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MONITORING OF HISTORICAL LAND USE CHANGES CAUSED BY UNDERGROUND MINING IN MIEDZIANKA TOWN, BASED ON A WEBGIS TOOL AND INSAR OBSERVATIONS

The article presents land surface changes caused by historical mining of metal ores on in the country town of Miedzianka in Lower Silesia, Poland. From the 19th until the middle of 20th century, mining in Miedzianka was in depression. Due to long-term and widespread mining activity, the town almost completely disappeared. The scale of the devastating effects of the mining appeared on the surface of the land, which led to the decision to abandon Miedzianka. Despite the damage the local authority made efforts to renew regional tourism. Unfortunately, it is impossible to carry out revitalization without recognizing the current threat of post-mining excavations. Therefore, the authors focused on analyzing collected archival documentation to understand the mining processes that have occurred and may still be occurring under the surface. The archival maps presented in the article have been indicated land use changes from 1886 to 1951. The current situation display WMS layer from Geoportal website. The collected materials allowed the spatiotemporal changes that occurred in Miedzianka to be presented. Additionally, the information

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base has been enriched with InSAR results for monitoring terrain deformation. The observations demonstrate that the biggest changes have taken place before 1936. In addition, current urban development constitute less than 25% of historical buildings. Analysis of InSAR method indicate that the research area require more accurate technique, because of the occurrence of large number of agricultural and forest areas.

Keywords: revitalization, historical mining impact, urban development, WebGIS tool, InSAR technique

1. State of the art

Miedzianka and its surroundings become famous thanks to the rich deposits of valuable minerals extracted there since at least the 19th century [1]. Due to this, over the years this area attracted the interest of many people, institutions, entrepreneurs and others. Centuries of extraction were an incentive for the creation of various data sets that allowed the mining history and city itself to be tracked. It should be noted that over time the methods of data storage changed, which makes analyzing and extracting information and relationships between data a challenging task. An integrated approach to the problem of creating an information system that allows for basic interoperability between these storage formats seems to be the right direction in which to proceed. In general, the term 'interoperability' refers to the ability of different applications to communicate between each other [2], but with GIS solutions it can also be applied to different kinds of spatial data. Using websites as a space for sharing spatial data has gained increasing attention since the end of last century [3]. Referring to [3], a geoportal is defined as "a web site where geographic content can be discovered", with emphasis on the fact that a primary focus of the website is this geographic content. In a broader scope it also fits solutions like web-based applications, one of which is presented in this paper.

As described by [2], infrastructures for spatial data, no matter the form, can be implemented on four levels. The highest level is the international one, for which there are many great examples, like the services provided by Copernicus [4]. Many international and national geoportals and services in Europe are the result of the European INSPIRE directive, whose main goal is to improve the flow of spatial information between countries [5].

On the national level, spatial data infrastructures provide data access for various units like private entrepreneurs, local governments [2] and many others. The third level distinguished by [2] is the regional level, which is represented by e.g. geoportals of voivodeships. Over recent years, a significant increase in the number of regional geoportals has been observed. Moreover, the spectrum of shared data has widened [6].

The last level, which is also a concern of this paper, is the local level, at which data about a particular city or small area are presented. For this purpose, geoportals or smaller web-based applications can be used. These are suitable for projects dedicated to a particular case or local area. This paper presents a simple application created for Miedzianka as an example of a local-level spatial data infrastructure. The usefulness and usability of this type of solution is described with the use of various examples of applications across a vast number of categories. Sharing spatial data on a local level is also used in tools that provide access to project data to project members. A solution like this allows diverse team members to share and organize results and knowledge, as for example described by [7]. The multitude of applications that are created worldwide are as varied as the needs of those who create and use them. The popularity of this type of solution rests on the ease of use of web-based GIS solutions, the low cost, and the possibility of providing data access to large groups of people [8]. Many ready-to-use solutions are offered, such as www.giscloud.com, or those provided by Esri. ArcGIS Online, also known as AGOL, allows user-friendly platforms to be created [9]. One of the objectives of this paper is to present a cloud-based WebGIS application to track changes in Miedzianka as a use case. The authors believe that creating an application for sharing and visualizing data about Miedzianka will be an important step in integrating the data organizing processes that have been created and collected over centuries.

2. The research area

Miedzianka is a small town located in the Western Sudetes, at an altitude of over 500 m above sea level, between the Bóbr River and the Copper Stream Valley (Fig. 1). In the years of its glory, it was considered one of the most beautiful towns in Lower Silesia. Due to mining damage, Miedzianka is currently mostly ruined [10].

The urban infrastructure in Miedzianka was inseparably related to the mining industry. The first confirmed reports of the existence of the historical mine and its surroundings appeared in the 14th century. More recently, in the 16th century the

Fig. 1. Location of Miedzianka (Lower Silesia). Source: www.openstreetmap.org

mining activity intensified for several decades, with a focus on shallow deposits. Another boom of underground works occurred in the 18th century with the extraction of bornite and chalkozine, with the deepest shafts reaching 110 m. Pyrite and copper also started to be extracted but the deposits turned out to be significantly poorer than expected and mining ceased after several years. Some low-level activity was recorded until 1925 [11]. In Miedzianka, the copper ore deposits are the biggest. Analysis carried out by German researchers show that the copper ore extracted at Miedzianka until 1925 contained 18.7% Cu, 22.82% Fe, 2.42% Zn 1.32% Pb, 1.18% Ag, 1.25%, 0.22% Ag and 0.09% Sn. In the past, silver and iron were also extracted in this region [12].

Before World War II, copper was mined in Miedzianka, with four fields of exploitation. In the 1930s, uranium was also extracted [13]. One of the last episodes of mining at Miedzianka happened after World War II in 1948–1952, with much more intensive works at "Miedzianka" mine site [11]. Exploratory works were carried out again for uranium ores. Old shafts were partly renovated; more than 15 km of historical mining drafts, shafts and adits in total were reported. This is a clear indication of the scale of historical exploitation [12]. Apart from reusing old tunnels, about 40 km of new drifts and one adit were routed next to new shafts [11]. The depth of roadways reached about 250 meters [14].

In the early 1950s the "Sudeckie Zakłady Górnicze" company (translated as Sudety Mining Plants) was created, with "Miedzianka" mine being part of it [15]. The Miedzianka deposits were carefully mapped again to document the ore resources. Work was completed in 1955 and the mine was finally closed by decision of Polish government due to the lack of prospects for profitable mining of any ore or minerals [16]. In the 1990s some gold deposits were documented in the Miedzianka area [17].

Due to the extensive exploitation in Miedzianka, many sinkholes often formed both in the main part of the city and in agricultural areas [18]. The rapid extraction was also accompanied by landslides. For this reason, surface structures were and are still the most threatened, including well-known architectural monuments such as The Church of St. Cross, The Church of St. John The Baptist, the "Schwarzer Adler" house and the old brewery. Nowadays, only the last three of these structures survive.

3. Project assumptions

In 2002, the non-profit Kaczawski Association was founded. Since then, with the aim of revitalizing abandoned cities and restoring tourist infrastructure, it has been running social campaigns for the development of the Kaczawski Foothills, of which the Miedzianka area is an important part. One of the successes of this association is the creation and running of the Sudeten Educational Farm (SZE). One of the statutory aims of SZE is also to preserve the history of regional mining, of which Miedzianka is a natural part. Therefore, there is a need to undertake research on the history of mining in the area of Miedzianka and to verify local suspicions concerning the current threat of post-mining deformation in Miedzianka.

The project aims to create a comprehensive database (geodatabase) which contains information about changes in Miedzianka as a result of the historical mining of copper ore. The purpose of the above geodatabase was:

1) creation of a low-budget land development plan that will be useful, among others, for town planners in the revitalization of the Miedzianka area,
2) data archiving and presentation of land use changes over time,
3) creation of a public application that will allow information about Miedzianka to be easily viewed.

The created geodatabase will be published using a web application. This will make the collected information available to the project team over the internet. The developed application will also be used to present information obtained from terrain deformation measurements, which will be carried out using several different techniques: GPS, remote sensing and surveying.

4. Application for geodata presentation

One of the project goals was to create a functional application that will serve as a tool to assist people involved, for example, in the study of land use changes. What is more, the application should allow maps based on various types of spatial data to be displayed and simple operations to be performed on these maps, i.e. distance and surface measurements, dynamic printouts, address search, or displaying multiple thematic layers at the same time. In the context of working with data from many sources and topographic and thematic maps (mining, geological), this last functionality seemed particularly important.

The second important assumption was the minimization of the amount of work due to the short time span of the project and the low budget. The goal was to prove that in a short time it is possible to create a good quality and truly functional tool. From a technical point of view, the aim of this study was to design a WebGIS architecture that requires no programming skills from the user and does not require him to set up a GIS server. Therefore, it was decided to use the WebGIS platform provided by ArcGIS Online (AGOL) technology, with an open academic license.

AGOL supports all the OGC standards such as WFS, WMS, WMTS as well as REST map services. What is more, AGOL provides configurable user-friendly WebGIS application templates that are designed for various map applications. Therefore, the application was generated without writing a line of code.

According to the required IT infrastructure, the solution is based on the Esri SaaS platform, so all the server functionalities (hosting web maps, geoprocessing tools, as well as web application) can be moved to the cloud. Nowadays, cloud-based WebGIS platforms (SaaS model) have moved logic and data layers to the cloud as a single tier. Therefore, it is now possible to develop WebGIS projects more easily with the use of only SaaS. The second tier of our application contains a desktop GIS which is linked to the AGOL app.

The affine method in desktop GIS (ArcMap 10.6) was used to calibrate the collected archival materials, perform digitization, develop graphical map projects, and upload spatial data to a file geodatabase. This kind of file geodatabase functions as a data layer that feeds graphic map projects prepared using the GIS desktop. All these data are subsequently transmitted to the cloud. This 2-tier (SaaS & Desktop) architecture creates new WebGIS architecture possibilities [7]. The main application interface is shown in the figure below (Fig. 2).

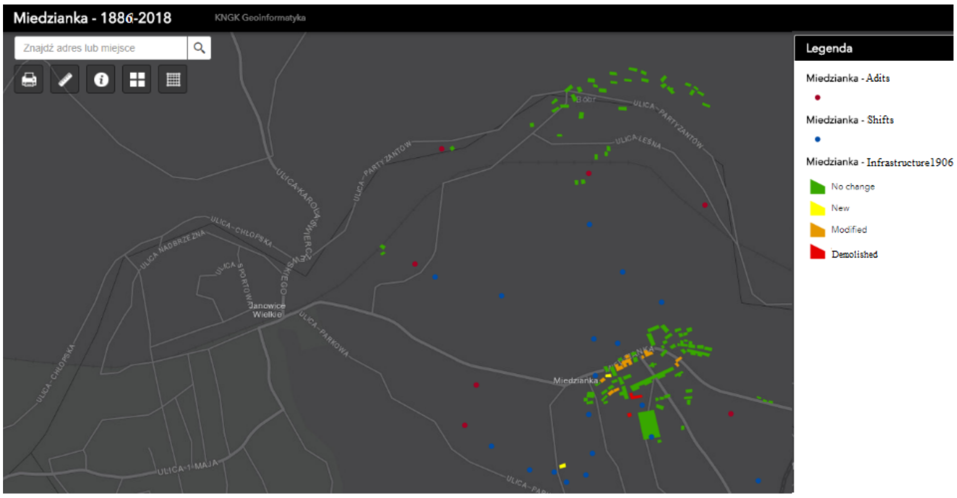

Fig. 2. The main application window

5. Input data

The article uses two types of input data to present both the historical and the current state of the area around Miedzianka:

- historical situation: received from the local geodetic and cartographic documentation center there are 7 archival maps from 1886 to 1951 in the Polish CS92 coordinate system, UTM, and the German Messtischblatt coordinate system on a scale of 1:25 000,
- current state of infrastructure: map of land and building records,
- current surface state: data from the Sentinel 1 satellite mission,
- 80 maps of mining excavations from the archive of the Higher Mining Office (WUG): maps of uranium mines from 1951–1953, drawn up in 1:500 scale; several maps were prepared with descriptions in Russian; some of them are made entirely by hand; some are made by a Polish company based in Stalinogród (currently Katowice).

5.1. Infrastructure change-over

Historical and current documentation in many fields of science is a valuable source of information. In this case, it was used to indicate changes that have occurred in the municipal infrastructure of Miedzianka town. The analysis used 7 archival maps, the first two of which were military maps (year of preparation: 1936, 1951) in the UTM and Poland CS92 coordinate systems. The scale of the maps was respectively 1:100 000 and 1:25 000. The next five maps were topographic maps in the German Messtischblatt coordinate system from 1886 (Fig. 3), 1906, 1913, 1936 and 1939 on a scale of 1:25 000.

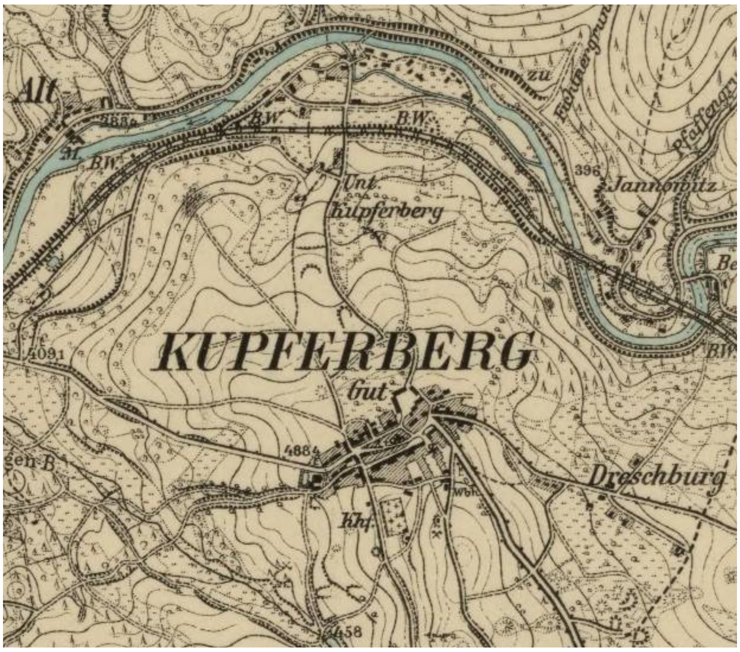

Fig. 3. Fragment of the German Messtischblatt topographic map from 1886 on a scale of 1:25 000

Information about the present development was obtained from the current map of land and building records in cooperation with the local geodetic and cartographic documentation center.

5.2. InSAR data

Interferometric Synthetic Aperture Radar is a remote sensing method that allows detection and measurement of dynamic terrain movements. This technology finds particular application in investigating the deformation of mining areas [19, 20]. The present research uses satellite imagery from the Sentinel mission, which is supervised by the European Space Agency “ESA” (website:

www.esa.int/ESA). The Sentinel 1 satellite, which operates under this program, has performed radar imaging of the surface of the Earth since April 2014. Data from the Sentinel 1 mission is obtained through a constellation of identical C-band synthetic aperture radars (two units: A and B), which makes it possible to work on images acquired within a 6-day timespan (reduced from 35 days for ERS-1 and ERS-2 or 30/35 days for ENVISAT) [20].

6. Results

On the basis of the obtained materials, the full interpretation was presented of the changes in Miedzianka from the late 19th century to the present day. The approach included:

- taking into account changes in urban development based on available maps using GIS software,
- obtaining information about the current surface area in Miedzianka by generating a DEM model from interferometric data.

6.1. Urban development

The surface structures in Miedzianka are a perfect example of the impact of mining operations on the land surface. Collected materials from various maps allowed direct identification of changes to buildings. To merge the information from all the maps, the military topographic map from 1936 was used as a reference. The calibration was performed for four adjustment points, with an RMS error of 9.07. Based on the calibrated map in the Poland CS92 coordinate system, further calibrations of 5 topographic maps and 1 military map from 1951 were made. Due to the unusual German coordinate system and the occurrence of both the Greenwich and the Ferro meridians on these maps, it was decided that the calibration would take place on characteristic points in the area such as crossroads, triangulation points, etc. On each map, 8 adjustment points were indicated where the RMS error ranged from 8 to 19.

After the above steps, the urban structure that existed in 1886–2018 was visually analyzed by performing manual vectorization of the buildings on the maps (Fig. 4).

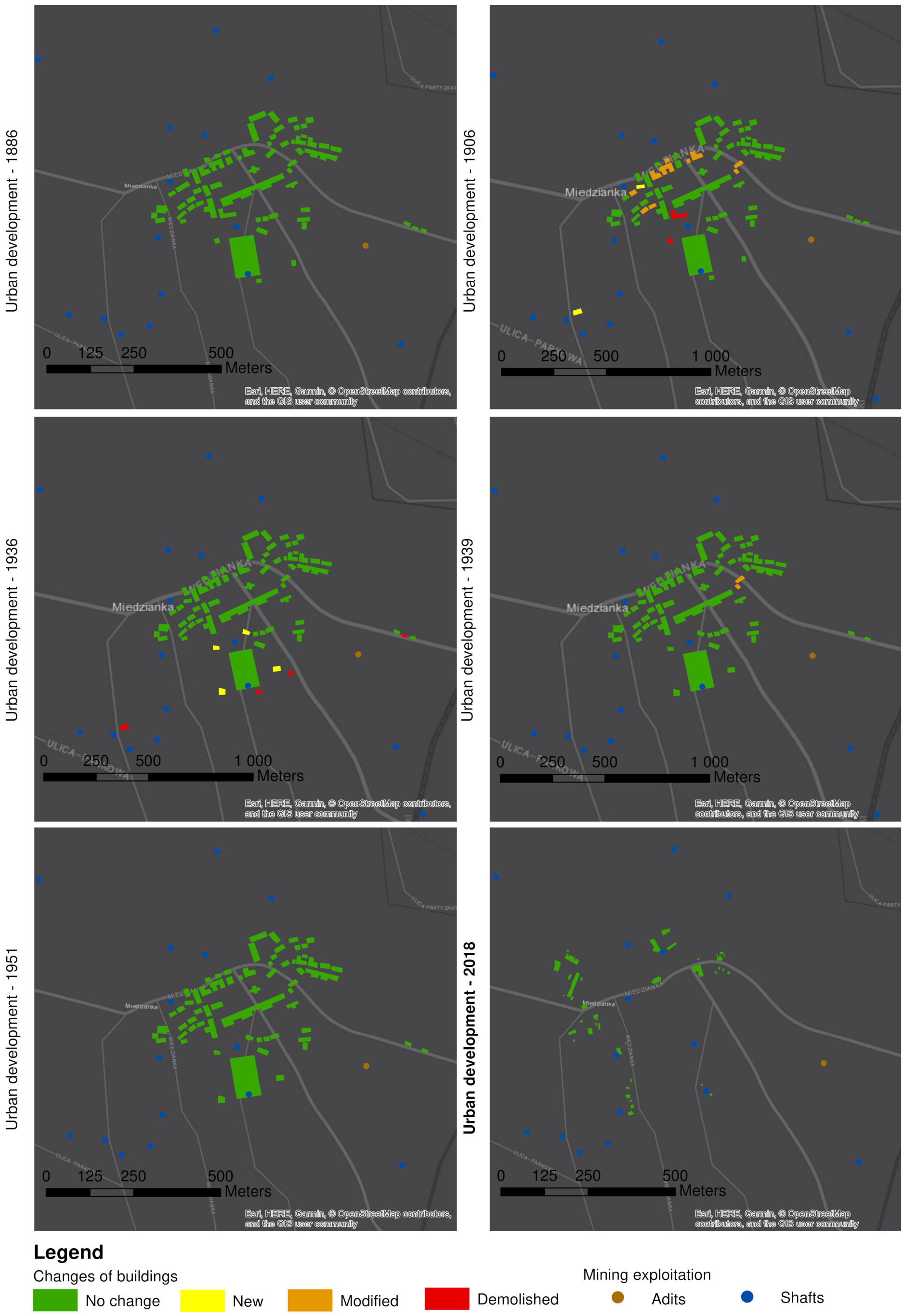

Fig. 4. Changes of urban development in Miedzianka between 1886–2018

Numbers of new, modified or demolished buildings were identified on the maps by comparing them in chronological order, Showing the result of the above analysis in Table 1, the biggest changes took place before 1936. In those years, more than 5% of the total number of buildings were newly built residential buildings (mainly in the upper part of Miedzianka), less than 7% were demolished buildings and about 10% of them were modified (either partially demolished or extended). However, the biggest changes were noticeable when comparing the historical and contemporary data. Only 22% of Miedzianka's current residential buildings are historic. Based on these statistics, it can be concluded that mining exploitation had a huge impact on local development.

Table 1. Characteristics of the urban infrastructure of Miedzianka

Year of information	Number of existing buildings	Number of new buildings	Number of demolished buildings	Number of modified buildings
1886	101	-	-	-
1906	101	2	2	10
1913	100	0	1	1
1936	105	6	1	2
1939	106	2	1	0
1951	106	0	0	0
2018	24	-	-	-

Based on the above analysis, it was found that in Miedzianka during these years there were significant changes in the urban infrastructure. These changes most likely reflected the extensive exploitation carried out during those times. These conclusions can be drawn from information obtained about mining activities such as the exact locations of shafts, adits and buildings that have disappeared, most of which were located near the shafts or adits. In addition, their deterioration was random, as is confirmed by some historical stories about Miedzianka.

6.2. InSAR technique

The indicator of the compatibility level between the phases of two different SAR images is coherence, or more precisely, the correlation coefficient of complex values. Deficiencies in mutual compliance may be the result of technical factors (temporal and perpendicular baseline) or environmental factors (land use and land cover, atmosphere impact, local slope). The coherence value for the area can be read from the coherence map generated on the basis of coregistered SAR images. Lack of mutual correlation of images generates noise and distorts the readability of results [21].

The analysis was carried out on the basis of 12 radarograms, from which 6 coherence maps were generated for different seasons of the year. The temporary baseline between SAR images was 6 days for all cases. The specific pairs of images on the basis of which coherence was examined were analyzed in terms of atmospheric similarity based on archival data from the www.meteomodel.pl portal in order to decrease the variability of conditions. The images with divergent geometrical baseline values were selected to determine whether any coherence deficiencies are caused by this.

The obtained coherence maps were clipped to equal parts of the Miedzianka area (18.58 square kilometers). The mean level of coherence was recorded for each case. The values are similar and do not exceed 0.4 (the threshold value of good readability of interferograms). The collation is shown in Table 2 and views of the coherence maps are shown in Figure 5. The numbers in column 1 correspond to the image numbers.

Table 2. Coherence collation

Number	Date	Min	Mean	Max
1	18.05.2017–24.05.2017	0.012	0.289	0.985
2	29.07.2017–04.08.2017	0.011	0.331	0.977
3	09.09.2017–15.09.2017	0.011	0.330	0.980
4	02.11.2017–08.11.2017	0.012	0.391	0.983
5	13.01.2018–19.01.2018	0.013	0.349	0.979
6	08.03.2018–14.03.2018	0.015	0.327	0.988

On the basis of the obtained values it was possible to state that the coherence for the studied area is weak; this could generate noise that makes it impossible to carry out thorough analyses. All the received coherence maps belong to class 1 (lack of coherence) [21]. Therefore an attempt to perform DInSAR or PSInSAR analysis may turn out to be ineffective [22]. Due to the rejection of the majority of options that may disturb coherence during the analysis, the terrain coverage for the studied area was analyzed.

A significant relationship between the coherence value and the type of land cover was noticed. It was concluded that the best coherence was recorded for arable land (without plants) and buildings; the worst was for meadows and forests. Coherence increases within months when the vegetation is of lower density.

The InSAR technique is often used to create a digital DEM model with an accuracy of up to 1 meter [23]. In this article, radar imagery from the period 14.02–02.03.2018 were used to generate the DEM model. When selecting specific imagery, the maximum possible size of the geometric base was selected.

The generated DEM model (Fig. 6) is characterized by a raster cell size of 0.5 seconds. In relation to the SRTM model, this value is twice as low, which may indicate a much better resolution of the obtained model. However, after completing the accuracy analysis, it was determined that the accuracy of the DEM model is in the range of 20 to 50 m. For the SRTM model, this accuracy is 1 meter. The low level of accuracy was caused by poor coherence, which was closely related to the type of the studied area: the occurrence of large number of agricultural, forest areas and small number of build-up areas (where the value of coherence is better). Therefore, it can be concluded that the generated DEM model only serves the general visualization of the digital terrain surface.

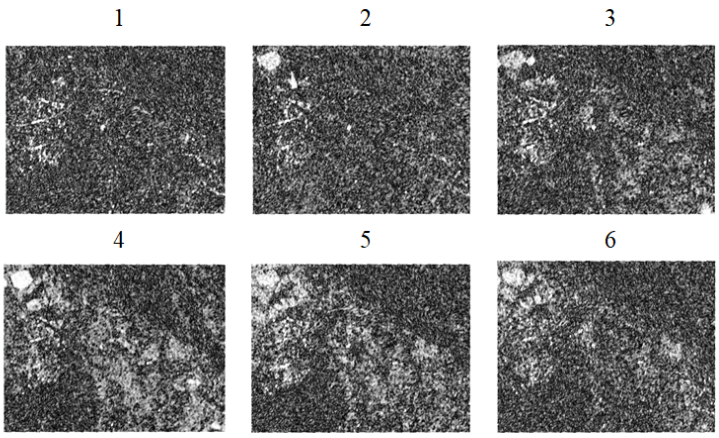

Fig. 5. Images 1-6 showing obtained coherence maps

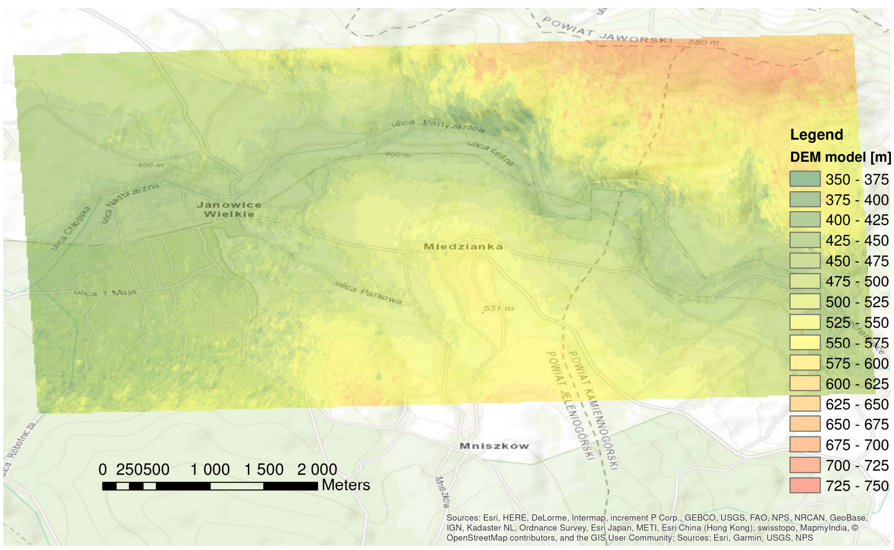

Fig. 6. Generated DEM model from Miedzianka town

7. Conclusions

Spatial planning and revitalization of areas such as Miedzianka require an interdisciplinary approach to the subject. On the basis of archival data and satellite imagery, it is possible to comprehensively present the characteristics of changes taking place in Miedzianka. With the use of tools such as AGOL, the content of the data and its transmission are largely simplified and easily accessible. The created application will be the core of a public database that aims to provide information about changes in land development. This information should be useful for many potential groups of planners. In addition, the great advantage of the created application is the ability to create it without the need for programming. All in all, the development and revitalization of post-mining areas such as Miedzianka will become much easier to manage.

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