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Specific Solution of Deformation Vector in Land Subsidence for GIS Applications to Reclaiming the Abandoned Magnesite Mine in the East of Slovakia

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Abstract

Mining activity influences on the environment belong to the most negative industrial influences. Mining subsidence on the earth surface is a result of underground mining. The present study deals with the theory of specific procedures for solving the deformation vector in the case of an objective disturbance of data homogeneity in the geodetic network structure of the monitoring station in monitoring mining subsidence. The theory was developed for the mining subsidence created on the earth surface of the mining landscape, where the abandoned magnesite mine Košice-Bankov in the East of Slovakia was operated for many decades in the twentieth century. The achieved results and outputs were implemented into the GIS tools for the plan of the process of gradual reclaiming the entire mining landscape of Košice-Bankov. The aim of the deformation measurements was to determine the exact boundaries of the subsidence edges with the residual movement zones for the purpose of comprehensive reclaiming the devastated mining landscape. Some numerical and graphical results from the deformation vectors survey in the abandoned magnesite mine Košice-Bankov are presented. The obtained results in GIS were supplied for the needs of the Municipality of the city of Košice to the realization of the reclaiming work.

Keywords: subsidence, deformation vector, geodetic network, Gauss-Markov model, test statistics, reclaiming

1. Introduction

At present, with an extremely sharp increase in people's material needs, priority must be given to their security from any economic prosperity of many countries around the world. As the extraction and processing mineral resources increase, so does the economic prosperity of the country. To protect the environment, which should be an intact ecosystem, it is necessary to protect the lives of people and their property from adverse industrial impacts. One of the most negative industrial impacts on the whole ecosystem is the adverse impact of any mining activity. The land subsidence (mining subsidence, hereinafter referred to as subsidence)

is created on the earth surface as a result of underground extraction of the mineral deposits especially at the chamber mining by a caving method [1, 2]. In many cases, the mine subsidence represents the large-scale and very deep downthrown blocks that is dangerous for any movement of people in them [1–7]. As at the deep mining there are many large voids created in the rock massif (especially during the aforementioned mining by the chamber method), their collapse occurs with the manifestations of deformations on the earth surface mostly in the form of subsidence. The collapse of these cavities can occur at different time horizons, i.e., from the commencement of mining up to several years, or even decades or more after the end of mining. Especially for endangering the lives of people and their property, the most dangerous are the sudden and unexpected formation of invasions of the earth surface over the mined rock massif, which often happens even in some abandoned mines [6, 8, 9].

In the sense of several scientific studies, as well as theoretical and practical knowledge on mining impacts on the earth surface, it is very difficult to accurately predict how long the movements in the subsidence will be in existence and when these movements will be ended [1, 2, 10–12]. Current statistics resulting from many deformation measurements in the subsidence confirm that around 60–90% of total subsidence movements occur within the first few weeks up to months after the excavation of the underground space in the rock massif. The remaining movements in the subsidence persist even after the end of mining, and at a decreasing rate these movements can last for 3–5 years and longer and in rare cases even several decades.

In order to protect the lives of people and their property, as well as the complex environment, it is essential to constantly investigate any movements in the subsidence on the earth surface even after mining has ended [2, 13, 14]. The most investigated movements in the subsidence with their prediction based on three-dimensional (3D) modeling are on coal fields [3, 5, 11, 12, 14–17].

The nature and magnitude of the subsidence on the earth surface depends mainly on tectonic and geological conditions and also on the overload of the rock massif above the excavated space. Knowing the range, i.e., localization of the edges (boundaries) of the subsidence in mining territories, may provide for more precise placement of technical barriers (fencings and warning boards) and thus help to prevent persons and animals from entering these danger zones. Geodetic methods for investigation of deformation vectors, which can be derived from the processing of some specific geodetic measurements at the monitoring stations based on these mining territories, are the priority methods for determining the extent of movement in the subsidence on the earth surface above the excavated underground space. The deformation vectors in their 3D model concept most markedly characterize any movements of the earth surface, buildings, and other civil engineering structures located in the mining territory with the occurrence of the subsidence. In many cases, 3D modeling of the deformation vectors is based on regular (periodic) monitoring of the spatial changes in suitably structured points of the geodetic network of a monitoring station located on the earth surface or on buildings and civil engineering structures. Such periodic monitoring of the spatial changes of 3D coordinates of the geodetic network points is mostly realized by the application of classical geodetic terrestrial methods (tacheometry, trigonometry, traverse surveying, leveling, etc.), which are used extensively up to now or are currently increasingly using advanced methods of the satellite technologies within the Global Navigation Satellite Systems (GNSS) based on the US Global Positioning System (GPS), Russian Global Navigation Sputnik System (GLONAS), European Galileo, and Chinese Compass (BeiDou II). At present, very specific measurement technologies such as Interferometric Synthetic Aperture Radar (InSAR), i.e., the radar surveying technology, and Light Detection and Ranging (LiDAR), i.e., the laser

surveying technology, are increasingly being applied to deformation measurements [14, 15, 18–26]. The deformation vectors are the outputs of 3D data processing from the abovementioned geodetic measurements of deformations (deformation measurements) of the earth surface or building structure objects, but several geodetic measurements are combined and thus confirmed by some physical measurements based on the measurement of stress and strain states. By their size and position in 3D space, deformation vectors can provide a global overview not only of the nature of the current state of deformation of the monitoring subsidence in the mining area, but also of the nature of the further development of these deformations with the required time predictions [1, 2, 10, 19]. At the same time, when monitoring particularly important buildings located close to the subsidence, additional geophysical measurements of stress–strain states of the rock massif must be carried out underground (in the extracted mining space). Achievement of the unstressing states in the rock massif above the extracted space can be realized in many cases by the so-called destress blasting [27, 28].

Periodically repeating measurements on parts respectively on the whole geodetic network of some monitoring stations to measure deformations of the earth surface (e.g., subsidence) or construction objects and engineering structures can sometimes be complicated for objective reasons. Most of the monitoring stations consist of a network of firmly stabilized points (geodetic network) on the surveyed earth surface or on surveyed buildings and other engineering structures. By various geodetic methods, measurements are made on these points of the geodetic network to determine their 3D positions (i.e., coordinates X , Y , and Z) in the given Cartesian coordinate system [5, 14]. During the realization of long-term (multiyear or even several decades) geodetic measurements, undesirable and unpredictable obstructions and interventions into the monitoring station and so into the geometric structure of the geodetic network may also occur. In many cases, such undesirable interventions into the structure of the geodetic network include predominantly loss or damage to points due to uncontrolled earthworks or construction work in the territory of the monitoring station. Due to such undesirable interference with the monitoring station, the geometric and data structure of the points of the geodetic network is not homogeneous during all periodic deformation measurements.

This means that the measured elements of the applied geodetic measurements at the points of the geodetic network of the monitoring station at individual time epochs are no longer identical and cannot be maintained as they were at the time of the initial (primary, i.e., zero) measured epoch. When changing the geometrical structure of the points of the geodetic network, it is no longer possible to maintain, in particular, the spatial configuration of the measuring sights between the determined points of the network. Disturbance of stability or destruction and the loss of multiple points of the geodetic network also results in a disturbance of the geometric and thus data structure of the whole network of the monitoring station. In such cases, the re-stabilization of destroyed or lost points (in particular object points) at the original or other places of the geodetic network will not help either. Nor will it help to replace the original measured variables (which are no longer measurable in the subsequent monitoring epochs due to damage of the geodetic network points) by other measured variables [1, 10, 25, 29].

In the evaluation of deformation vectors and their 3D modelling, the time factor of the gradual creation of the subsidence over the mined-out space underground plays an important role in its overall evaluation of the earth ground movements.

The possibility in improving polynomial modeling of the subsidence is conditioned by the knowledge to detect position of the so-called breakpoints, i.e., the points in the surface in which the subsidence border with a zone of breaches and bursts start to develop above the mined mineral deposit. This means that the

breakpoints determine the edges of the subsurface at which the naturally consistent coherent of the earth surface is broken and the subsidence begins to form. 3D deformation vector models help to support the location of the breakpoints [10–13, 18, 21].

2. Theory of the deformation vector specific solution

As already mentioned in the Introduction, the geometric and thus data structure of the geodetic network of the monitoring station in the subsidence may be changed by some external intervention, such as some unforeseen earthworks and construction works at the monitoring station. Estimation of the structures of geodetic networks based on the Gauss-Markov model is the most used and the most effective method for their processing. In determining the statistical formulation of the Gauss-Markov model, we start from the following equations [11, 12, 17, 30–33]:

$$\mathbf{v} = \mathbf{A}(\hat{\mathbf{C}} - \mathbf{C}^o) - (\mathbf{L}_{(0)} - \mathbf{L}^o) = \mathbf{A}d\hat{\mathbf{C}} - d\mathbf{L} \quad (1)$$

$$\boldsymbol{\Sigma}_L = \sigma_0^2 \mathbf{Q}_L \quad (2)$$

where \mathbf{v} is the vector of corrections of the measured (observed) values \mathbf{L} , \mathbf{A} is the configuration (modeling) matrix of the geodetic network (otherwise called also the Jacobian matrix), i.e., the matrix of the partial derivatives of functions $\mathbf{L}^o = f(\mathbf{C}^o)$ by the vector \mathbf{C}^o , $\hat{\mathbf{C}}$ is the vector of the aligned 3D coordinate values, \mathbf{C}^o is the vector of the approximate 3D coordinate values, $\mathbf{L}_{(0)}$ is the vector of the approximate observation magnitude values of the observed elements in the first measuring epoch $t_{(0)}$, \mathbf{L}^o is the vector of the approximate observation magnitude values of the observed elements, $d\hat{\mathbf{C}}$ is the deformation vector, $d\mathbf{L}$ is the vector of the measured values supplements, $\boldsymbol{\Sigma}_L$ is the covariance matrix of the measured values, σ_0^2 is a priori variance, and \mathbf{Q}_L is the cofactor matrix of the observations.

It will also be appeared in the changed structures, let us say in a size of the matrixes and vectors \mathbf{A} , \mathbf{Q}_L , \mathbf{C}^o and \mathbf{L}^o . These matrixes and vectors enter into the presupposed model of a network adjustment following out from the Gauss-Markov model [11, 12, 29–31].

2.1 Deformation vector

If between monitoring epochs there are no changes in the geometrical and observational structure of the geodetic network, then the matrixes and vectors \mathbf{A} , \mathbf{Q}_L , \mathbf{C}^o and \mathbf{L}^o remain identical for each epoch. Only in such case the deformation vector $d\hat{\mathbf{C}}$ can be determined by a conventional procedure according to the following model [2, 16, 17]:

- In the basic (first) monitoring epoch $t_{(0)}$, we have the vector $\hat{\mathbf{C}}_{(0)}$ of the adjusted 3D coordinates of the observed points which are obtained according to the Gauss-Markov model:

$$\hat{\mathbf{C}}_{(0)} = \mathbf{C}^o + (\mathbf{A}^T \mathbf{Q}_L^{-1} \mathbf{A})^{-1} \mathbf{A}^T \mathbf{Q}_L^{-1} (\mathbf{L}_{(0)} - \mathbf{L}^o) = \mathbf{C}^o + \mathbf{G}(\mathbf{L}_{(0)} - \mathbf{L}^o) \quad (3)$$

- In the other following epochs $t_{(i)}$, we also obtain the vector $\hat{\mathbf{C}}_{(i)}$ of the adjusted 3D coordinates of the observed points according to the equation:

$$\hat{C}_{(i)} = C^o + (A^T Q_L^{-1} A)^{-1} A^T Q_L^{-1} (L_{(i)} - L^o) = C^o + G(L_{(i)} - L^o) \quad (4)$$

- Thus, for the deformation vector $d\hat{C}$ will be valid in the following equation:

$$d\hat{C} = \hat{C}_{(i)} - \hat{C}_{(0)} = G(L_{(i)} - L^o) \quad (5)$$

where $L_{(0)}$ and $L_{(i)}$ are the vectors of the observed magnitude values in the epochs $t_{(0)}$ and $t_{(i)}$.

Furthermore, we consider the case when there is a change in the geometric and thus in the data structure of the geodetic network of the monitoring station between the individual epochs of measurements. It means that the geometric and data structure of the geodetic network between the basic epoch $t_{(0)}$ and the actual epoch $t_{(i)}$ is changed. Then the original matrixes and vectors A , Q_L , C^o and L^o are transformed into the following equations:

$$\bar{A} = A + dA \quad (6)$$

$$\bar{Q}_L = Q_L + dQ_L \quad (7)$$

$$\bar{C}^o = C^o + dC^o \quad (8)$$

$$\bar{L}^o = L^o + dL \quad (9)$$

According to Eqs. (6)–(9), the vectors $\hat{C}_{(0)}$ and $\hat{C}_{(i)}$ of the adjusted 3D coordinates of the observed points in the epochs $t_{(0)}$ and $t_{(i)}$ will be determined:

$$\hat{C}_{(0)} = \bar{C}^o + (\bar{A}^T \bar{Q}_L^{-1} \bar{A})^{-1} \bar{A}^T \bar{Q}_L^{-1} (L_{(0)} - \bar{L}^o) = \bar{C}^o + \bar{G}(L_{(0)} - \bar{L}^o) \quad (10)$$

$$\hat{C}_{(i)} = \bar{C}^o + (\bar{A}^T \bar{Q}_L^{-1} \bar{A})^{-1} \bar{A}^T \bar{Q}_L^{-1} (L_{(i)} - \bar{L}^o) = \bar{C}^o + \bar{G}(L_{(i)} - \bar{L}^o) \quad (11)$$

and then the deformation vector $d\hat{C}$ is expressed according to Eq. (5) in the form

$$d\hat{C} = \hat{C}_{(i)} - \hat{C}_{(0)} \quad (12)$$

which not only expresses the 3D changes in the coordinates of the geodetic network points between the individual epochs of measurement, but such deformation vector can also express changes in the overall structure (geometric and data structure) of the geodetic network. The deformation vector $d\hat{C}$ thus obtained will not provide reliable data for testing the particular deformations in the subsidence.

The proposed and presented theory of the specific solution of the deformation vector in the case of any structural changes in the geodetic network will be acceptable for its proving in an analytical way, if we compare the deformation vector structures $d\hat{C}$ and $d\hat{C}$ expressed according to Eqs. (5) and (12). Then the structure of the deformation vector $d\hat{C}$ is expressed according to Eq. (12), and the further equation will be valid:

$$\begin{aligned} d\hat{C} &= [\bar{C}^o + \bar{G}(L_{(i)} - \bar{L}^o)] - [C^o + G(L_{(0)} - L^o)] \\ &= \bar{G}(L_{(i)} - \bar{L}^o) - G(L_{(0)} - L^o) + \bar{C}^o - C^o \end{aligned} \quad (13)$$

and on the base of Eqs. (6)–(9) and also on the base of the linearization of \bar{G} into $\bar{G} = G + dG$, the following derivation will be applied for the deformation vector $d\hat{\bar{C}}$:

$$\begin{aligned} d\hat{\bar{C}} &= (G + dG)(L_{(i)} - \bar{L}^o) - G(L_{(0)} - L^o) + dC^o = \bar{G}[L_{(i)} - (L^o + dL^o)] + dG(L_{(i)} - \bar{L}^o) - \\ &- G(L_{(0)} - L^o) + dC^o = G(L_{(i)} - L^o) + GdL^o + dG(L_{(i)} - L^o) - G(L_{(0)} - L^o) + dC^o = \\ &= G(L_{(i)} - L_{(0)}) + GdL^o + dG(L_{(i)} - \bar{L}^o) + dC^o \end{aligned} \quad (14)$$

and finally the deformation vector $d\hat{\bar{C}}$ will be calculated according to the following equation:

$$d\hat{\bar{C}} = d\hat{C} + \delta d\hat{C} \quad (15)$$

Eq. (15) notates that the deformation vector $d\hat{\bar{C}}$ (calculated at some changes in the geodetic network structure) is different from its vector of the correct values $d\hat{C}$ only by the component $\delta d\hat{C}$ (i.e., the correction component of the deformation vector corrections). In such a set case, the component $\delta d\hat{C}$ is generated not only by the spatial movement of points in the geodetic network between the particular epochs of the geodetic measurements, but at the same time it is generated by changes in the geometric and data structure of the network between the particular epochs due to some changes in its point field.

To avoid the so-called degradation of the deformation vector $d\hat{C}$ due to changes in the geometric and data structure of the geodetic network and at the same time for the deformation vector to express the real spatial changes in the subsidence, the presented theory offers the following procedures:

- The geodetic networks at the monitoring stations shall be designed in order to achieve the maximal physical integrity of its points (object and especially reference points) throughout the entire monitoring period. When designing a monitoring station, expert consultation with representatives of a spatial planning and also with the mine district owners is essential.
- If some reference points were lost or destroyed, new points should be stabilized in enough proximity to these lost or destroyed reference points as possible. The same principle is held for the object points.
- However, if the matrixes A and Q_L are significantly or even slightly changed between the monitoring epochs $t_{(0)}$ and $t_{(i)}$ (e.g., in $t_{(0)}$ the geodetic network was measured by a trilateration measurement way, and in $t_{(i)}$ by traverse measurement way, it is necessary to observe (measure) other new magnitudes, etc.), then the deformation vector $d\hat{C}$ can be determined according to the following equations:

$$\begin{aligned} d\hat{C} &= C^o + (A^T Q_L^{-1} A)_{(i)}^{-1} A_{(i)}^T Q_{L(i)}^{-1} (L_{(i)} - L^o) \\ &- [C^o + (A^T Q_L^{-1} A)_{(0)}^{-1} A_{(0)}^T Q_{L(0)}^{-1} (L_{(0)} - L^o)] \end{aligned} \quad (16)$$

and

$$d\hat{C} = G_{(i)} L_{(i)} - G_{(0)} L_{(0)} - L^o (G_{(i)} - G_{(0)}) \quad (17)$$

because using the identical C^o and L^o are not the problem to adhere in the individual epochs. Or the deformation vector corrections $\delta d\hat{C}$ are calculated according to Eqs. (10), (11), and (13), so that the deformation vector $d\hat{C}$ is then corrected according to the introduced Eq. (15).

3. Study case example

3.1 Study region description

The monitoring station is situated in the territory of the mining field of the abandoned magnesite mine of Košice-Bankov. This territory was characterized by a devastated mining surface with many mining tailing piles and especially the large subsidence. The city district of Košice-Bankov is located in the northern part of the city of Košice. In addition to the abandoned magnesite mine, there is a very popular urban recreational and touristic resort, located in the large urban forest park of the city of Košice. The territory of the urban recreational and touristic resort and forest park are situated in close proximity, respectively, in the territory above the mining field of the former magnesite mine (**Figure 1**).

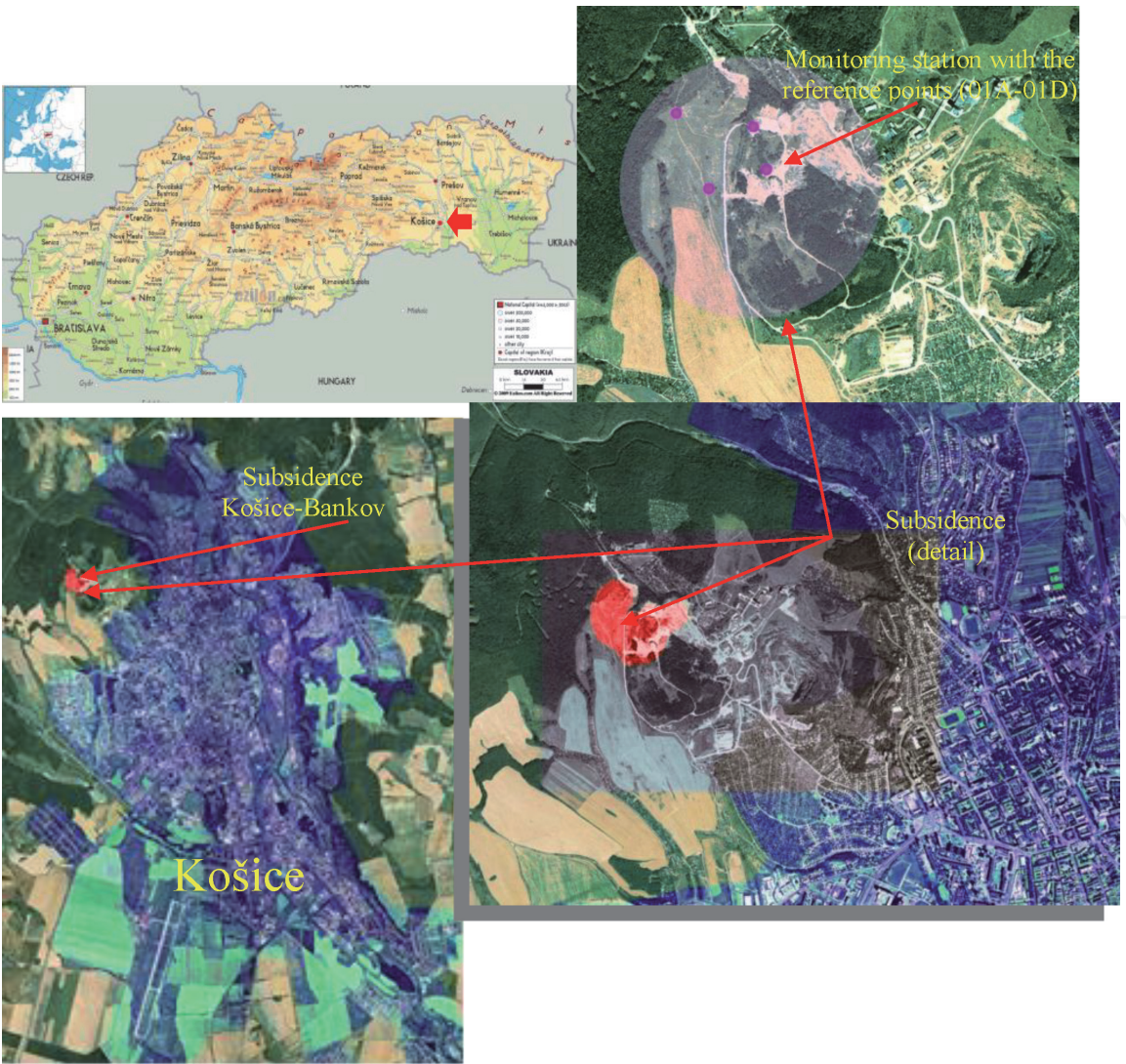


Figure 1.
Ortho-photo map of the city of Košice with a detail view to the mine field of Košice-Bankov.

Until the 1970s of the twentieth century, any systematic attention was not paid to the extent of mining damage on the earth surface at the territory of Košice-Bankov as a result of magnesite mining. It was only after this period that scientific studies began to be taken into account when dealing with the creation of the large subsidence and devastation of the protected area of the forest park and the environmental protection in the tangent territory of Košice-Bankov. The gradual development of the subsidence in the mining area of the magnesite mine of Košice-Bankov in the east of Slovakia has been monitored since the end of the 1970s by systematic geodetic measurements. The monitoring station project to monitor the development of the subsidence in the territory of Košice-Bankov was designed and implemented by researchers of the Technical University of Košice in 1976, when the first geodetic measurements were carried out and later by researchers of the Pavol Jozef Šafárik University in Košice. The first observed data were obtained from this monitoring station in autumn 1976, and since then the regular periodic spring and autumn geodetic terrestrial and satellite (GPS, GNSS) measurements were performed every year.

Before reclaiming the mining landscape on the territory of Košice-Bankov, the monitoring station was located on the site of the former subsidence at the mining shaft, which was called the Western shaft. The monitoring station was built from the geodetic network consisting of the network of the reference points (No: 01A, 01B, 01C, 01D) and the network of the object points (78 points in total). The object points were geometrically grouped into six geodetic network profiles (0–V) (**Figure 2**). All geodetic network profiles of the monitoring station of Košice-Bankov were geometrically spaced across and along the expected movements in the subsidence (**Figure 2**). Gradually, by creating the subsidence, some object points were destroyed by the nature destructive processes in the subsidence. **Figures 3 and 4** show the panoramic views to the subsidence of Košice-Bankov from the southwestern edge of this subsidence in 2001 and 2002. In that time the magnesite mine had been out of its operation for 3 years.

3D data (elements) of geodetic network points of the monitoring station were initially (since 1976) measured by 3D geodetic measurements (position and leveling measurements) by the application of the classical terrestrial geodetic technologies using the optical geodetic theodolites, electro-optical total stations, and leveling devices for a very precise leveling. Later, since 1977, the periodic measurements at the monitoring station have been made by the satellite geodetic methods GPS and GNSS, i.e., Trimble 3303DR Total Station, GPS: ProMark2, and GNSS: Leica Viva GS08.

In both geodetic periodic measurement technologies (terrestrial and satellite), regular geodetic measurements were performed twice a year, i.e., during the spring and autumn months [12, 17]. In 1981, some of the object points of the geodetic network of the monitoring station were damaged, respectively; the points were completely destroyed by some unplanned and uncontrolled earthworks in the vicinity of the subsidence (points No. 2, 3, 30, 38, 104, and 105 and 227¹ on the profiles No. 0, I, and II). Most of the damage or destruction of the abovementioned points occurred during the adjustment of some forest stands in the nearby forest park and by some earthworks on the surrounding mining tailing piles.

3.2 Accuracy and quality assessment of the geodetic network

1D, 2D, and 3D accuracy of the geodetic network points of the monitoring station was evaluated by testing the global and local network indices. The global indices were numerically expressed to assess the accuracy of the entire geodetic network.

¹ The reference point No. 227 (profile II) was rebuilt instead of the point No. 226.

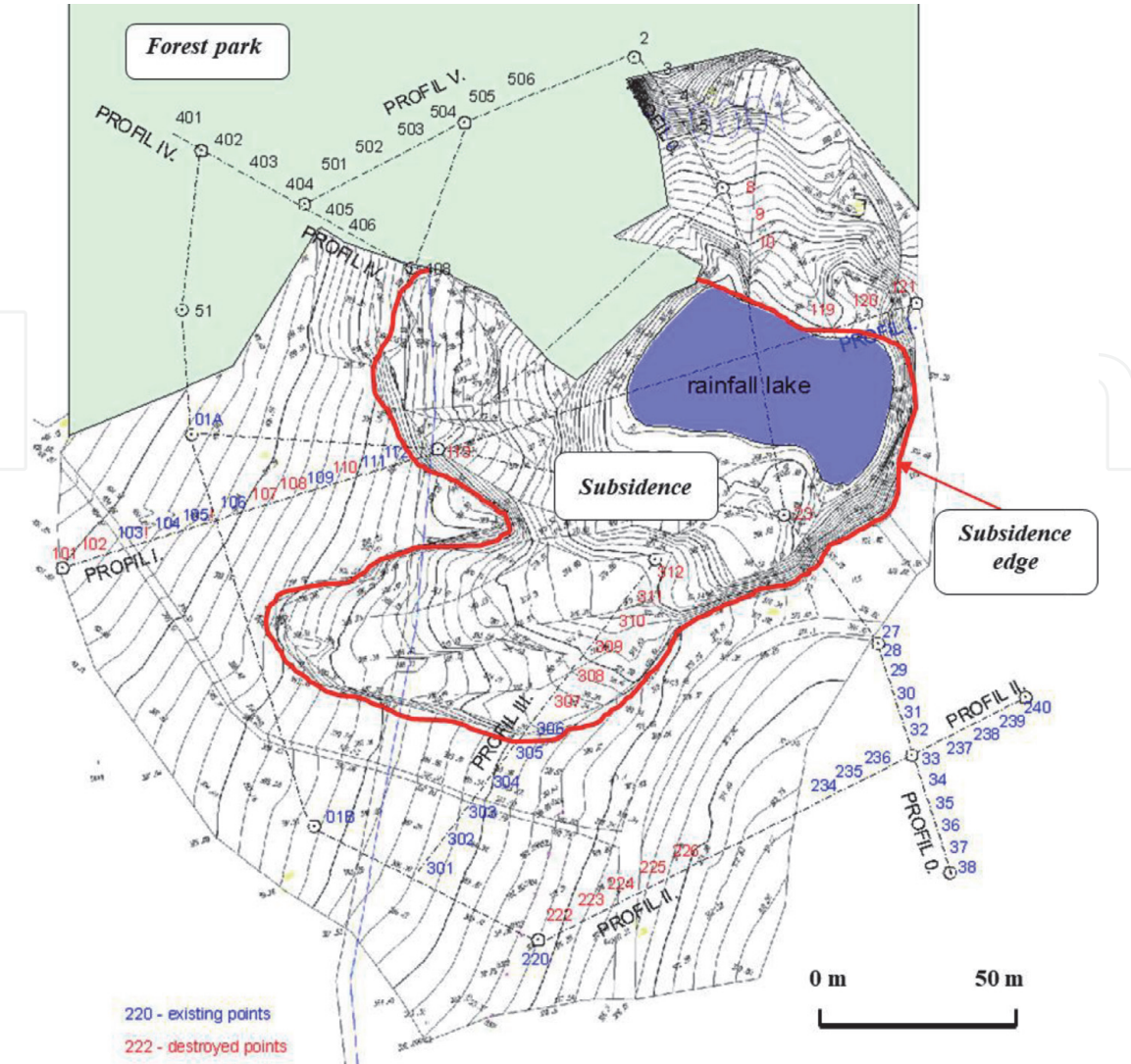


Figure 2.
The monitoring station of Košice-Bankov (reference points 01C and 01D destroyed points).



Figure 3.
The subsidence of Košice-Bankov; panoramic view: Autumn 2001.

For the global indices, the following were tested: $tr(\Sigma_{\hat{C}})$, i.e., the track of the covariance matrix $\Sigma_{\hat{C}}$, the volume global indices, and $\det(\Sigma_{\hat{C}})$, i.e., the determinant of the covariance matrix.

In fact, the local indices were the point indices that characterize the reliability of the geodetic network points: the mean 3D error $\sigma_p = \sqrt{\sigma_{\hat{X}_i}^2 + \sigma_{\hat{Y}_i}^2 + \sigma_{\hat{Z}_i}^2}$, the mean



Figure 4.

The subsidence of Košice-Bankov; panoramic view: Spring 2002.

coordinate error $\sigma_{XYZ} = \sqrt{\frac{\sigma_{X_i}^2 + \sigma_{Y_i}^2 + \sigma_{Z_i}^2}{3}}$, and the confidence absolute ellipses or ellipsoids, which were used to assess the real 2D or 3D point accuracy. It is necessary to know the design elements of the ellipse of errors, i.e., the semi-major axis a , the semi-minor axis b , the bearing φ_a of the semi-major axis, and the ellipsoid flattening f ($f = 1 - b/a$).

The geodetic network quality characteristics to be assessed are, above all, the accuracy and reliability of the position of the points. In addition to numerical expressions, the accuracy of the point position can also be expressed using the graphical indicators such as the reliability curves and the ellipse of confidence (ellipsoids of reliability in the case of 3D space). The ellipsoids determine the random space in which the actual location of the points will lie with a probability of $1-\alpha$, where α is the level of significance chosen according to which the ellipsoids are of different size. For 3D space in a geodetic practice, the standard confidence ellipsoids are usually used. The design parameters of such ellipsoids can be derived either from the cofactor matrix Q_L of the adjusted coordinates, where the design parameters are arranged on the main diagonal of the matrix, or from the covariance matrix of the coordinate estimations $\Sigma_{\hat{C}}$ of the determined points, which are arranged also on the main diagonal of that matrix.

All calculated data according to the submitted specific theory of the deformation vector solution in the case of any geometric and data changes in the geodetic network of the monitoring station are shown in **Tables 1–5** which are focused on the accuracy and quality assessment of the network in the years 1976 and 2014 (1976/2014²) (**Tables 1–5**). **Tables 1–5** comprehends the adjusted mean errors of the individual coordinates, global and local 3D indices, and their absolute confidence ellipsoid elements determining 3D accuracy of some chosen replaced points; the numbers in front of the slash belong to 1976; the numbers after the forward slash belong to 2014. In 2007 the points No. 2, 3, 30, 38, 104, 105, and 227 were re-stabilized due to small earthworks for the purpose of some preparation work for the future reclaiming of the mining territory of Košice-Bankov. The values of the deformation vectors confirm the fact that the presented theory of the deformation vector specific solution is suitable and variable adapted to various damages of geodetic networks [7]. In geodetic practice, however, there are cases where the values of deformation vectors need not mean any displacement of the geodetic network points (movement around the point of the geodetic network). Although the geodetic network points were adjusted according to the conventional method using the Gauss-Mark model, the deformation vector values may be loaded by the accumulation of some measurement errors. For this reason, when evaluating the

² Deformation survey on the monitoring station of Košice-Bankov without the reclaiming work intervention was finished in the autumn 2014.

Point	m_x (mm)	m_y (mm)	m_z (mm)
2	15.7/16.4	32.9/45.5	12.5/72.4
3	14.8/34.3	27.2/58.9	30.5/69.1
30	21.1/25.6	26.5/24.1	45.5/32.7
38	16.6/14.9	16.3/8.1	20.1/18.4
104	18.2/41.3	34.1/69.0	55.4/78.0
105	28.2/31.6	17.1/21.1	9.9/17.8
227	20.0/16.9	8.5/4.7	10.9/10.8

Table 1.
Mean errors (1976/2014).

Point	a_i (mm)	b_i (mm)	φ_{a_i} (gon)	f
2	49.9/51.0	5.9/5.1	172.303/172.695	1.8818/0.9
3	40.8/32.5	12.3/3.7	172.704/179.151	0.6985/0.8862
30	43.0/45.9	18.2/21.5	160.340/160.058	0.5767/0.5316
38	23.5/28.1	21.8/22.4	40.966/41.203	0.0723/0.2028
104	47.5/79.2	24.0/9.9	211.146/217.148	0.4947/0.875
105	42.8/42.4	15.3/17.6	370.337/370.624	0.6425/0.5849
227	28.8/25.2	8.1/10.9	19.634/19.781	0.7188/0.5675

Table 2.
Absolute confidence ellipse elements ($\alpha = 0.05$) (1976/2014).

Rank $\text{rk}(\Sigma_C)$	Track $\text{tr}(\Sigma_C)$ [mm ²]	Determinant $\det(\Sigma_C)$	Average mean error $\sigma_{C_{pr}}$ [mm]	Norm $\text{nor}(d_C)$ [mm]
14/14	7041.901/ 7041.054	2.869.10 ²⁵ / 2.869.10 ²⁵	22.428/22.971	124.218/ 126.155

Table 3.
Global indices (1976/2014).

Point	Mean 3D error σ_p (mm)	Mean coordinate error σ_{XYZ} (mm)
2	36.4/37.5	25.7/18.8
3	30.9/28.4	21.8/24.5
30	33.9/33.0	23.9/23.0
38	23.3/26.7	16.5/13.8
104	38.6/14.1	27.3/54.9
105	32.9/27.4	23.3/19.9
227	21.7/22.5	15.3/17.4

Table 4.
Local indices (1976/2014).

	Point						
$\hat{d}\hat{C}$ [mm]	2	3	30	38	104	105	227
	2.4	-2.9	-8.0	6.7	-4.0	0.6	9.7

Table 5.
Deformation vector values (1976/2014).

significance of deformation vectors, it is necessary to test them by means of the global and localization test of a congruence (see Chapter 3.3). After a series of the last geodetic measurements in spring 2014, the deformation vectors at the tested points No. 2, 3, 30, 38, 104, 105, and 227 of the geodetic network of the monitoring station have moved from -4 to 9.7 mm (**Table 5**). 3D mean errors ranged from 14.1 to 38.6 mm, and the mean coordinate errors were from 13.8 to 54.9 mm (**Table 4**). In autumn 2014 all points of the monitoring station of Košice-Bankov were destroyed by the reclaiming work, i.e., the reference points were removed and the object points were backfilled by a secondary imported soil.

3.3 Global test of the geodetic network congruence

Significant stability, respectively instability of the geodetic network points, is rejected or not rejected by verifying the null-hypothesis H_0 and also other alternative hypothesis [11, 12, 17, 34].

$$H_0 : d\hat{C} = 0; \quad H_\alpha : d\hat{C} \neq 0 \tag{18}$$

where H_0 expresses insignificance of the coordinate differences (deformation vector) between epochs $t_{(0)}$ and $t_{(i)}$.

The test statistics T_G can be used for a global test:

$$T_G = \frac{d\hat{C} Q_{d\hat{C}}^{-1} d\hat{C}^T}{k \bar{s}_0^2} \approx F(f_1, f_2) \tag{19}$$

where $Q_{d\hat{C}}$ is the cofactor matrix of the final deformation vector $d\hat{C}$, k is the coordinate number entering the geodetic network adjustment ($k=3$ for 3D coordinates), and \bar{s}_0^2 is the posteriori variation factor common for both epochs $t_{(0)}$ and $t_{(i)}$.

The critical value T_{KRIT} is searched in the tables of F distribution (the Fisher-Snedecor distribution) according to the degrees of freedom $f_1 = f_2 = n - k$ or $f_1 = f_2 = n - k + d$, where n is number of the measured values entering into the network adjustment and d is the network defect at the network free adjustment. Through the use of methods, MINQUE is $s_0^{2_{t(0)}} = s_0^{2_{t(i)}} = \bar{s}_0^2 = 1$ [2, 11, 12, 16, 17, 34]. Test statistics T should be compared to critical test statistics T_{KRIT} . T_{KRIT} is found in the distribution Tables F according to the degrees of freedom of the geodetic network.

When comparing test statistics, there may be two cases:

1. $T_G \leq T_{KRIT}$: The null-hypothesis H_0 is accepted. That is, the differences in coordinate values (i.e., deformation vectors) are not significant.
2. $T_G > T_{KRIT}$: The null-hypothesis H_0 is refused. This means that the differences in coordinate values (deformation vectors) are statistically significant. In this

Point	$T_{G(i)}$	$< \leq >$	F	Notice
2	1.297	$<$	3.724	Deformation vectors are not significant
3	3.7236	\leq		
30	3.501	$<$		
38	3.7237	\leq		
104	2.871	$<$		
105	1.403	$<$		
227	2.884	$<$		

Table 6.
Test statistics results of the geodetic network points at the monitoring station of Košice-Bankov.

case, it can be stated that the deformation occurred with the level α of a reliability.

Table 6 presents the global tested results of the geodetic network congruence.

4. Subsidence in GIS for reclaiming mining landscape

The Geographical Information Systems (GIS) of the mining landscape of Košice-Bankov is based on the following key points [25]: basic and simple presentation of geodata, management of the basic database, and wide availability of information. The best feasible solution for the implementation of the GIS project is the Free Open Source software applications, which are easily available on the Internet. The general function of the Free Open Source software application is the viability of free code and data sources via HTTP and FTP protocols located on the project website. Other features of the Free Open Source range include ease of use, access to data and information, centralized system configuration, modular things, and any Open Source platform (depending on PHP, MySQL, and ArcIMS ports) [7, 25, 35–39]. The network application MySQL is currently the most advantageous database system on the Internet and was also applied to the deformation survey outputs from the monitoring station of Košice-Bankov.

Whole database part in GIS for the subsidence of Košice-Bankov in all applications was processed into the MySQL database (**Figure 5**). 3D model of the subsidence of Košice-Bankov with the multilayered GIS applications has been implemented into the reclaiming plan of the mining territory of Košice-Bankov for the needs of the municipality of the city of Košice.

Given the fact that extraction of magnesite mineral has been completed at the mine of Košice-Bankov and this mine is abandoned since the end of the 90 years of the twentieth century and the investigation concluded that the Košice-Bankov with the huge subsidence is stable at the end of the deformation investigation, the municipality of the city of Košice (Department of land planning of the city) has adopted a definitive plan for reclaiming this mining landscape. Numerical and graphical analyses of the results from the long-term geodetic measurements of the deformations in the subsidence at the monitoring station of Košice-Bankov with their subsequent testing analyses of the deformation vectors confirmed the stability not only in the subsidence but also in the surrounding mining landscape. The subsidence and other mining earthworks of huge dimensions destroyed the entire surroundings of the mining plant (mining tailings piles, various excavations in the

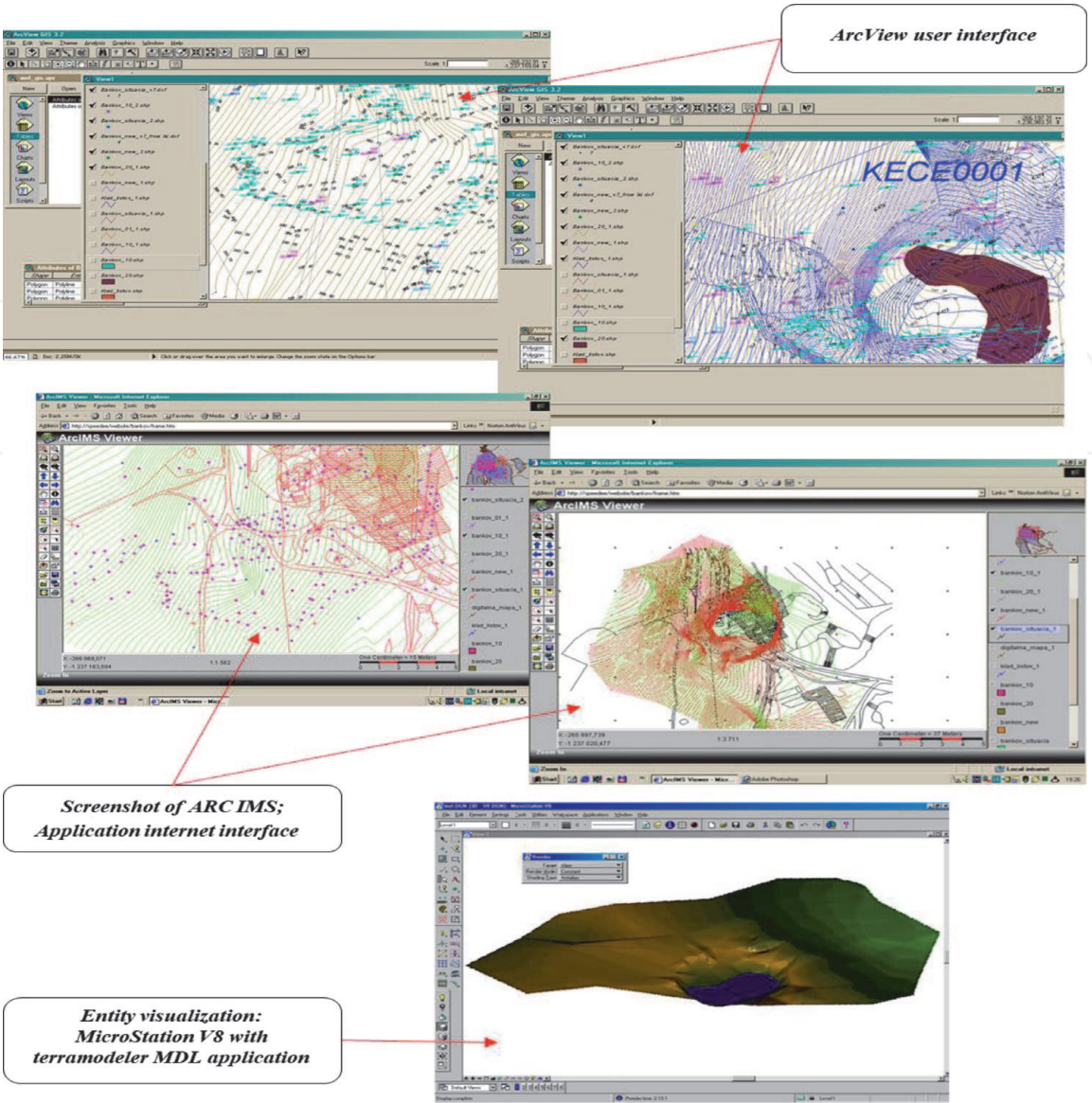


Figure 5.
ArcView user interface visualization of the subsidence.

working of the earth surface, and other mining works in the surroundings of the former mine plant) were gradually filled with imported secondary soil. Based on the results of the extensive geodetic measurements of deformations of the mining subsidence and its surroundings in the destroyed mining area of Košice-Bankov, reclaiming works began at the beginning of this century. Some recent reclaiming works were completed in the summer of 2016.

In the territory of the former large subsidence, the new forest park was built as an environmental forest greenery in the part of the Košice-Bankov urban recreation and touristic area of the city of Košice. The subsidence was filled with imported natural and secondary materials from many construction works and earthworks in the city of Košice and its surroundings. Given that the subsidence was of huge proportions, such sporadic embankment works took too long, more than 10 years. After the embankment and other earthworks were completed, the new forest park was planted in the area of the former subsidence (**Figure 6**). Especially birch was planted. Birch trees are known for their rapid growth, and their root system is not demanding on the underlying soil. At present, the birch grove represents almost 5 years of a healthy forest park. The reconstruction of the recreational and touristic area of Košice-Bankov was completed in spring 2016 (**Figure 7**). The mining tailing piles and the entire ruined area of the former mining plant were also reclaimed.



Figure 6.
The subsidence of Košice-Bankov after reclaiming; panoramic view—Summer 2016. Solar collectors on the places of the former mining tailing piles; new forest park in the background on the places of the former subsidence.

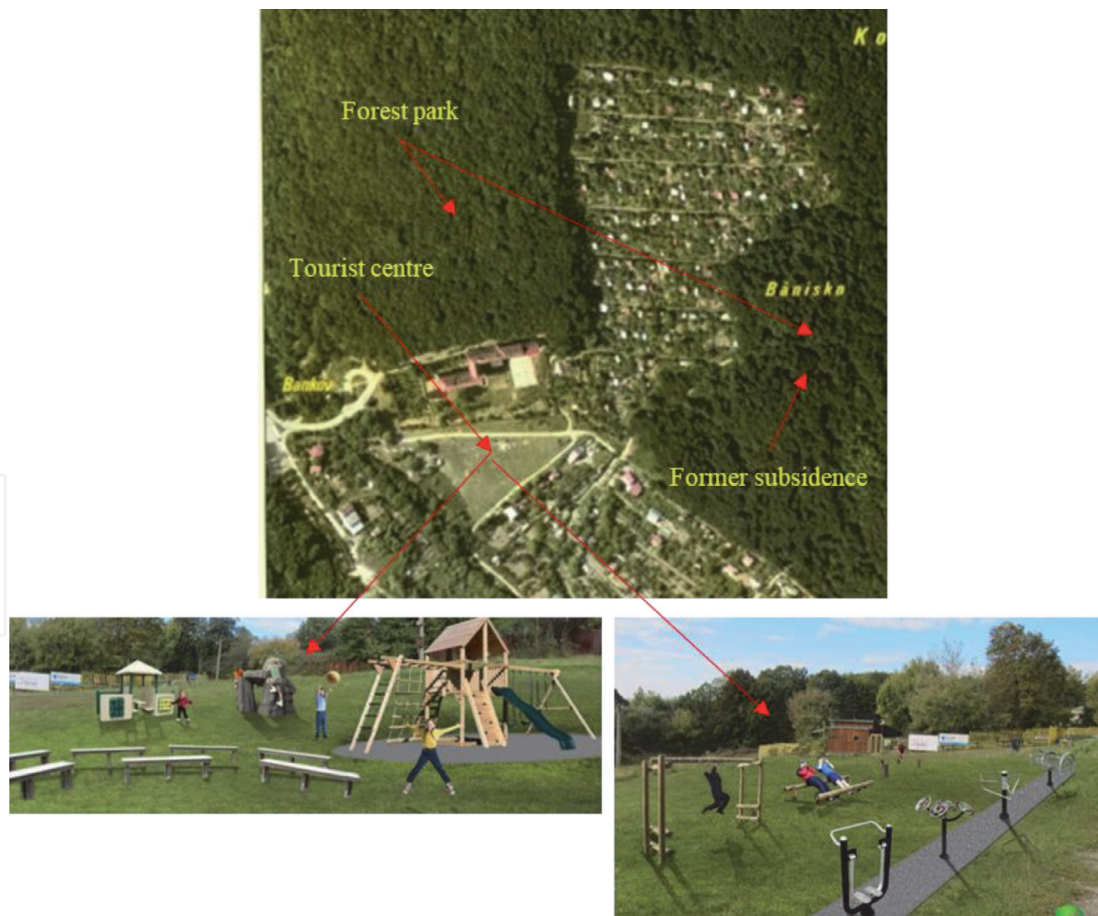


Figure 7.
The reconstructed recreation and touristic zone and revitalized forest park after reclaiming the mining landscape of Košice-Bankov.

Many solar collectors have been built on the places of the former mining tailing piles, which contribute to the renewable sources of electricity for the city of Košice (Figure 6).

5. Conclusions

The determination of the deformation vectors from the differences between the adjusted geodetic point coordinate vectors obtained from at least two monitoring epochs is readily achievable if the original geometric and data structure of the geodetic network of the monitoring station between the individual monitoring epochs is strictly preserved. The presented research study provides both the theoretical and practical results of the possibility of solving deformation vectors in the geodetic network of the monitoring station in the case of its geometrical and data structure violation during the period of monitoring the movements of the earth surface, i.e., if the points of the geodetic network were damaged or completely destroyed between the different epochs of measurements, i.e., the geodetic network was nonhomogenous. The deformation vectors solved in accordance with the proposed specific theory of solving monitored deformations of the earth surface in the case of disturbance of the geodetic network homogeneity of the monitoring station provide via 3D models in GIS a reliable idea of spatial changes in the coordinates of the geodetic network points. The proposed theory of the specific deformation vector solution leads to a reliable support in investigation of various deformations of the earth surface, such as mining subsidence, landslides, geotectonic (recent movements), movements of dams, and other important building objects.

The largest values of the deformation vectors given in **Table 5** occurred at points No. 30 and No. 227. However, due to the fact that the deformation vectors tested at these points were not significant according to the test statistics, we can declare these points as static. The mentioned study case from the mining territory of the abandoned magnesite mine of Košice-Bankov confirmed the availability and applicability of the presented specific theory in the solution of the deformation vector in the deformation monitoring in the mining subsidence, where several violations of the geometric and data structure (homogeneity) of the geodetic network of the monitoring station occurred. Despite the validated method for the specific solution of the deformation vector in the geometric and data inhomogeneity of the geodetic network at the monitoring station, it should be stated that it would be preferable to maintain the homogeneity of the geodetic network during the whole monitoring period. Maintaining the homogeneity of the data of the geodetic network structure can ensure the permanent stabilization of the network points and the correct technically and physically implemented protection of the whole monitoring station from unexpected external interventions into such a station.

3D model situations of the mining subsidence in GIS platform from the mining territory of Košice-Bankov were delivered to the municipality of the city of Košice (especially for the Department of Land Planning and Chief Architect of the City) to deal with a spatial planning for the future environmental reclaiming of this abandoned mining region, such as the magnesite mines of Košice-Bankov. The analysis of the deformation vectors at the geodetic network points of the monitoring station located in the mining subsidence and in the surrounding mining territory of the abandoned magnesite mine of Košice-Bankov was important in defining and specifying the subsidence edges and the subsidence zones with a number of dangerous cracks and fissures. The very precise identification of 3D position of such delimitation of the mining subsidence constituted the basic document for the plan of the municipality of the city of Košice for the reclaiming of the entire devastated mining landscape of Košice-Bankov. The revitalization of the Košice-Bankov recreational and tourist zone with the adjacent urban forest park has been achieved through the comprehensive reclaiming that devastated mining landscape. The variability of 3D models of the mining subsidence allowed a wide spectrum at modeling of natural and also industrial disasters in the former mining territory of Košice-Bankov.

3D models of the mining subsidence in GIS are useful tools for many reclaiming works in restoring ecosystems with some essential elements of the security measures against the possible and unforeseen consequences of former mining activities for the protection of the health and life of people moving in various mining areas.

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References

- [1] Knothe S, editor. Forecasting the Influence of Mining (in Polish). Katowice: Śląsk Publishing House; 1984
- [2] Whittaker BN, Reddish DJ, editors. Subsidence: Occurrence, Prediction and Control. 3rd ed. Amsterdam: Elsevier; 1989. p. 528
- [3] Cui X, Miao X, Wang J, Yang S, Liu H, Hu X. Improved prediction of differential subsidence caused by underground mining. *International Journal of Rock Mechanics and Mining Sciences*. 2000;**37**(4):615-627. DOI: 10.1016/S1365-1609(99)00125-2
- [4] Díaz-Fernández ME, Álvarez-Fernández MI, Álvarez-Vigil AE. Computation of influence functions for automatic mining subsidence prediction. *Computational Geosciences*. 2010;**14**(1):83-103. DOI: 10.1007/s10596-009-9134-1
- [5] Djamaluddin I, Mitani Z, Esaki T. Evaluation of ground movement and damage to structures from Chinese coal mining using a new GIS coupling model. *International Journal of Rock Mechanics and Mining Sciences*. 2011;**48**(3): 380-393. DOI: 10.1016/j.ijrmms.2011.01.004
- [6] Kratzsch H, editor. Mining Subsidence Engineering. Berlin: Springer-Verlag; 1983
- [7] Sedlák V. Mathematical testing the edges of subsidence in undermined areas. *Journal of Mining Science*. 2014; **50**(3):465-474. DOI: 10.1134/S1062739114030089
- [8] Bauer RA. Mine subsidence in Illinois: Facts for homeowners. In: Circular 569 [Internet]. Champaign: Illinois State Geological Survey; 2006. p. 20. Available from: https://www2.illinois.gov/iema/Mitigation/Documents/Link_Mine_Subsidence_Facts_Homeowners.pdf [Accessed: 24 September 2016]
- [9] Colorado Geological Survey: Mine Subsidence [Internet]. 2016. Available from: <http://coloradogeologicalsurvey.org/geologic-hazards/subsidence-mine/> [Accessed: 26 September 2016]
- [10] Donnelly LJ, Reddish DJ. The development of surface steps during mining subsidence: "Not due to fault reactivation". *Engineering Geology*. 1994;**36**(3-4):243-255. DOI: 10.1016/0013-7952(94)90006-X
- [11] Sedlák V, editor. Modelling Subsidence Development at the Mining Damages. Košice: Štroffek; 1997. p. 52
- [12] Sedlák V. Modelling subsidence deformations at the Slovak coalfields. *Kuwait Journal of Science & Engineering*. 1997;**24**(2):339-349
- [13] Alehossein H. Back of envelope mining subsidence estimation. *Australian Geomechanics*. 2009;**44**(1):29-32
- [14] Can E, Mekik Ç, Kuşçu Ş, Akçın H. Monitoring deformations on engineering structures in Kozlu Hard Coal Basin. *Natural Hazards*. 2013;**65**(3):2311-2330. DOI: 10.1007/s11069-012-0477-x
- [15] Jung HC, Kim SW, Jung HS, Min KD, Won JS. Satellite observation of coal mining subsidence by persistent scatterer analysis. *Engineering Geology*. 2007;**92**(1):1-13. DOI: 10.1016/j.enggeo.2007.02.007
- [16] Sedlák V, Kunák L, Havlice K, Šadera M. Modelling deformations in land subsidence development at the Slovak coalfields. *Survey Ireland*. 1995;**12**(13): 25-29
- [17] Sedlák V. Measurement and prediction of land subsidence above

longwall coal mines, Slovakia. In: Borchers WJ, editor. *Land Subsidence: Case Studies and Current Research*. Belmont: U.S. Geological Survey; 1998. pp. 257-263

[18] Cai J, Wang J, Wu J, Hu C, Grafarend E, Chen J. Horizontal deformation rate analysis based on multiepoch GPS measurements in Shanghai. *Journal of Surveying Engineering*. 2008;**134**(4):132-137. DOI: 10.1061/(ASCE)0733-9453(2008)134:4(132)

[19] Can E, Mekik Ç, Kuşçu Ş, Akçın H. Computation of subsidence parameters resulting from layer movements post-operations of underground mining. *Journal of Structural Geology*. 2013;**47**: 16-24. DOI: 10.1016/j.jsg.2012.11.005

[20] Hu LY. Gradual deformation and iterative calibration of Gaussian-related stochastic models. *Mathematical Geology*. 2000;**32**(1):87-108. DOI: 10.1023/A:1007506918588

[21] Lü WC, Cheng SG, Yang HS, Liu DP. Application of GPS technology to build a mine-subsidence observation station. *Journal of China University of Mining and Technology*. 2008;**18**(3):377-380. DOI: 10.1016/S1006-1266(08)60079-6

[22] Marschalko M, Fuka M, Treslin L. Measurements by the method of precise inclinometry on locality affected by mining activity. *Archives of Mining Sciences*. 2008;**53**(3):397-414

[23] Ng AH, Ge L, Zhang K, Chang HC, Li X, Rizos C, et al. Deformation mapping in three dimensions for underground mining using InSAR - Southern highland coalfield in New South Wales, Australia. *International Journal of Remote Sensing*. 2011;**32**(22): 7227-7256. DOI: 10.1080/01431161.2010.519741

[24] Sedlák V. GPS measurement of geo-tectonic recent movements in east

Slovakia. In: *Proceedings of the 6th International Symposium on Land Subsidence-SISOLS 2000*; 24-29 September; Ravenna. Ravenna: C.N.R.; 2005. Vol. II, 2000. pp. 139-150

[25] Sedlák V. Possibilities at modelling surface movements in GIS in the Košice depression, Slovakia. *RMZ-Materials and Geoenvironment*. 2004;**51**(4): 2127-2133

[26] Wright P, Stow R. Detecting mining subsidence from space. *International Journal of Remote Sensing*. 1999;**20**(6): 1183-1188. DOI: 10.1080/014311699212939

[27] Koníček P, Souček K, Staš L, Singh R. Long-hole destress blasting for rockburst control during deep underground coal mining. *International Journal of Rock Mechanics and Mining Sciences*. 2013;**61**:141-153. DOI: 10.1016/j.ijrmms.2013.02.001

[28] Strazalowski P, Scigala R. The example of linear discontinuous deformations caused by underground extraction. *Transection of the VŠB - Technical University of Ostrava, Civil Engineering Series*. 2005;**V**(2):193-198

[29] Li PX, Tan ZX, Deng KZ. Calculation of maximum ground movement and deformation caused by mining. *Transactions of the Nonferrous Metals Society of China*. 2011;**21**(3): s562-s569. DOI: 10.1016/S1003-6326(12)61641-0

[30] Christensen R. General Gauss-Markov models. In: Christensen R, editor. *Plane Answers to Complex Questions/the Theory of Linear Models*. 4th ed. New York: Springer; 2011. pp. 237-266

[31] Gene H, Golub GH, Van Loan ChF, editors. *Matrix Computations*. 4th ed. Baltimore: JHU Press; 2013. p. 756

[32] Groß J. The general Gauss-Markov model with possibly singular dispersion

matrix. *Statistical Papers*. 2004;**45**(3): 311-336. DOI: 10.1007/BF02777575

[33] Lindgren F, Ruel H, Lindström J. An explicit link between Gaussian fields and Gaussian Markov random fields: The stochastic partial differential equation approach. *Journal of the Royal Statistical Society, Series B: Statistical Methodology*. 2011;**73**(4):423-498. DOI: 10.1111/j.1467-9868.2011.00777.x

[34] Lehmann EL, Romano JP, editors. *Testing Statistical Hypotheses*. 3rd ed. New York: Springer; 2008. p. 786

[35] Blachowski J. Application of GIS spatial regression methods in assessment of land subsidence in complicated mining conditions: Case study of the Walbrzych coal mine (SW Poland). *Natural Hazards*. 2016;**84**(2):997-1014. DOI: 10.1007/s11069-016-2470-2

[36] Gallay M, Kaňuk J, Hochmuth Z, Meneely JD, Hofierka J, Sedlák V. Large-scale and high-resolution 3-D cave mapping by terrestrial laser scanning: A case study of the Domica Cave, Slovakia. *International Journal of Speleology*. 2015;**44**(3):277-291. DOI: 10.5038/1827-806X.44.3.6

[37] Kaňuk J, Gallay M, Hofierka J. Generating time series of virtual 3-D city models using a retrospective approach. *Landscape and Urban Planning*. 2015;**139**:40-53. DOI: 10.1016/j.landurbplan.2015.02.015

[38] Yang KM, Xiao JB, Duan MT, Pang B, Wang YB, Wang R. Geo-deformation information extraction and GIS analysis on important buildings by underground mining subsidence. In: *Proceedings of the International Conference on Information Engineering and Computer Science-ICIECS 2009*. 19-20 December, 2009; Wuhan. Wuhan: IEEE; 2009. p. 4

[39] Yang KM, Ma JT, Pang B, Wang YB, Wang R, Duan MT. 3D visual technology

of geo-deformation disasters induced by mining subsidence based on ArcGIS engine. *Key Engineering Materials*. 2012; **500**:428-436. DOI: 10.4028/www.scientific.net/KEM.500.428