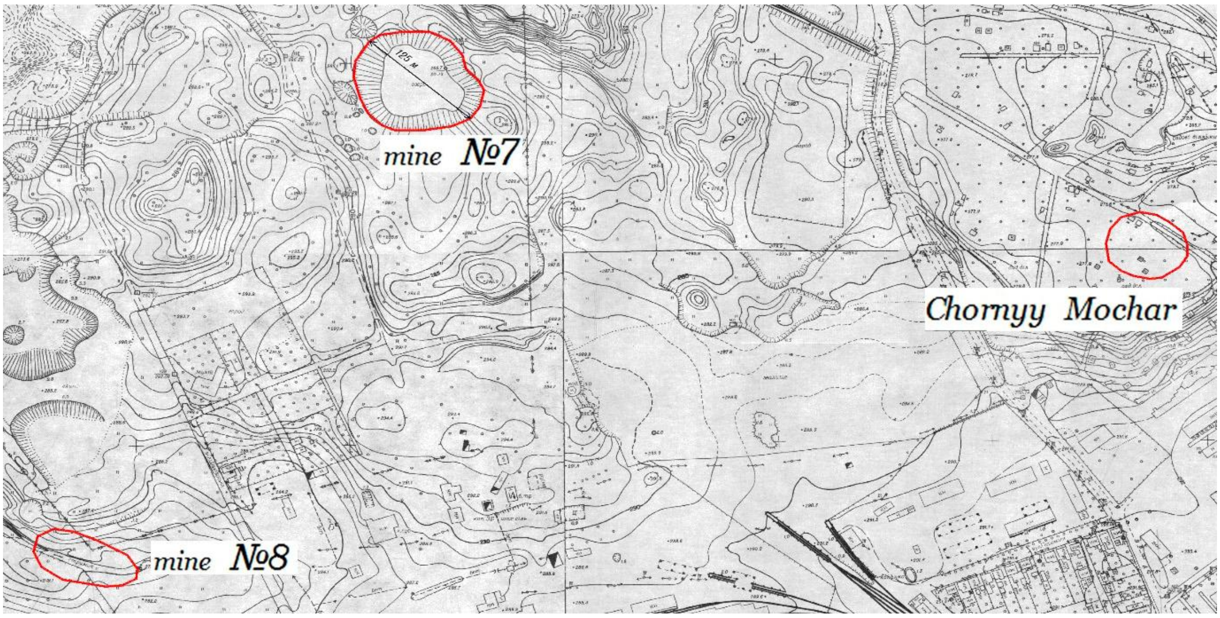

Fig. 3. Stereotopographic survey of 1995
The objects of the study are shown in the figures in red, the deformation displacements are shown in green

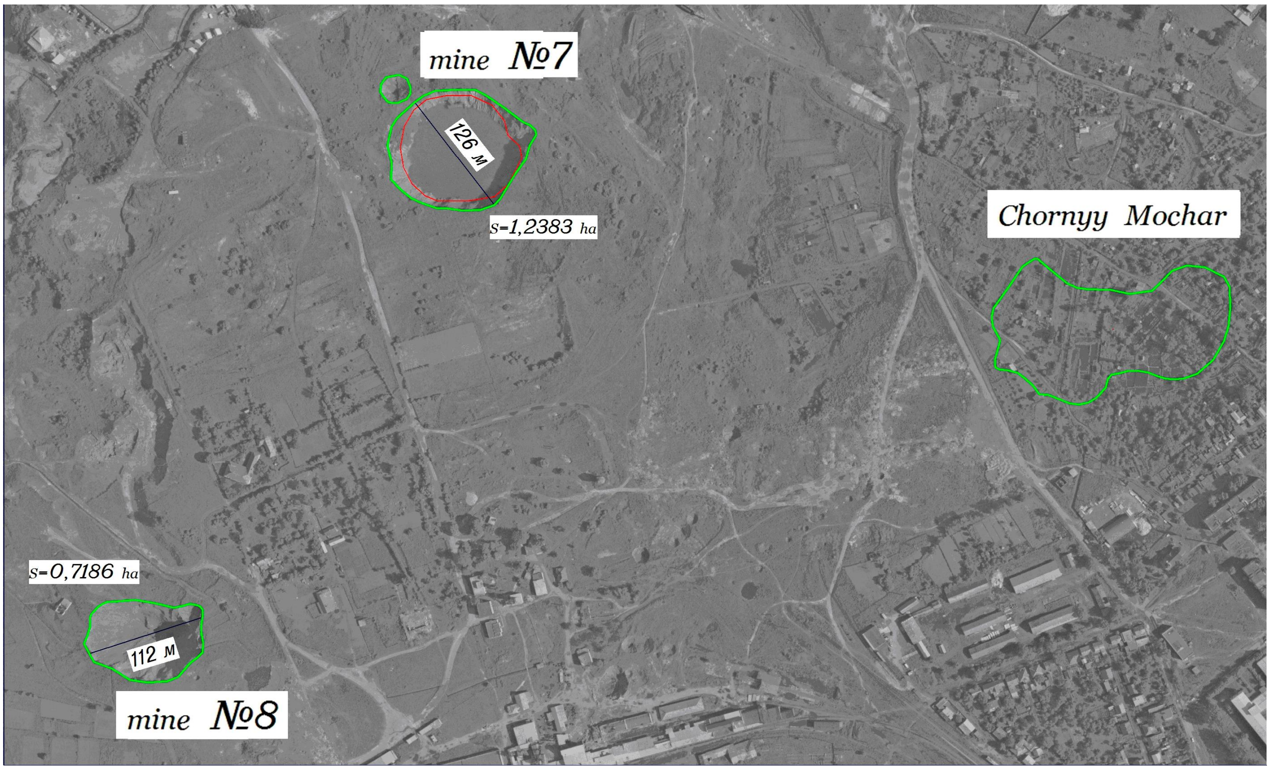

Fig. 4. Karst monitoring (aerial photography materials as of 2005) [Technical Report, 2010]

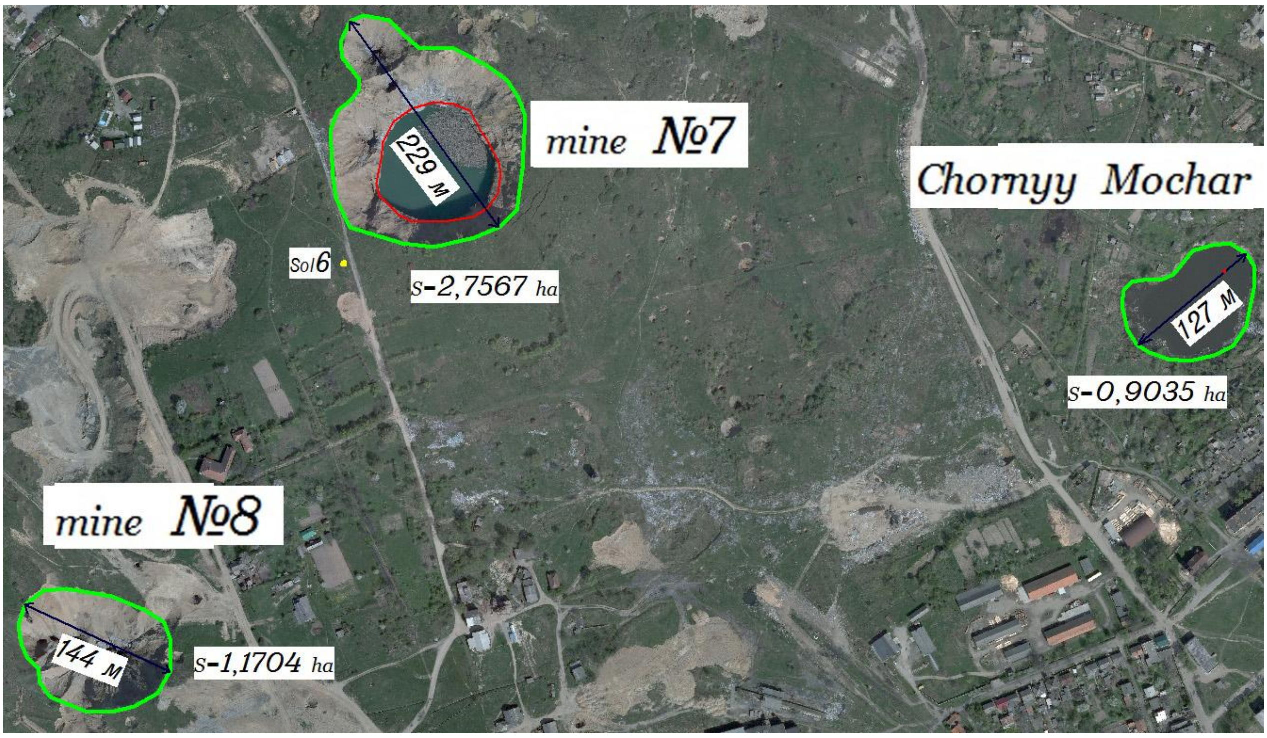

Fig. 5. Monitoring of deformations (aerial photography materials as of 2010) [World Bank Project]

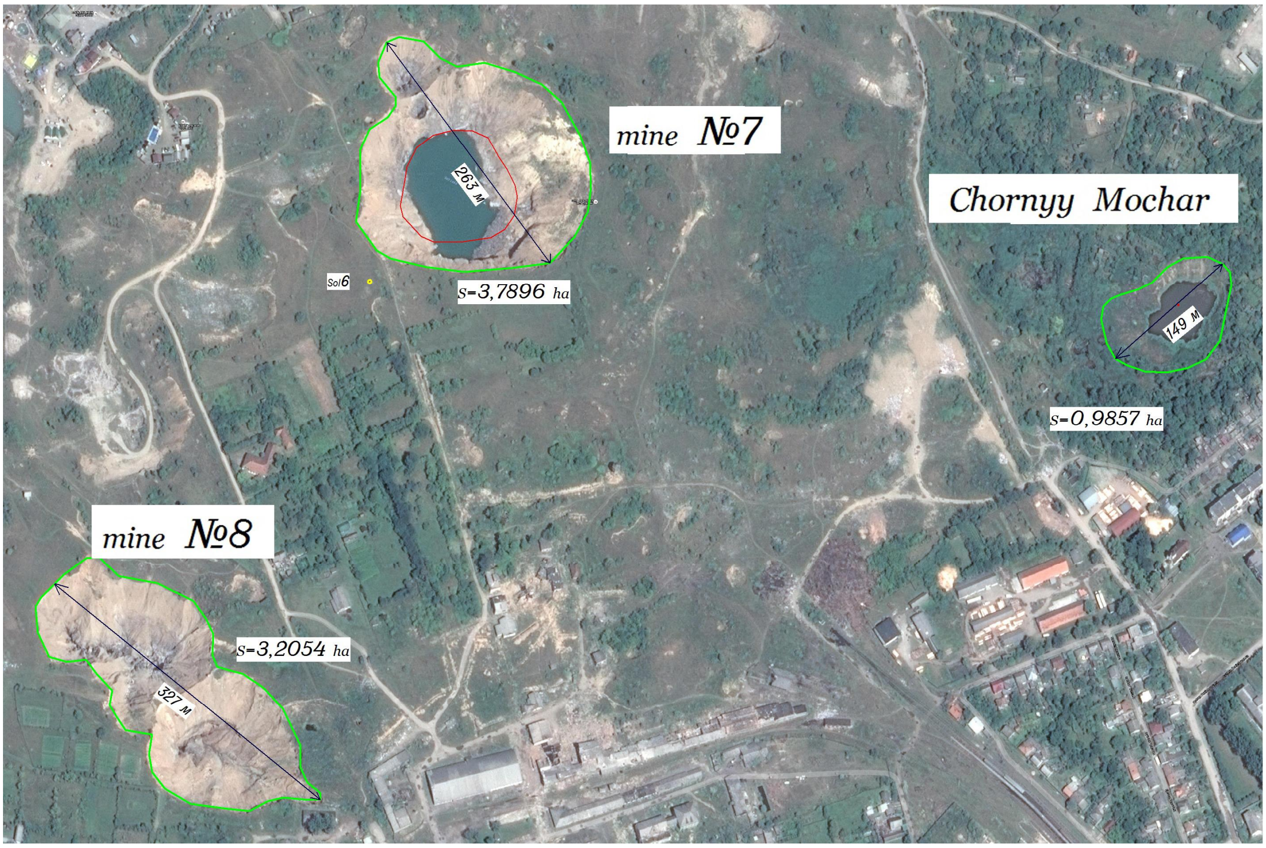

Fig. 6. Karstomonitoring (satellite images 2016)

Fig. 7. Karst monitoring (materials of topographic survey of 2018 from the archive of SE "Transcarpathian Geodesy Center")

Fig. 8. Monitoring of landslide processes in the village of Bila Tserkva (aerial photography in 2005 on the left and 2011 on the right) [Technical report, 2010]

Fig. 9. Monitoring of landslide processes on the territory of Dilove village (aerial photography in 2011)

Research results

Digital aerial photography is an extremely effective tool for the study of geodynamic processes. Its correct application ensures the objectivity and reliability of the results of work; increases accuracy; makes it possible to obtain such information that cannot be obtained by other methods (or can be obtained only at the expense of much more money and time); ultimately increases the economic efficiency of work. In this regard, aerial work is increasingly used in almost all types of geodynamic research, and work carried out without their use can not be considered complete.

Compared to manned aircraft, UAVs have: better accessibility, ease of use, lower costs for equipment and operations, high mobility and efficient data collection, processing and updating.

However, the use of UAVs for monitoring is often limited by accuracy requirements [Stupar et al., 2020].

Therefore, the advantage of the UAV is the ability to obtain large datasets, as well as by-products such as DEMs and, of course, to avoid the presence of a person near dangerous surveillance areas.

To determine the dynamics of landslides, karst digital aerial survey must be repeated several times at certain intervals.

Thus, in the study areas, aerial survey work was carried out in two stages: in spring 2020 and autumn 2021. Based on the results of the aerial survey, orthophotomaps and digital elevation models were created to predict karsts and displacements. Digital aerial photography was carried out in accordance with the requirements of regulatory documents [Requirements, 2014, Instructions, 1998, Instructions, 2000, Information classifier, 2010, Basic provisions, 1994, Symbols, 2000].

At the first stage, the survey was carried out using an unmanned aerial vehicle – Tarot 680PRO Hexacopter [Tarot 680 PRO, 2020].

– camera sensor Sony A 6000; 24.3 MP. The division in the matrix is 6000×4000 pixels. F lens = =16 mm. Frame size 294 m×195 m;

– Digital airborne scale is 1:7000;

– resolution of aerial photographs 5 cm on the ground;

– Digital aerial photography was carried out from a height of 110 m;

– longitudinal overlap is 70 %, while transverse is 60 %;

– Orthomosaic was obtained with a resolution of 2.68 cm/px.

At the second stage, aerial photography was carried out using an unmanned aerial vehicle – Autel EVO II Pro RTK [Autel EVO II Pro RTK, 2021]

– Camera sensor 1' Autel Robotics XT705; 20.0 MP. The division in the matrix is 5472×3648 pixels. F lens = 11 mm;

– digital airborne scale is 1:10000;

– the resolution of aerial photographs is 5 cm on the ground;

– Digital aerial photography was carried out from a height of 110 m;

– longitudinal overlap is 70 %, while transverse is 60 %;

– As a result of the work performed, 1614 images were obtained;

– We obtained orthophotomap with a resolution of 2.72 cm/px.

Self-calibration was performed using photogrammetric software. Initial and optimized parameters of the non-metric aerial camera are given in Table 2.

2 Table

Aerial camera self-calibration results Autel Robotics XT705

	Matrix pixel size, *μm*	Sensor size (x, y), *pixels*	*F,* mm	*C0x, pixels*	*C0y, pixels*	*R1*	*R2*	*R3*	*T1*	T2
Initial values	5472x 3648	416,667x 416,667	11	0	0	0	0	0	0	0
Calibrated values	5472x 3648	416,667x 416,667	10.6	0.026	0.022	$3.2*10^{-5}$	$1,3*10^{-5}$	$1,7*10^{-5}$	$2.1*10^{-6}$	$1.6*10^{-6}$

Volumes of digital aerial photography by objects:

Object Bila Tserkva:

– The area of the digital aerial photography is 13 ha;

– We used sparse layout of planned high-rise identification marks, which are evenly distributed over the area and perimeter of the object. In total, the coordinates of 7 identification marks were determined.

Solotvyno object:

– The area of the digital aerial photography is 200 ha;

– The survey was made from three flight projects of 25 minutes each;

– We applied sparse layout of planned high-rise identification marks which are placed evenly over the area and perimeter of the facility. In total, the coordinates of 46 identification marks were determined.

Dilove object:

– The area of the digital aerial photography is 16 ha;

– A sparse layout of planned high-rise identification marks was applied. They were placed evenly over the area and perimeter of the object. In total, the coordinates of 7 identification marks were determined.

Contour points were selected for identification marks. They are recognized on an aerial photograph of the area with an accuracy of at least 0.1 mm on the scale of the plan being created [Instruction, 1998, Basic provisions, 1994]. The points of the survey network were fixed on the ground by centers that ensured their safety during the shooting – a pin, a tube, a dowel, a railway bone, a wooden stake or clearly marked objects of the situation, etc.

When the points of preliminary work were included in the network, the previously assigned numbers were stored for them.

Mathematical processing of geodetic GPS measurements was performed using the Trimble Geomatics Office software with lines brought to sea level and reduced to the Gauss-Kruger projection plane.

The accuracy of the created surveying GPS network meets the requirements of current regulatory technical documents [Instruction, 1998, Instruction, 2000]. The marginal errors in relation to the points of the state geodetic network and geodetic thickening networks do not exceed 0.2 mm in open areas and built-up areas on the scale of the plan being created and 0.3 mm in places covered with trees or shrubs.

Photogrammetric and stereotopographic works

Photogrammetric thickening was performed after obtaining the aerial photographs and the results of the aerial photograph vertical reference.

Photogrammetric work was conducted using Agisoft Photoscan. The initial data for the work performance were the planning and altitude preparation materials of aerial photographs – the coordinates and marks of the planning and altitude identification marks.

Photogrammetric work consisted in determining the internal and external orientation elements of stereopairs relative to a given coordinate system for each pixel of aerial photographs.

Aerial photographs have been hue and color corrected to achieve RGB colors as close as possible to real ones on the ground.

After photogrammetric processing, the quality control of the obtained results was carried out and digital elevation models were created using DEM and TIN methods.

To determine the accuracy of the planned and height coordinates of terrain points using opto-electronic cameras, [Burshtynska, 2020] was used:

$$m_{x,y} = (H / f) * P_m \ , \qquad (1)$$

$$m_h = (H / B) * P_m \ , \qquad (2)$$

where H – height; f – focal length of the camera; P_m – pixel size on the terrain; B – survey basis.

The accuracy of determining the planned coordinates is calculated according to (1)

$$m_x = m_y = 0.0055 \times (110/11) = 0.055 \text{ m} = 5{,}5 \text{ cm}$$

Image overlap selected 70 %. Then the basis in the image is:

$$\text{b} = 13{,}3 \times (100 - 70)/100 = 3{,}99 \text{ mm}.$$

The error in determining elevations for the selected basis (2) is:

$$\text{m}_\text{h} = 110/3.99 \times 0.0055 = 0.15 \text{ m}.$$

Creation of digital orthophotos

Orthophotomaps on a scale of 1:1.000 were made from raster images of aerial photographs, taking into account the created digital elevation model. The digital elevation model was developed by determining the marks of the regular grid nodes in stereo mode with a step of 10.0 m. The heights of its nodes were determined in the interactive stereo mode. At the second stage, in manual stereo mode, breaklines were built in places with a sharp difference in heights (retaining walls, slopes, ravines, etc.) and in characteristic places with complex relief forms, where the density of a regular grid of 10.0 meters is insufficient.

When transforming, the central parts of the images were used, since they have the smallest perspective distortion and error for the relief. Mosaic of all orthophotomap fragments was made using the Agisoft Photoscan program. The accuracy of the created orthophotomaps was checked by control points and "stitching" lines of the orthophotomap parts. The control point coordinates were determined when performing a horizontal-altitude reference using a Trimble R8 GPS receiver in RTK mode from the ZAkPOS network of base stations.

The accuracy of snapping to control points is:

$$m_x = 4.4 \text{ cm} \quad m_y = 3.4 \text{ cm} \quad m_h = 0.135 \text{ m}.$$

In addition, points of the existing geodetic network were used to control the accuracy of orthophotoplans.

As a result of aerial surveying of the UAV, orthophotos were obtained at the Solotvyno, Dilove and Bila Tserkva sites. 3D karst schemes and topographic plans at a scale of 1: 500 were created. The results are presented in Figs. 10–18.

Scientific novelty and practical significance

There was a need for monitoring work as a result of the importance to update information on the state of modern karst formations and sites with exogenous processes in Solotvyno and Bila Tserkva, Tyachiv district and the village Dilove, Rakhiv district, Transcarpathian region.

The study developed and tested the technology of topographic and geodetic works using UAV and GPS measurements in mountainous areas.

The results of aerial photography were used to visualize the objects of study and report information about the deformation processes to local governments. The development of individual approaches when using UAVs is required for natural or technogenic processes (displacements, karsts). Such monitoring studies bring a new level of study of the natural environment. In addition, the scientific value of the obtained materials will increase every year. A data bank is formed with the massive use of UAV surveys. This cannot be obtained applying other methods.

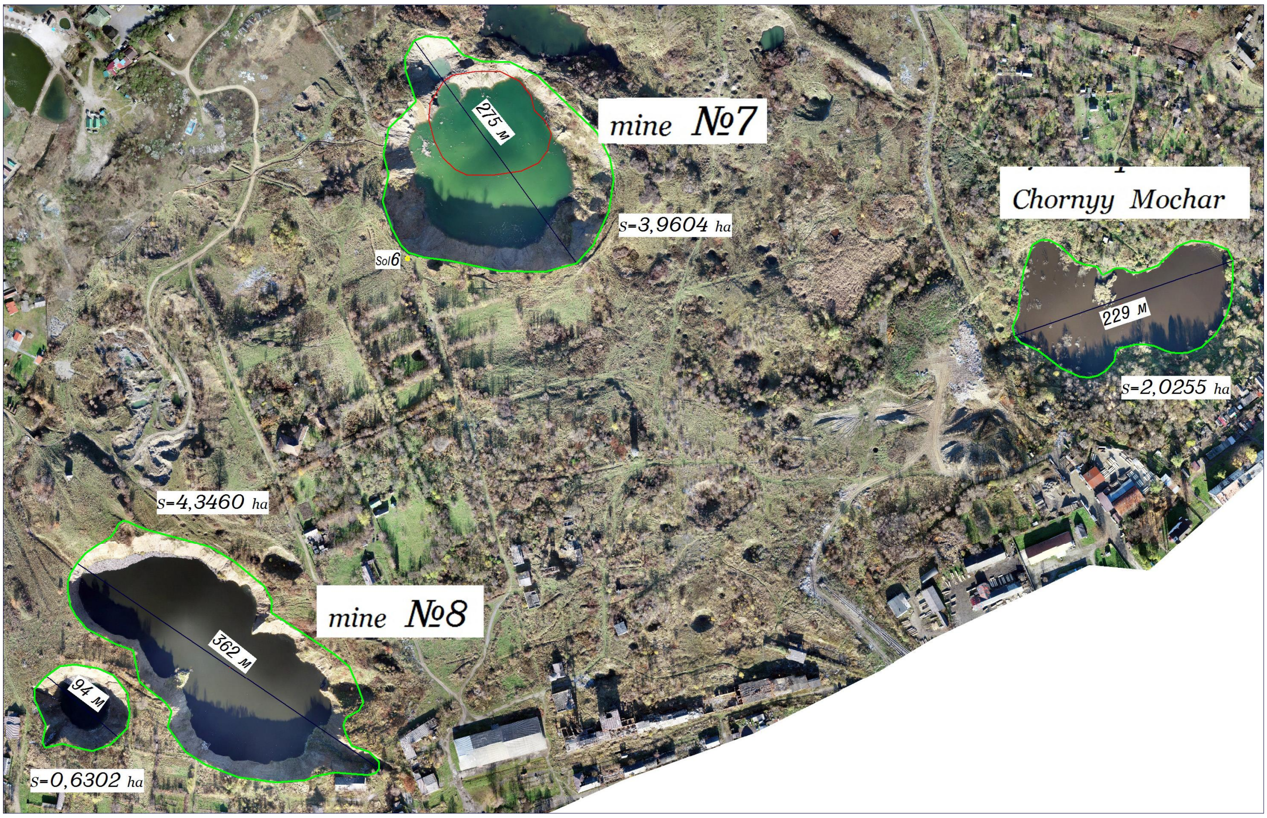

Fig. 10. Monitoring of displacements at the Solotvyno facility (aerial photography materials 2020)

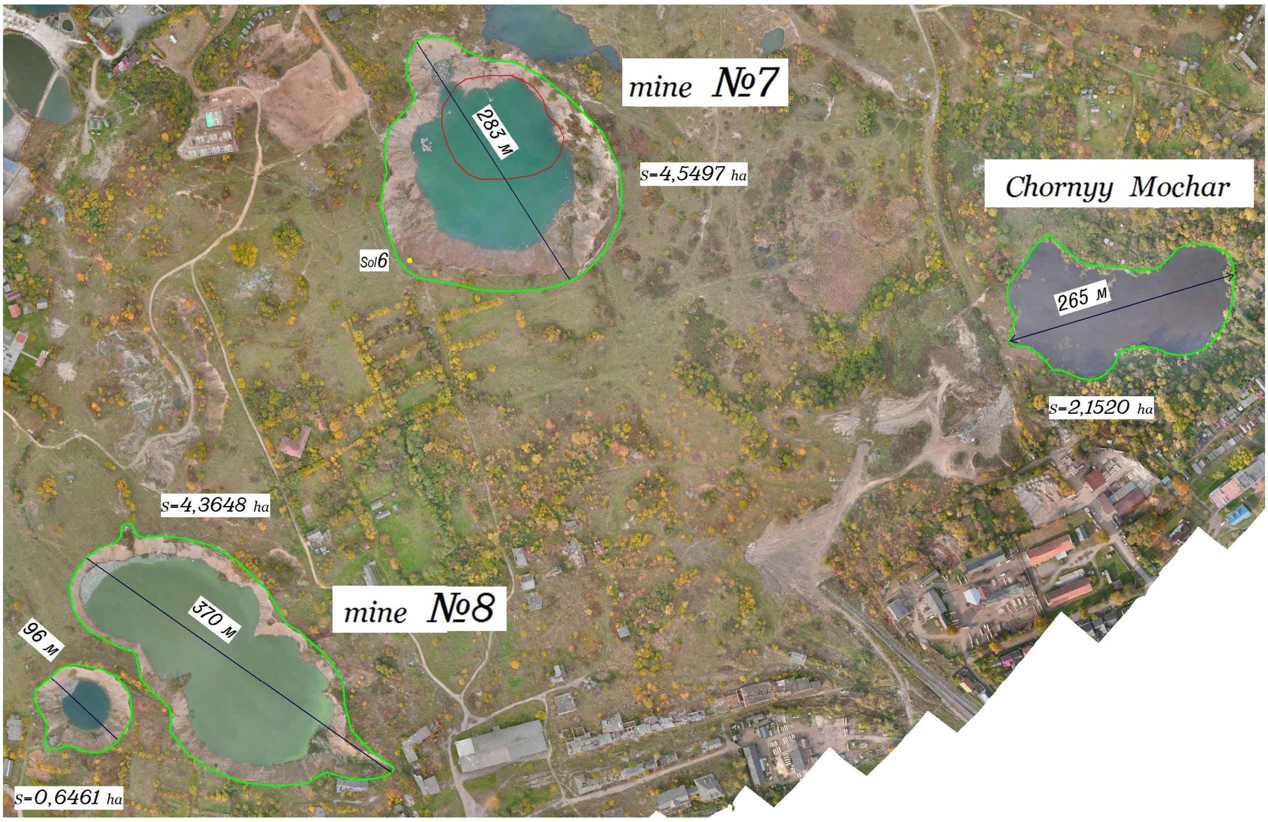

Fig. 11. Monitoring of displacements at the Solotvyno facility (aerial photography materials 2021)

Fig. 12. 3D karst scheme. Karst 1: mine No. 7

Fig. 13. 3D karst scheme. Karst 2: Chornyy Mochar

Fig. 14. 3D karst scheme. Karst 3: mine No. 8

Fig. 15. Deformation monitoring (aerial photography 2020–2021) Bila Tserkva

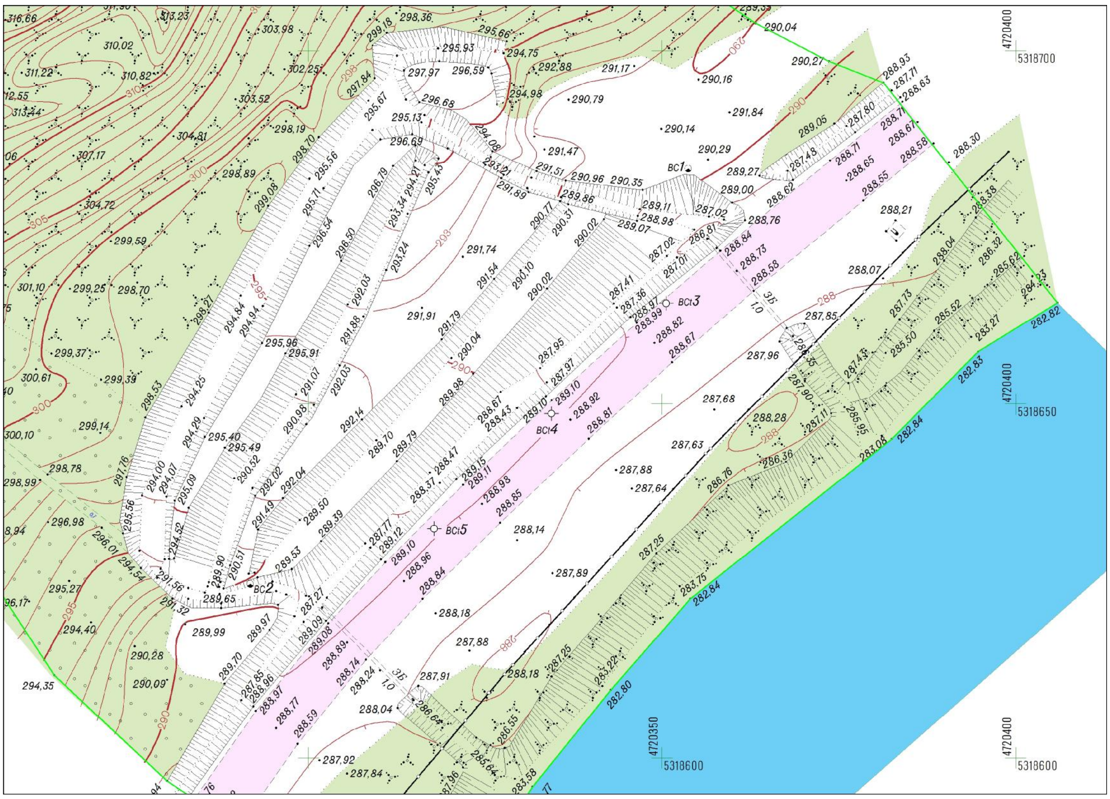

Fig. 16. Topographic survey 1:500 Bila Tserkva

Fig. 17. Deformation monitoring (aerial photography 2020–2021) Dilove

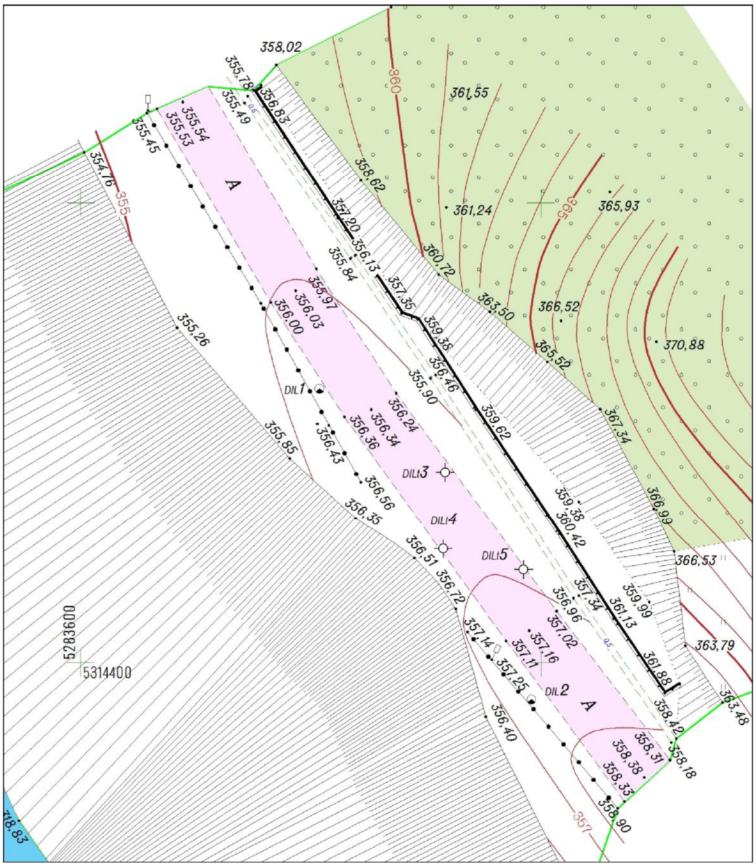

Fig. 18. Topographic survey 1:500 Dilove

The practical significance of the results obtained lies in proving the possibility of creating a homogeneous planned and high-altitude base according to satellite measurements and relevant modifications of modern models in a single state coordinate system; creating methods for the complex determination of movements in exogenous and technogenic areas of the terrain in mountainous areas, using the latest technologies.

As a result, a new high-precision wireframe geodetic network was created on the territory of the Solotvyno, Bila Tserkva and Dilove sites using GPS and digital aerial photography.

Conclusions

As a result of the geodetic studies carried out in landslide areas and in karst areas, the following results were obtained:

The analysis of cartographic materials and digital aerial photography materials in the period 1995–2018 established the geodynamic processes of mines No. 7, 8, located in the village Solotvyno.

Modern digital orthophotomaps and topographic plans at a scale of 1:500 with a relief section of 25 cm were obtained with the help of aerial surveys, using UAVs.

The presented data indicate the current critical and catastrophic state of the geological environment within the Solotvyno rock salt deposit, which is primarily due to the intensive development of salt karst in recent years.

At the Bila Tserkva and Dilove sites, the displacements are insignificant. Work is underway to stabilize the landslides.

In the future, high-precision leveling will be carried out within the study areas, which confirms the results obtained. Research will be presented in the next publication.

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МОНІТОРИНГ ГЕОДИНАМІЧНИХ ПРОЦЕСІВ У БАСЕЙНІ РІЧКИ ТИСА ЗА ДОПОМОГОЮ ЦИФРОВОГО АЕРОЗНІМАННЯ ІЗ ЗАСТОСУВАННЯМ БПЛА AUTEL EVO II PRO RTK

Мета. Ця стаття присвячена дослідженню геодинамічних процесів в басейні річки Тиса в межах Закарпатської області з аналізом геодезичних спостережень, отриманих за останнє десятиліття. Методика. Карстомоніторинг було розпочато із виявлення найнебезпечніших ділянок земної поверхні, які піддаються вертикальним зміщенням. Після виявлення найбільш небезпечних ділянок для попередження можливих аварій був проведений локальний геодезичний моніторинг на об'єктах в межах смт. Солотвино, с. Ділове та с. Біла Церква. Для відпрацювання методики виявлення змін ландшафтів та форм рельєфу під впливом геодинамічних процесів використано також колекцію архівного аерофотознімання. Результати. Для знімання карстів використовувались БПЛА. На основі даних цифрового аерознімання створено: ортофотоплани і цифрові моделі рельєфу для прогнозування карстів та зміщень. Цифрове аерознімання виконувалось відповідно до вимог нормативних документів. Перевагою аерознімання є можливість отримати додаткову інформацію про положення річкових русел, зміни в рослинному покриві, активізацію ерозійних процесів. Для визначення динаміки зсувів, карсту цифрове аерознімання необхідно повторити кілька разів через певні інтервали. Аерознімальні роботи виконано у два етапи у 2020 та 2021 р. Для розпізнавальних знаків вибирались контурні точки, які розпізнаються на цифровому аерознімку і місцевості з точністю не менше 0,1 мм у масштабі створюваного плану. Математичну обробку геодезичних GPS-вимірювань виконано за допомогою програмного забезпечення Trimble Geomatics Office з приведенням ліній на рівень моря і редукуванням на площину проекції Гаусса-Крюгера. Після фотограмметричної обробки виконано контроль якості отриманих результатів та створено цифрові моделі рельєфу прийомами DEM та TIN. Ортофотоплани в масштабі 1:1000 виготовлені за растровими зображеннями аерознімків з урахуванням створеної цифрової моделі рельєфу. Для оновлення інформації про стан сучасних карстоутворень та ділянок з екзогенними процесами в Солотвино та Біла Церква Тячівського району та с. Ділове Рахівського району Закарпатської області виникла необхідність у проведенні моніторингових робіт. Розроблено та апробовано технологію топографо-геодезичних робіт із застосуванням БПЛА і GPS-вимірювань в гірських районах. Результати аерознімання використані з метою візуалізації об'єктів дослідження та донесенні

інформації про деформаційні процеси до органів місцевого самоврядування. Для процесів природного чи техногенного характеру (зміщення, зсуви, карсти) потрібна розробка індивідуальних підходів при використанні БПЛА. Подібні моніторингові дослідження виводять на новий рівень вивчення природного середовища і з кожним роком підвищуватимуть наукову цінність отриманих матеріалів. При масовому використанні знімань з БПЛА формується банк даних, який неможливо отримати іншими методами. Створено методику комплексного визначення рухів на екзогенних та техногенних ділянках місцевості в гірських районах з використанням новітніх технологій, що дає можливість оперативного створення планово-висотної основи необхідної точності у референцній системі координат при розв'язанні низки задач прикладної геодезії з використанням супутникових технологій і БПЛА для спостереженнями за об'єктами.

Ключові слова: цифрова фотограмметрія, цифрові моделі поверхні, моніторинг деформацій земної поверхні, безпілотний літальний апарат, ортофотоплан.

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