OPTIMIZATION OF THE LOCATION OF OBSERVATION NETWORK POINTS IN OPEN-PIT MINING'S

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Abstract

The article discusses the use of "Open Source" software Quantum GIS (QGIS) to search for the optimal location of observation network points in open-pit mines. The exploitation time of open-pit mines is ranges from a few to several years. Interference in the geological structure causes significant degradation of the surrounding terrain. Monitoring the risks associated with the mining areas requires a properly designed measurement networks. The network geometry should ensure its stability, accuracy and the ability to study changes in the excavation even after its closure. The network design is a compromise solution that takes into account the accuracy requirements and off-road capabilities. Point location optimization supports software for spatial analysis. The purpose of the software is to use raster and vector queries in a specific scope. Data in the form of Digital Terrain Model and existing public databases allow efficient selection of a network location for large mining areas. Conducting the analysis requires current data of the studied area. Currently, a standard data collection tool is GNSS technology and Unmanned Aircraft Systems UAS. Current data and GIS software can be gradually used in Poland for open-pit mines require monitoring.

Key words: GIS, open-pit mines, observation networks, spatial analyzes.

Introduction

Geographic information systems (GIS) are systems that connect geographic databases, computer hardware and software together with their creators and users. The data in the database are identified according to their position. Computer hardware allows you to collect and store them, and the software allows you to sort and display them (BLIŠŤAN, 2003). In relation to GIS systems, we often find detailed information about land information systems (LIS) and building information systems, as well as other management systems. They group particular issues in relation to large-scale maps using the full range of GIS topics (FELTYKOWSKI, 2013).

The basic interpretation of the GIS abbreviation is software allowing the presentation of specific information in a digital form in relation to their spatial position. The mentioned characteristics result from the initial definition of geographic information systems referring only to the software component. The development of information systems in the last decade of the twentieth century has extended the definition of including a single user in the group of other users performing spatial analysis operations. Information systems relate not only to the phenomena studied but also to the quality and the manner of receiving the obtained results (GSDI Assosiation, 2012).

Free and Open Source Software (FOSS) is made available on licenses without many restrictions. It allows free use for scientific, didactic and commercial purposes. The software can be disseminated, and the obtained results and studies used for profit. Quantum GIS (QGIS) is one such program. It belongs to the most popular software for spatial information systems under the "Open Source" license. Thanks to its simplicity and successive updates, it gains more and more popularity and allows free and commercial analyzes (SZCZEPANEK, 2012).

This study focuses on the use of free and open software for spatial analysis in order to optimize the location of observation network points in open-pit mining's. Digital terrain model (DTM) created on the basis of aerial photographs taken unmanned aerial vehicles (UAV). DEM was used to conduct spatial queries and analyzes in the Quantum GIS program. The obtained results allow the selection of optimal observation sites of measurement networks in order to monitor the impact of open-cast mines on the surrounding environment.

Spatial Information systems

Geographic information systems (GIS) or spatial information systems (SIS) are systems used to acquire, store, process and share information gathered in geographic databases. Computer systems, software together with the creators and users create a unique combination allowing the creation of spatial analyzes (LITWIN, MYRDA, 2005).

Databases contain information in relation to their geographical location. The details of the data depend on the size of the analyzed area. The accuracy of the data for a small area of the commune or open-pit mine will be much larger than the data for the whole country. The data is generalized due to the area. The simplification of the model must correspond to the objective of the analysis. Geographical data in GIS systems can be obtained in two ways. Based on existing paper documents subject to digitization or direct field measurements. The information in the database has the character of descriptive and spatial attributes. Descriptive attributes describe relationships between objects and store non-spatial data, and spatial attributes determine the location and geometry of the analyzed objects (BLIŠŤAN, 2003; LONGLEY et al, 2008).

The aim of systematizing data collected information is compiled into thematic layers. Their range covers the same area but applies to different descriptive attributes. The data is presented in a vector or raster form. The GIS software allows users to spatial query to the collected information regarding their location, dependencies between existing phenomena, their variability over time, and even to check the terrain conditions for their occurrence.

Quantum GIS Software

The concept of free and open source software (FOSS) refers to two aspects: the software model and the model of its creation. FOSS is devoid of many restrictions, and its openness concerns the possibility of free use. The license allows the use of software for scientific, educational and commercial use. Software can be distributed, and the results and studies used for commercial purposes. Free GIS software includes: Quantum GIS (QGIS), GRASS, SAGA GIS, ILWIS, etc. (SZCZEPANEK, 2012).

Among the listed programs, Quantum GIS (QGIS) deserves special attention. It is one of the most popular geographic information systems software licensed under the "Open Source" license and has a global reach. The program is built by programmers, translators and users from around the world. The last group, testing the capabilities of the software, captures the errors and imperfections of the program. Bug reports registered in the database are only removed by programmers expecting changes. However, due to the availability of the code, each user can add changes. The basic operating system for QGIS is the Linux system, which is why the software testing in Windows is so ineffective (GSDI Assosiation, 2012; SZCZEPANEK, 2012).

Quantum GIS allows you to read, analyze and save vector and raster data in many formats. Additional software plugins extend the base of program functions. Initially, the program was oriented to vector layers, but the availability of raster data forced programmers to introduce advanced functions for their analysis. Thanks to its simplicity and successive updates, it gains more and more popularity and allows free and commercial analyzes.

Classic functions of spatial data analysis can be used to carry out queries regarding the selection of the location of observation network points for monitoring inactive open-pit mines. QGIS enables data import, pre-processing, analysis and visualization of results in the form of a map. Attention is drawn to the WFS service that allows you to track changes and edit the attributes of geographic and descriptive data.

Open-pit mining's – "Zgórsko" stone-pit

There are thousands of open-pit mining's in Poland due to the numerous needs of construction and road construction. Many of them exist in the form of inactive objects that require monitoring to observe their negative impact. The end of exploitation does not end the harmful impact on the surrounding environment. Opencast mines are usually deprived of buildings within their impact, but their impact on the terrain and surrounding environment is one of the main problems of the harmful effects of exploitation. Exploitation of opencast mines is short and usually only a few years. After the completion of mining works, the most often negative effects of the devastation of the land cease, but require cyclical observations (FRĄCKIEWICZ et al, 2018).

The basic negative effects of open-cast mines include changes in the relief, violation of the geological structure of the rocks and changes in their properties and changes in water conditions. Most often after the end of exploitation, the changes stabilize and do not cause additional negative impact under the condition of restoring the original or other terrain function – land reclamation. In other cases, for example, atmospheric conditions may cause further changes in the geological structure, eventually leading to the displacement of rock masses. Disturbance of the existing balance of stresses in the rock mass can lead to sudden and unpredictable effects (DUMA et al, 2016).

In the case of surface mines, the most common changes are continuous and discontinuous deformations. Continuous deformations are horizontal or vertical deformations and curvature. The occurring deformations are most often associated with the relaxation of the rock mass and the formation of deformations towards the operational cavity. Discontinuous deformations are most often caused by discontinuities in the structure of rocks. Cracks and fissures in open-pit mines are usually caused by the technological process of extraction, but they can also occur as a result of water migration, atmospheric conditions and structure disturbance by occurring woody vegetation (DUMA et al, 2016; Ordinance, 2015).

An example of an opencast mining facility is the closed Devonian limestone mine – the Zgórsko stone-pit. The object is located in the Świętokrzyskie Voivodeship in the area of Sitkówka-Nowiny commune about 10 km from Kielce (Fig.1). Exploitation began in 1928 on the initiative of the Goldferb brothers. Originally, extraction was carried out manually in a shift system, and after the Second World War the exploitation was carried out mechanically. Initially, the mineral products was used as stone breakstone, and only later on for lime and cement purposes. From 1966 to 1990, the extracted raw material was used by cement-lime facility in Nowiny. In 1990, the extraction was completed and the facility was flooded with water to a depth of 5 meters. The facility rented the "Nowiny" Fishing Society with fish farming. Currently, due to the lack of tightness of the rock mass and evaporation, the water level has dropped significantly. Currently, the facility is used for recreational and tourist purposes. The geological structure and exploitation led to the occurrence of large loose rock blocks, which are a danger (Fig.2). Stone-pit monitoring is therefore necessary.

Fig. 1. The geographical position of the area. *Source: Own study*

Fig. 2. "Zgórsko" – stone-pit. *Source: Own study*

Measurement networks in the open-pit mine

The basic document characterizing the measurement networks in mining plants is the Ordinance of the Minister of the Environment of 28 October 2015 on the survey-geological documentation. The regulation regulates, among other things, the requirements for conducting surveying work: the establishment the measurement network, guidance and accuracy of measurements.

The assumption of a suitable measuring network depends on the type and accuracy of controlled deformation indices. The assessment of deformation indices is carried out using statistical or geostatistical methods to further forecast the occurrence of phenomena. The study of indicators: vertical and horizontal displacement fields, tilt, horizontal deformations and curvatures is based on the results of geodetic works. Modern geodetic instruments allow to determine measurement networks with very high accuracy of a few millimeters. Post-mining deformations cause displacements of points many times exceeding the accuracy with which they were determined. Therefore, the Regulation on geological survey documentation allows for geodetic basic networks in the mine area the average position error $m_p \leq 0.15$ m and the average azimuth error of the sides $m_A \leq 45^{cc}$. The basic measurement network in mining areas should be stabilized permanently and referred to the basic geodetic control network located outside the area of interactions. The horizontal detailed network should have an average position error $m_p \leq 0.30$ m and mean side azimuth error $m_A \leq 100^{cc}$. If possible, it should be stabilized permanently and together with the basic network it should be the basis for establishing the measurement network for the duration of operation or soon after completion. The average position error of the measuring center should not exceed $m_p \leq 0.50$ m and the mean side azimuth error $m_A \leq 500^{cc}$ (POPIOŁEK, 2009; SZPETKOWSKI, 1966).

The presented accuracy proves that in the case of exploration of mining areas more important are other aspects than the millimeter error of the location of the point. In order to forecast and monitor the mine, it is necessary to establish measuring bases – geodetic observation lines, which are characterized by stability and mutual visibility of points, and the distance between particular points of the line should be equal or similar.

Direct and indirect methods for planning the measurement network

The selection of the optimal location of the network in the areas of open-cast mines can be carried out directly in the field by searching for suitable places or indirectly selecting places (areas) using software for spatial analysis. The first method is effective in the case of small areas affected by the negative impact of the mining area. For extensive mining areas, the search for an optimal location can take a long time due to the required conditions for the mutual visibility of points and the length of the bases. The software supports the decision-making process provided it works on current geographic data.

Unmanned aircraft systems (UAS) currently belong to the basic instruments used in geodesy. UAS devices are equipped with scanning media – cameras and video cameras placed on stabilizers to ensure stability and high-quality images (BLIŠŤAN et al, 2018).

For the existing *Zgórsko* stone-pit, 25 evenly distributed fotopoints were established. The coordinates were determined using GNSS technology using the TOPCON GRS-1 receiver (Fig. 3a). A raid was carried out the DJI Phantom 3 drone (Fig. 3b). Three air raids were carried out – each for 15 minutes. A total of 297 aerial photographs were obtained.

Digital Terrain Model was developed in the area Agisoft PhotoScan. The acquired photos were leveled and a dense point cloud was created. Then the netting and texturing of the model was made. The obtained model faithfully mapped the stone-pit area.

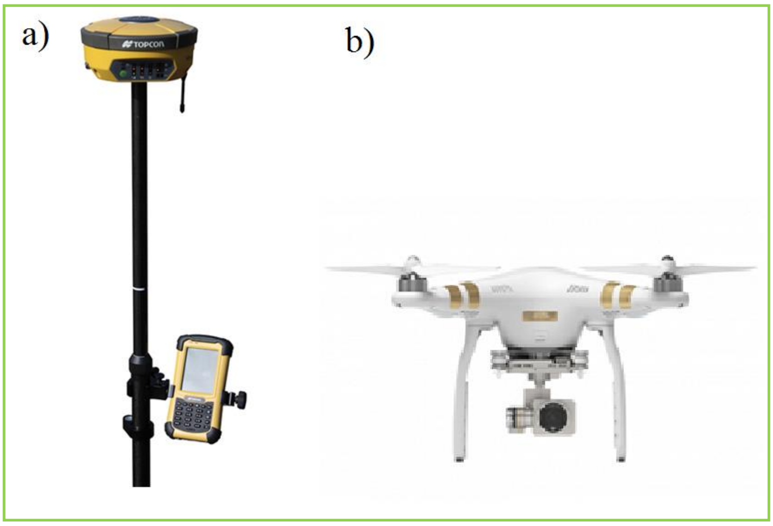

Fig. 3. DJI Phantom 3. *Source: Own study*

Spatial analyzes

The first stage of spatial analysis in order to search for the optimal location of the observation network points should be precise determination of the assumptions that must be met by the points sought (areas). In the case of open-pit mines, the basic assumption is the mutual visibility of network points. The formation of the mining area, the technological process and the mode of transport must not prevent observation of the mine.

The second criterion for selecting the location of points is their even distribution – the lengths of the individual sides of the network should be equal or close to each other. Points should be stabilized to the maximum outside the area of extraction while allowing observation of each part of the object. In addition, they should be separated from internal roads used for transport, so that they are free from the impact of vibrations associated with it. The high position of the points boils down to stabilizing them on flat surfaces, i.e. with a slight tilt – maximum 10 degrees.

Among publicly available data to optimize the selection of the network location, you can exchange the GIS database – hydrographic map. The database contains information on the aquifer and its depth. The variability of the water conditions destabilizes the location of the point, in particular its height, in time. The available information allows you to exclude or minimize the areas of effective location of points.

The generated Digital Terrain Model and the database – the hydrographic map of WMS in the QGIS program – were used for the needs of the works carried out. The study was carried out in the QGIS program using the following tools: raster calculator, polygonization of raster per vector, buffer around green objects and determination of areas with a decrease less than 10 degrees. Subsequently, areas whose decrease does not exceed a certain slope were selected. The areas related to the green zones buffer were subtracted from the obtained fragment in order to maintain the mutual visibility of the points. The whole was controlled with the WMS orthophotomap and aerial photographs.

Interpretation of results

Among the potential areas, 15 areas with the most regular shape for the location of the observation network points were selected using the field calculator and the attribute-specific area queries. The acquired data was compiled with a hydrographic map. None of the selected areas in the upper part of the quarry coincided with aquifers. In the lower part, the program chose two areas. One of them lies 100% on the water surface, and the other one is on the headland that leads above the water surface.

In order to verify the areas under the map was read in the form of an orthophotomap from the site geoportal.gov.pl. The analysis of the map foundation was based mainly on the exclusion of the location of points on communication routes and places covered with vegetation. In the case of larger objects, it would be more efficient to use the vector layer containing internal roads and update the layer of green areas to the current range. Out of 15 areas created as a result of analyzes in QGIS, 11 were selected and the points of the observation network for monitoring the area of the open cast mine were initially located. The result of the work is presented in Fig. 4. The image contains orthophotomap, designated areas using spatial analysis and 11 network points. The points were evenly distributed, as shown in Figure 5 containing the distances between selected points.

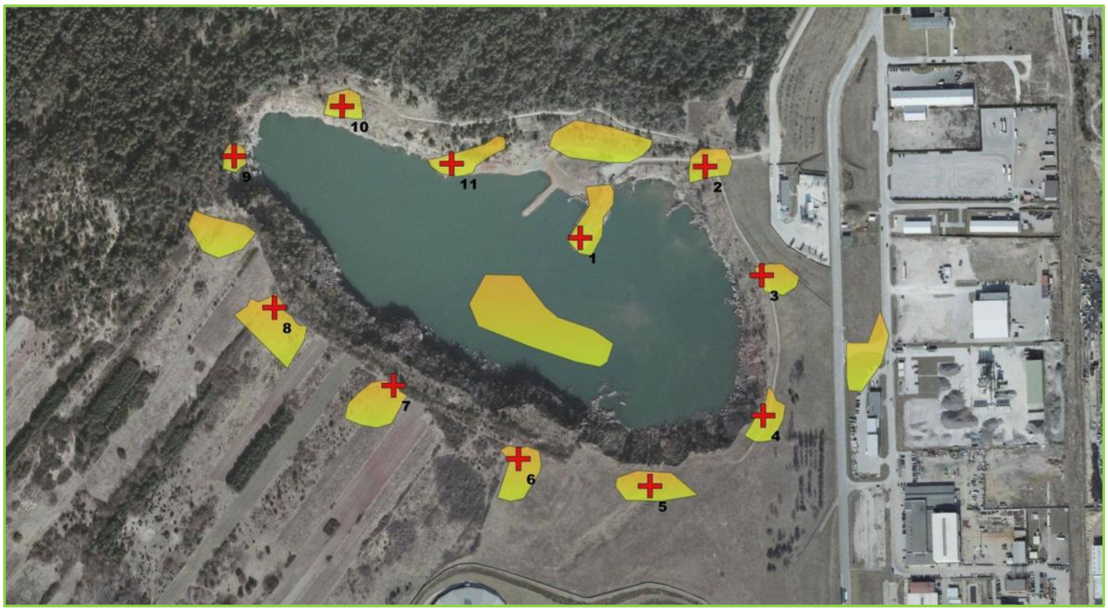

Fig. 4. Selected areas from spatial analysis of QGIS and 11 selected points of the network. *Source: Own study*

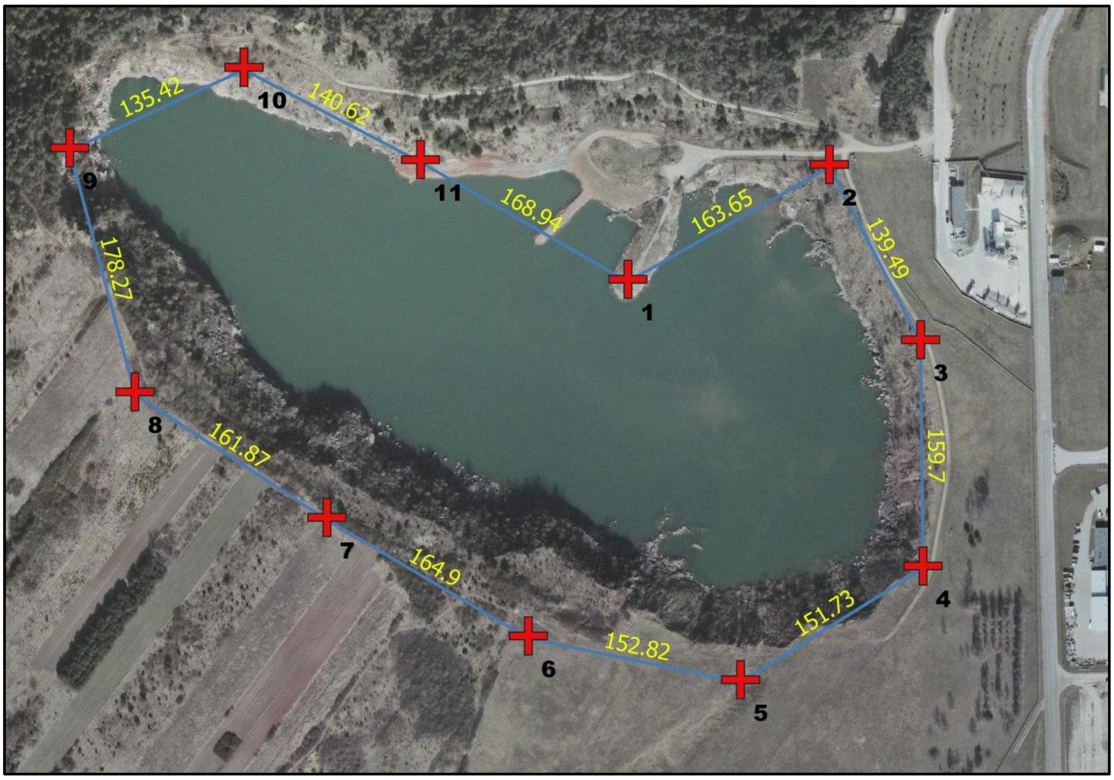

Fig. 5. Location of the measuring network points. *Source: Own study*

To ensure the consistency of the network, it is necessary to link to additional points. In the case of the *Zgórsko* stone-pit, 4 locations have been selected to control the constancy of the network. The distribution of points (I-IV) and sample link is included in Figure 6. The location and method of stabilizing points I, II, II and IV should ensure their durability in time and the possibility of using them for measurement at any time.

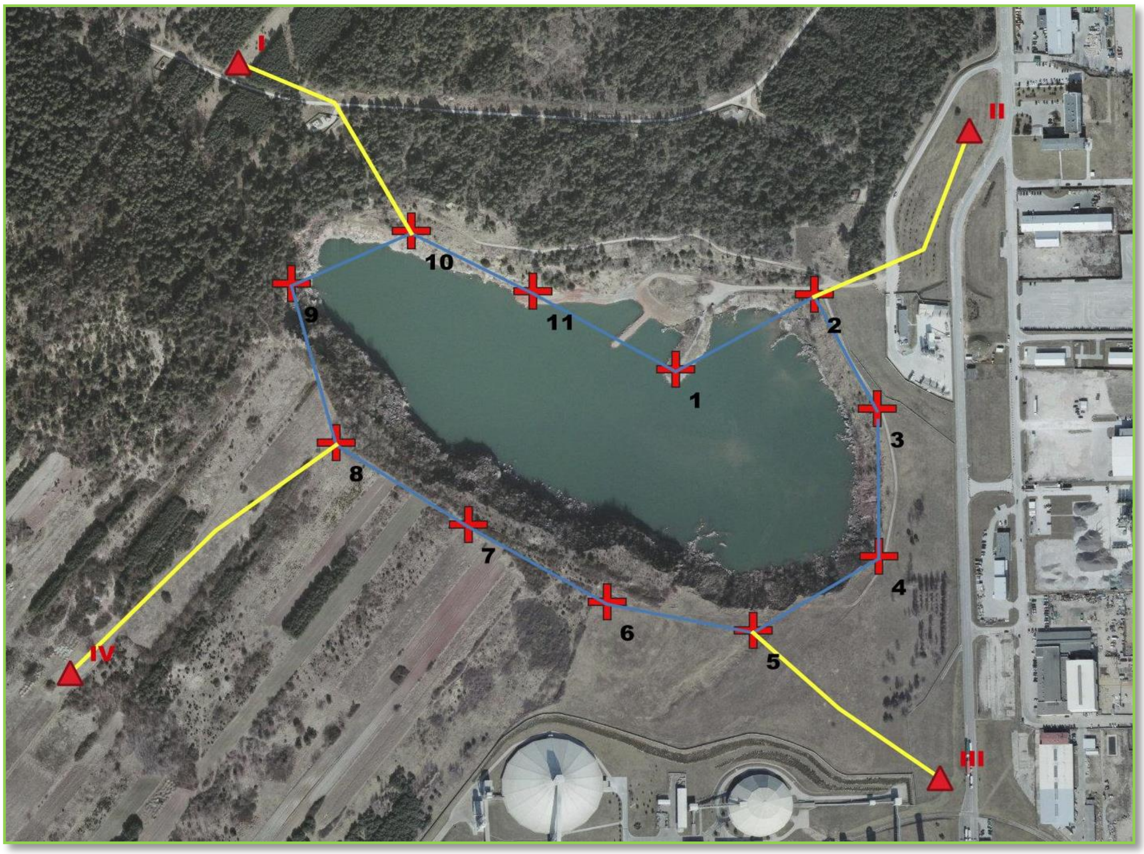

Fig. 6. Connection of the measuring network. *Source: Own study*

Conclusions

The exploitation period of open-pit mines is usually a few or a dozen years. Interference in the geological structure and degradation of the surrounding area is significant, and after the extraction is completed, the area is usually not reclamation. Affecting negative atmospheric factors, surrounding the tree vegetation and disturbing the continuity of the rock structure leads to the formation of many cracks and leaks, as well as the chipping of rock material. These changes can lead to a threat to human life in unprotected areas and are accessible to every human being. A properly stable and correctly geometrically constructed network supports the assessment of changes in the area.

The main task of geodesy is to monitor and forecast areas of potential threats. Efficiency and optimality of observation begins at the stage of designing and selection of the location of the measurement network points. The aim of the work was to select the most optimal areas for the location of observation stations using free and open sources Quantum GIS software. The results of spatial analyzes carried out indicate that the use of program algorithms greatly facilitates the initial selection of location areas for points.

Conducting the analysis requires current data of the studied area. The basis for conducting spatial analyzes of open-pit mines is the Digital Terrain Model. UAS unmanned aerial systems and GNSS technology have become the standard geodesy tool for its development. Public databases supplement spatial information to clarify the network's assumptions.

Optimal network design allows observation of the mine, 3D modeling using laser scanning and statistical and geostatistical development of the obtained results based on very precise data. Indicating potential places of change and threats of landslides in open-cast mines allows for early response and protection of the area from passing people.

The measurements carried out and the spatial analyzes carried out confirm the usefulness of the Quantum GIS application to increase the efficiency of the selection of measurement sites in the area of the Zgórsko stone-pit. The established network will be used for further work carried out as part of monitoring the post-mining area. The measurement works will be carried out cyclically at annual intervals.

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