TERRAIN MOTION OF SELECTED ABANDONED HARD COAL MINES IN THE NORTH – EASTERN PART OF THE UPPER SILESIAN COAL BASIN (SOUTHERN POLAND) IN VIEW OF SAR INTERFEROMETRIC DATA

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ABSTRACT

Application of PSInSAR satellite interferometric method for observations of ground deformations in the north-eastern part of the USCB is presented in this paper. As test sites four hard coal mines located in Upper Silesian Coal Basin were selected. Water inflow in the mine may also cause different phenomena like surface instability (subsidence, uplift), induced seismicity and chemical degradation of the water. The paper presents the relationship between dewatering process in closed mines and surface changes indicated on the satellite interferometric data. The first "Terrafirma Sosnowiec" PSInSAR dataset from 1992 to 2003 shows active mines and indicates values of ground motions from -9.4 to +2.1 mm per year. It is estimated that 97 % of PS points show subsidence. On the other hand second PSInSAR database (Terrafirma "Bedzin") from 2003 to 2010, in the period of abandoned mines shows values from - 7.6 to +9.8. Almost 97 % of PS points indicating uplift of the terrain. In common opinion after period of 5 years from mine closure the area is considered as safe. The obtained results show that it is not true, and the ground motions still exist at these area. This may lead to generating potential hazard to people, buildings and infrastructure.

INTRODUCTION

The Upper Silesian Coal Basin (USCB) is located in the southern Poland and in the region of Ostrava-Karvina in the Czech Republic. It covers an area of 7,250 km^2. This is the major coal basin in Poland, and also one of the largest in Europe.

Many centuries of mining activity in the Upper Silesia has caused irreversible changes in the earth's surface over large areas. Extraction of minerals and their processing is accompanied by the transformation of the terrain as:

- Subsidence (basins, bowls and depressions).
- Flooding and inundations.
- Overburden drainage of exploiting deposits.
- Seismic shocks.
- Storage of waste rocks at heaps.

In the last years the method of coal mining is mainly longwall with caving. It is estimated that in some areas of the USCB – central, north and north – west, coal seems with a total thickness about 50 – 60 m. were exploited. The subsidence on these area locally exceed 30 m and usually reach values from a dozen to 20 m. On the other parts of USCB, where exploitation is carried out from at least 25 years, values of subsidence are ranging from 5 to 10 m.

Presently in northern and north – eastern part of USCB, despite the operation of underground dewatering systems the aquifers in abandoned mines have steady tendency to rise up. As the result, in areas where until recently subsidence occur in the surface, the terrain uplift is observed. This phenomena could be excellently monitored using SAR interferometry technology. Examples of ground motion changes above abandoned Coal Mines ”Grodziec”, “Paryż”, “Saturn” and “Sosnowiec” were presented in this paper.

DESCRIPTION OF THE INTERFEROMETRIC TECHNIQUES AND DATA

Synthetic Aperture Radar Interferometry (InSAR) from satellite radar images has revolutionized the field of ground deformation research since its first geological applications about a two decades ago. This past 20 years allowed for significant development of the processing techniques as well as for increased use of InSAR data to study displacement associated with, as an example, active faults, volcanoes, landslides, aquifers, oil fields, glaciers or mining, at a spatial resolution of less than 100 m and centimetre precision. The method is based on the principle of wave interference. As a result of a combination of two radar images of the same area, acquired before and after the occurrence of ground displacement, an interferogram is created. Changes in ground surface are visible in the form of the interferometric fringes. InSAR is particularly sensitive to vertical deformation (1). To improve the ability to determine millimetre-level displacement, more than 10 years ago a new approach, Permanent Scatterer SAR Interferometry (PSInSAR) has been introduced (2)(3). The processing is made on a basis of more than 15 SAR images, acquired for the same area in long period . As a result of the processing of the stack, set of thousands of permanent scatterers (PS) is identified. PS are objects, which are characterized by stable reflection of the radar beam. For each point displacement time series and velocity of movement for whole period of acquisition can be calculated (4). PSInSAR allows to identify motion at a level of 1 mm per year (1).

InSAR has been world-wide successfully used for monitoring mining-inducted ground movements as well as movements indirectly related to the activity or closure of the mine. The possibility to study deformation over mining areas have been widely presented for example by (5). Also, Upper Silesia Coal Basin in Poland has been subject of many studies conducted by several research institutions in Poland, examples can be found in (6),(7),(8). For this study several stacks of ERS and ENVISAT C-band satellite data from 1992 to 2010 were analyzed to investigate terrain motion over four (“Grodziec”, “Paryz”, Sosnowiec” and “Saturn”) abandoned hard coal mines.

GEOLOGICAL SETTING AND HYDROGEOLOGICAL CHARACTERISTICS

The region of the Upper Silesian Coal Basin can be divided into two hydrogeological subregions: the north-eastern subregion (I) and the south-western subregion (II) (Fig. 1). Subregion I is described as a hydrogeologically "open" area. Quaternary, Jurassic and Triassic aquifer formations are present in the overburden. These formations are hydraulically connected to the Carboniferous formations. Sandstones of high porosity and permeability are present in the Carboniferous profile. The research area comprising the abandoned mines of: Grodziec, Paryż, Saturn and Sosnowiec is located in the north-eastern part of the USCB, being a part of the uncovered subregion I. Three lithostratigraphic series are present in the profile of Carboniferous strata: the Upper Silesian Sandstone Series, the Paralic Series and the Mudstone series. The Carboniferous outcrops are located within the area of the “Paryż” and “Grodziec” mines, with the Carboniferous being covered by not very thick Triassic or Quaternary deposits in the remaining areas. The research area is characterised by complex tectonics and it is intersected by numerous faults. The main fault is the Będzin-Wojkowice fault extending NWN-ESE with a slip of 200-250 m towards the SW. Another characteristic fault is the meridional Grodziec fault with a 260 m slip in the western direction.

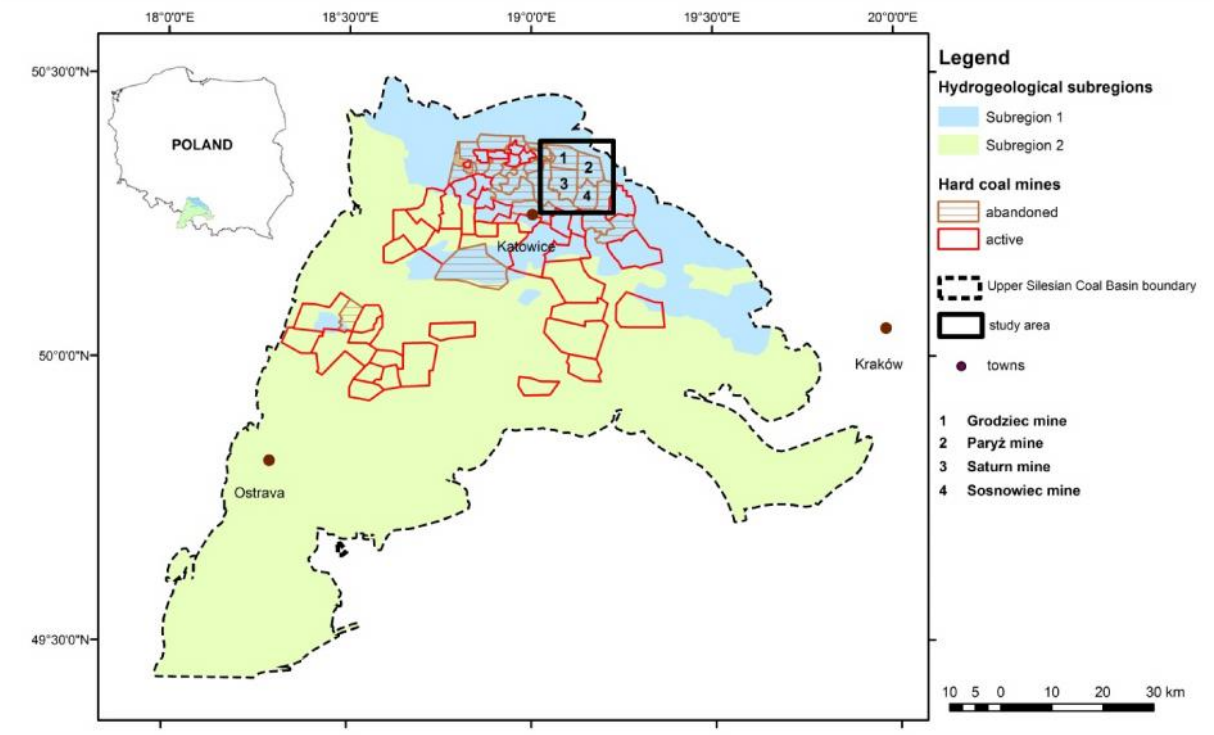

Fig. 1 Simplified hydrogeological map of the Upper Silesian Coal Basin

MINE FLOODING WITHIN THE RESEARCH AREA

The restructuring process of Polish hard coal mining began in 1989. About 70 coal mines were functioning in the Upper Silesian Coal Basin near the end of the 1980s, with just 30 of them left today. Among others, the following unprofitable mines of the Dąbrowa Basin have been liquidated: "Paryż" (December of 1996), "Saturn" (December of 1996), "Sosnowiec" (December of 1998) and "Grodziec" (June of 2000). Mine shutdown processes are associated with water risks related to flooding of mine workings. Submersible or stationary dewatering systems are used in order to minimise these risks. A controlled mine workings flooding process was conducted for the regions of the above mentioned mines. According to the data from monitoring for the period between 2001 and 2008, underground water reservoirs were created inside the flooded mines, their respective volumes being 10.1, 8.1, 7.4 and 4.5 mln m^3 (9). Continuous dewatering was conducted in the Paryż, Saturn and Sosnowiec mines, with the natural inflow of water into the mine workings and goafs being controlled simultaneously. The stationary dewatering system was deactivated in the Grodziec mine between October of 2000 and December of 2005, implementing the mine flooding process. Having reached the water table level of 57 m a.s.l. the submersible pumps were activated, maintaining that level till February of 2007. After that period water damming process was initiated again in the mining workings and goafs, reaching the level of 88 m a.s.l. in May of 2008.

RADAR INTERFEROMETRY DATA AND RESULTS

Three sets of radar data were available for the research area:

- 54 ERS satellite images, C band, descending mode, 1992 – 2003 period;

- 31 Envisat satellite images, C band, track 222, descending mode, 2003 – 2010 period;
- 26 Envisat satellite images, C band, track 484, descending mode, 2002 – 2010 period.

The maximum displacements between 1992 and 2010 ranged from – 19.39 to +12.15 mm per year. This data indicates that the land uplift process began during a period of several years after the liquidation of mines near the end of the 1990s and the initiation of the flooding of mine headings. Particularly interesting information is presented in the data from the flooding of the Grodziec mine between 2000 and 2009. An underground reservoir was created during that time with the volume of 11.6 mln m^3 and the water table level raised by as many as 279 metres. The analysed interferometric data from the time series (TS) for this period indicate a surface uplift process. In this case the magnitude of uplift amount to about a dozen mm/year. There is a direct correlation between flooding of mine workings in abandoned mines and the land surface uplifting process. Discontinuation or temporary suspension of dewatering of an abandoned mine leads to shrinkage of the depression cone, creation of massive underground reservoirs and reconstruction of previous groundwater regime. The oldest data originating from the ERS satellite for the 1992-2003 period proves that minor land subsidence is a predominant process taking place within the research area (Fig. 2).

Fig. 2 ERS (1992-2003) Permanent Scatterer velocity and Time Series of selected points within abandoned mines (black arrows – the date of liquidation of mine)

The greatest subsidence of about a dozen millimetres per year occurs within the area of the Grodziec and Sosnowiec mines, which were closed in June of 2000 and December of 1998 respectively. Within the mining areas of the Paryż and Saturn mines shut down in December of 1996 the predominance of PS points which may be considered stable is visible. The liquidation date of each mine has been marked by a vertical black arrow on the time series plots for individual mining areas.

A different picture is presented by the data from the Envisat satellite: 2002-2010 (track 494)- Fig. 3. During this time period an uplifting process is predominant (Fig. and Fig.). The highest values of uplift for the PS points exceed 10 mm per year. The main causes of vertical upward movement of points are flooding of mine workings and discontinuation or temporary suspension of dewatering of liquidated mines. As an effect, reconstruction of previously drained aquifers takes place along with an increase in pressure in the aquifer and with creation of huge groundwater reservoirs. The volume of water in flooded goafs exceeds about a dozen million m^3. The data from radar interferometry indicates that the areas of highest uplift are located in the proximity of fault zones. The fissures in overburden layers, especially the Triassic limestones contribute to the change in groundwater circulation regime. The presence of greatest displacements in the area surrounding the Będzin-Wojkowice and Grodziec faults probably evidences the process of unsealing the fault zones.

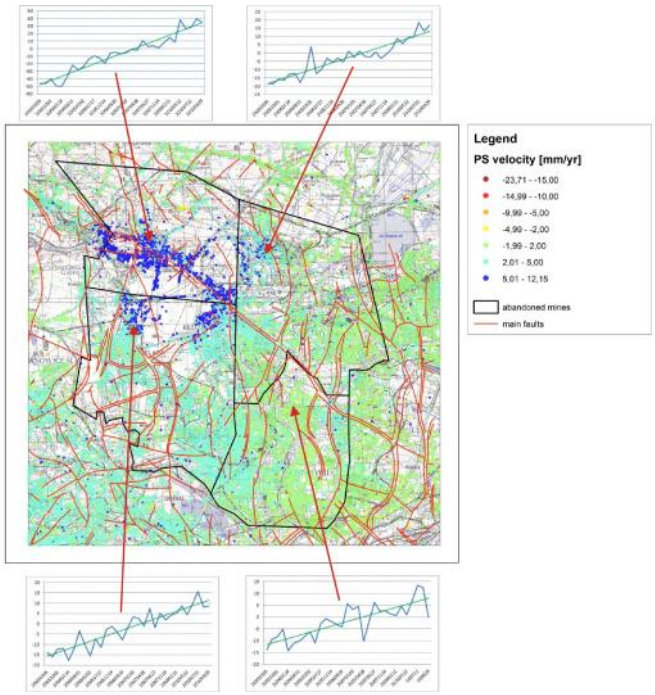

Fig. 3 Envisat – track 494 (2002-2010) Permanent Scatterer velocity and Time Series of selected points within abandoned mines.

CONCLUSIONS

During mine liquidation the presence of water in the rock mass, resulting from the reconstruction of hydrogeological conditions in a past mining area dewatered during extraction, and the pressure of groundwater associated with it may cause slight uplift of the surface, especially in the vicinity of fault zones. In turn, the reascension of water table after discontinuation of mine dewatering causes land uplift. Based on the observation of the data from radar interferometry it can be concluded that ascending movements are usually small and in reality amount to approximately 10 % of the value of subsidence from the period of mine activity. The existing regulations demand that the area of a liquidated mine be monitored for 5 years after the extraction is over. Based on the radar interferometry data it appears that land movements within a past mining area are maintained even for over 10

years after mine shutdown. From the experience of the authors it can be concluded that the application of radar imagery and radar interferometry technique provides a more detailed picture of surface movements than geodesic methods. It is particularly important considering the fact that no continuous geodetic monitoring takes place within the areas of abandoned mines.

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