LAND AND SOIL MOISTURE CHANGE ANALYSIS IN THE LAKE MOST SURROUNDINGS FROM THE SENTINEL-1 AND COSMO IMAGES (CZECH REPUBLIC)

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ABSTRACT: Lake Most (Czech Republic) is an anthropogenic lake, which was created as a project for the reclamation of a former brown coal surface mine. The lake does not have a natural surface runoff, and after the complete filling with water it is supposed to be a recreation area as well as its surroundings. During the filling of the lake, however, significant water losses occurred. Obviously, these losses are not due to evapotranspiration. The water leak may be caused by imperfect sealing of the bottom of the lake. Another reason for the lake's leak may be old mining works, which are the remains of the underground mining in this area.

In 2017 a project was launched to find out the cause of water loss from the lake. The project should also propose technical measures to avoid further water losses. The evaluation of data obtained by remote sensing techniques helps to identify phenomena on the Earth's surface (landslides, anomalous soil moisture and other) that may be related to water leakage. Analyses of Sentinel-1 and Cosmo images currently are being used for the area of interest.

The project is expected to support higher education consequently. New tutorials focused on remotely sensed image processing are being created. These outcomes should contribute to the improvement of the tasks university students have to fulfil in the practical part of the subject.

1. INTRODUCTION

Surface brown coal mining means total devastation of the landscape not only in the mining area but also in the surroundings. The opening of the surface mine changes the original terrain and causes major changes in surface water resources. During the mining of the overburden layers and the coal seam, the original aquifers are disturbed. As a result of mining, a residual pit was created which is often flooded (Stottmeister, U., et al., 2002) with water from its catchment area.

Abandoned coal mining sites must be reclaimed according to the law in the Czech Republic. These complex interventions in the landscape are carried out in such a way so that the area concerned could be used most appropriately. Residual pits are often used as mining lakes (Klapper, H., 200) after the mining process.

In post-mining landscapes after surface coal mining, some negative effects are a risk to the environment (Harat, A. et al., 2015). Slight movements normally occur. In the Czech Republic, surface mining of coal frequently happens in places where coal had already been mined in an underground way. Some old mining works are not included in mine maps. In such areas, groundwater spills from old underground mines, loss of water from flooded parts of the surface mine or spontaneous combustion of residual coal in old mine works, may occur. Some of these negative phenomena can also be found in the reclaimed post-mining landscape. When designing remediation measures, not all data describing old mine works were always available.

In the case of large-scale environmental hazards, the cause of occurrence must be identified. Measures to eliminate the cause and measures to eliminate possible risks are subsequently carried out. The process of identifying latent geo-hazards or assessing geo-hazards, whose manifestations are already evident, is carried out by a variety of methods. These include, for example, modelling of different phenomena using spatial data. The key source of spatial data describing the area of interest is remote sensing.

Since spring 2017, our team has been working on a project aimed at assessing the causes of water loss from a mining lake. We analyse several water loss possibilities that may be relevant. Expected natural causes are lake water evaporation and transpiration of coastal plants. The last option is the underground drainage, which should be minimal, as the bottom of the lake had been sealed before the lake was filled. If a significant underground runoff still occurs, it may be caused by imperfectly functional sealing of the lake bottom. In this case, water leakage can be expected from the rock environment. However, water can also escape from old mining parts that are found in the surrounding rock environment. The old mining works originate in the mid-19th century until the 20th century, when brown coal was mined in these sites exclusively by underground mining.

Image products from satellite systems are often a key source of information describing the areas referred to as the post-mining landscape. In the Lake Most project we use Sentinel-1 and Cosmo products as important sources of information for identifying changes in terrain relief and soil moisture in the post-mining landscape environment. Significant landslides, subsidence and soil moisture can signal phenomena such as the occurrence of old mine workings, instability of reclaimed slopes, and so on. These phenomena can adversely affect the water level in the lake.

2. METHODOLOGY

The process of looking for causes of water loss requires to get acquainted with the environment of the area of interest. This is a prerequisite for understanding the processes that take place there. A useful tool and method for describing this environment are modelling methods. Gradually we have compiled a geomorphological model of the territory and we are currently preparing a model of the geological environment of the area of interest. Following this, models (hydrological and hydrogeological) will be developed to explain the water balance of the lake catchment area.

The data used in these models can be supplemented with important information that can be derived from satellite data. This can make the data in the models significantly more accurate.

2.1 Geomorphological model

If these computational models are to be as perfect as possible, it is necessary to obtain the most accurate description of the area of interest. The basis is the area of interest geomorphological model, based on the digital model of the landscape relief. To create a geomorphological model, we used the Digital Terrain Model of the Czech Republic – the 5th generation (DMR 5G).

According original product description (CUZK, 2017) "DMR 5G represents natural or by human activity modified terrain surface in digital form as heights of discrete points in irregular triangle network (TIN) with X,Y, H coordinates, where H means the altitude in the Baltic Vertical Datum - After Adjustment with total standard error of 0.18 m of height in the bare terrain and 0.3 m in forested terrain. The model is based on the data acquired by altimetry airborne laser scanning of the Czech Republic territory between years 2009 and 2013. DMR 5G is established to analyse terrain situation at local scale and character, e.g. for land adaptations projecting, transport and water management projects planning, local natural phenomena modelling etc. DMR 5G is the fundamental source database for creation of contours established for maps of large scales and computer visualisation of altimetry in territorially oriented information systems at high level of detail."

2.2 Geological model

Successful hydrogeological modelling requires sufficient knowledge of the geological environment, best described in the form of a digital model. Many data are available for the area of interest (borehole investigation, geophysical survey, geotechnical measurements, meteorological measurements, surface and groundwater monitoring, etc.). Some data were obtained before and during the coal mining process. Other data refer to the reclamation of the mining impacts.

2.2 Hydrological and hydrogeological model

In the next phase, we will use mainly hydrological and hydrogeological modelling methods, which will contribute to the knowledge of water balance of the lake basin. The water evaporation from the lake and the transpiration of the plants will be quantified based on hydrological modelling. Further modelling will verify the loss of water from the lake due to possible leakage through the rock environment or possible escape by old mining parts. We will use the method of hydrogeological modelling (Rapantova, N. et al., 2007).

3. STUDY AREA AND DATA

Lake Most (see Fig. 1) was created on the site of the former brown coal mine Lezaky. The lake (399 metres above sea level) is situated among the towns of Most (1,5 kilometres), Zaluzi u Mostu (2 kilometres) and Branany (3 kilometres) directly below the Hnevin hill (1 kilometre) on the site of the old town of Most. The original city Most was displaced and demolished in the 1970s and a brown coal opencast mine was opened. Coal mining in the mine was finished in 1999. Subsequently, remediation of abandoned surface mine was carried. In the period 2008 - 2012, the remediated site was filled with water from the Ohre river. A closed basin designed for recreation was created. The lake has an area of 311 hectares, 2.5 kilometres long and 1.5 kilometres wide. The altitude of the water surface is 199 metres above sea level. The maximum depth is 75 metres and the average depth of 22 metres. The lake has a volume of 69.8 million cubic metres.

The source of water for the Most lake is the Ohre river. From there water is supplied by an industrial water pipeline. Another source was the mine water from the Kohinoor mine, about 5 kilometres away. A natural source of water is the inflow from its catchment basin. Filling the lake began in October 2008 and should have been completed in 2011. In fact, the process of filling finished in 2012. According to the project, the lake should be transferred to the planned use in 2018. The current owner of the lake is the Czech Republic.

The closed basin normally retains water, but after the lake was filled, the significant water loss was found out. Refilling such water losses is costly and has reached about € 770,000 (in 2016). In a long-term perspective, the situation like that is unsustainable because spending on the purchase of water would be enormous. The original water level variation tolerance of ± 60 cm was reduced to ± 5 cm and then cancelled completely. The reason is to prevent the banks from drying out and the necessity to re-soak them when refilling. In the future, it is planned to build a mine water treatment plant in the Kohinoor mine and the clear water is to be syphoned into the lake.

It is in the interest of the lake owner to find the cause of water leakage. Subsequently, technical measures should be taken to eliminate the loss of water.

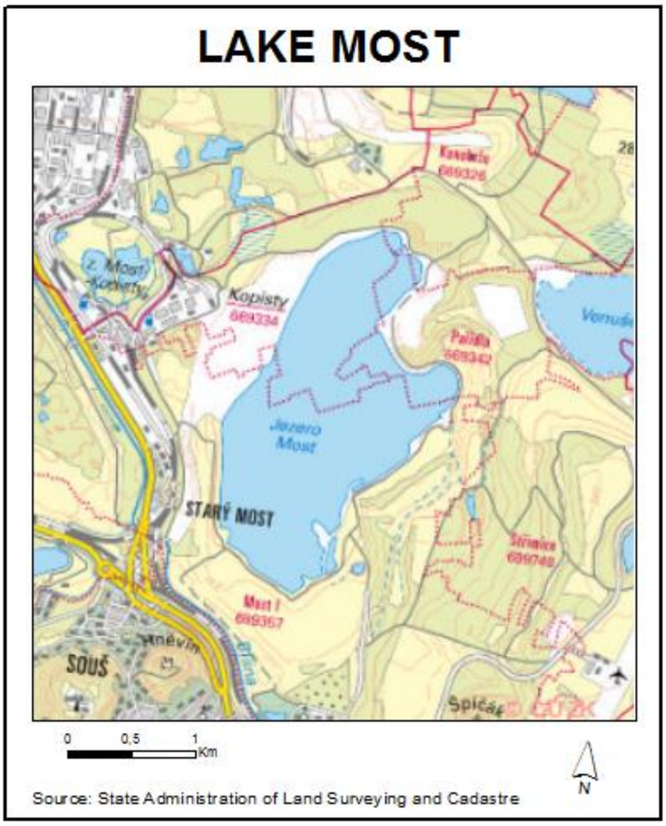

Figure 1. Study area

4. RADAR IMAGES PROCESSING

4.1 Persistent Scatterers SAR Interferometry using Cosmo and Sentinel-1 images

Persistent Scatterers (PS) SAR Interferometry (PS InSAR) method uses radar phase values from a series of SAR images of only selected (persistent) points that reflect the radio signal within a stable intensity through the period of the whole dataset, such as non-vegetated areas and built structures. This method needs at least twenty images for a reliable processing (Ferretti et al., 2000).

For the analysis, all available Cosmo and Sentinel-1 (relative orbit 95) data have been used. Both datasets are from descending satellite pass that means they look from the SEE direction. Ninety-four Cosmo images were scanned between 08/2011-06/2014 with a variable revisit time between 8-32 days and ninety-one Sentinel-1 images between 10/2014-06/2017 with a revisit time 6-12 days. Data were coregistered and processed by SARPROZ software to reach the mean velocity maps over Most lake surroundings (see Fig. 2).

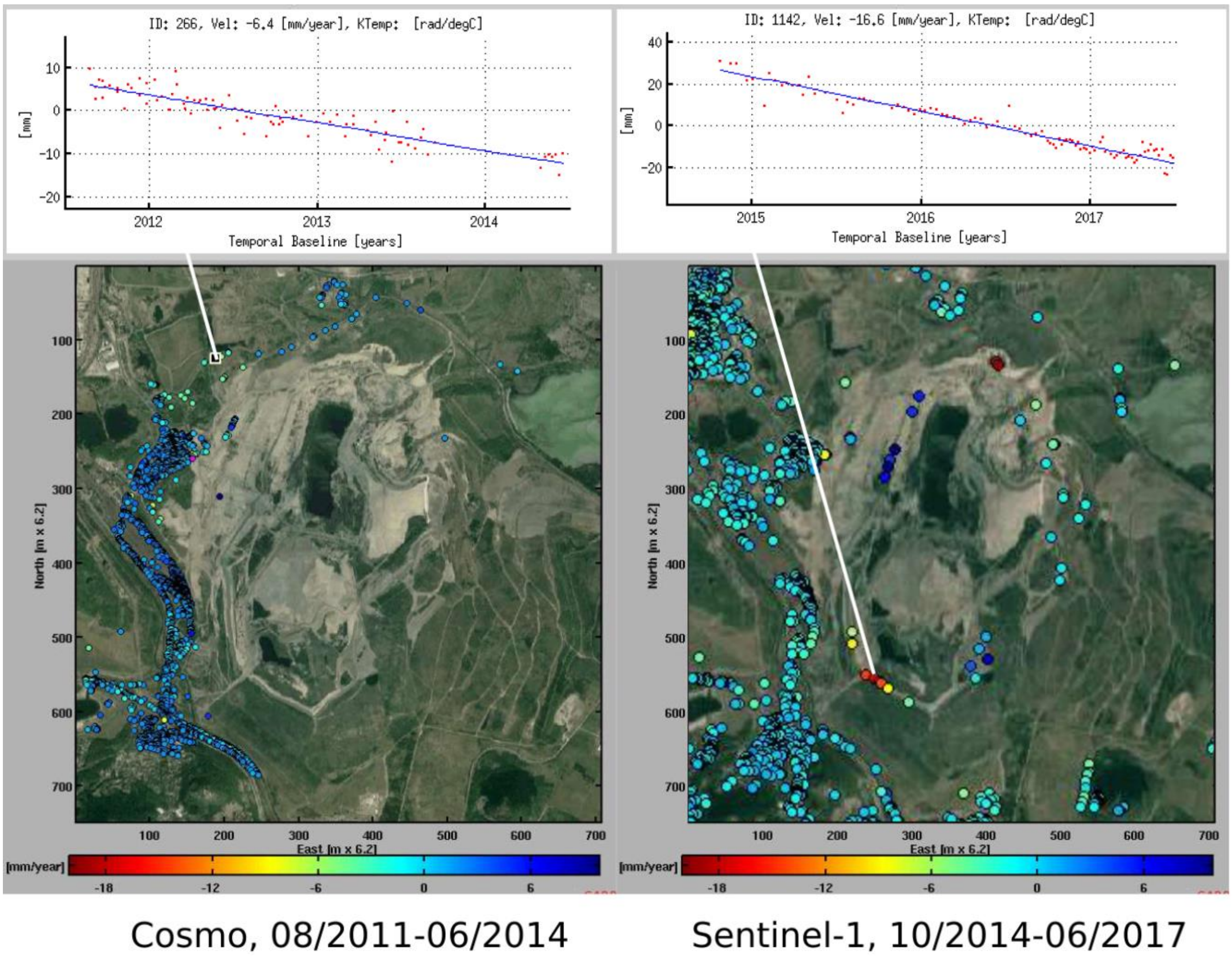

Figure 2. Mean velocity maps of selected points as results from processing Cosmo (left) and Sentinel-1 (right) SAR images using PS InSAR method.

4.2 Analysis of soil moisture changes

SAR data, especially of longer wavelengths, are sensitive to humidity and soil moisture. There are several approaches incorporating satellite data to identify soil moisture. A convenient approach is to process multitemporal series of SAR intensity images - having an additional suitable knowledge in the form of a quantified spatial database of land cover indices. It is possible to extract soil moisture index (SMI) from Sentinel-1 images in the precision better than 5% and resolution down to 100x100 m (Mattia et al., 2011). Our approach is its simplified version and attempts only approximately to identify changes without the proper quantification of SMI.

The problem of soil moisture identification from Cosmo data over Most lake area has several points. Cosmo data are of very high spatial resolution (3 metres per pixel) but are affected strongly by a speckle noise. Radar is sensitive to humidity as well as to physical changes on the surface. Therefore the signal is mixed. A seasonal character of changes as well as the speckle noise can be reduced by averaging SAR images into normalized mean reflectivity maps (MRM) for selected time periods. The first consideration about preparation of annual maps would not fit the needs because there is a long gap in the data time series between 09/2013 and 05/2014. To achieve a set of comparable MRMs without removing data from 2014 (7 images between 05-06/2014), we have decided to prepare only springtime MRMs, i.e. MRMs using May and June images. This was possible for years 2012, 2013, 2014, which gives us a proper chance to identify springtime moisture development after the lake changes in 2012. In addition, we have prepared also MRM for 2011 data but these were available only between August and September. After preparation of MRMs, we have prepared their difference with regards to the 2012 MRM and visualised the outputs in Fig. 3. Indeed, changes in the figured time series maps of the close surroundings of Most lake can be interpreted as continuous changes of soil moisture.

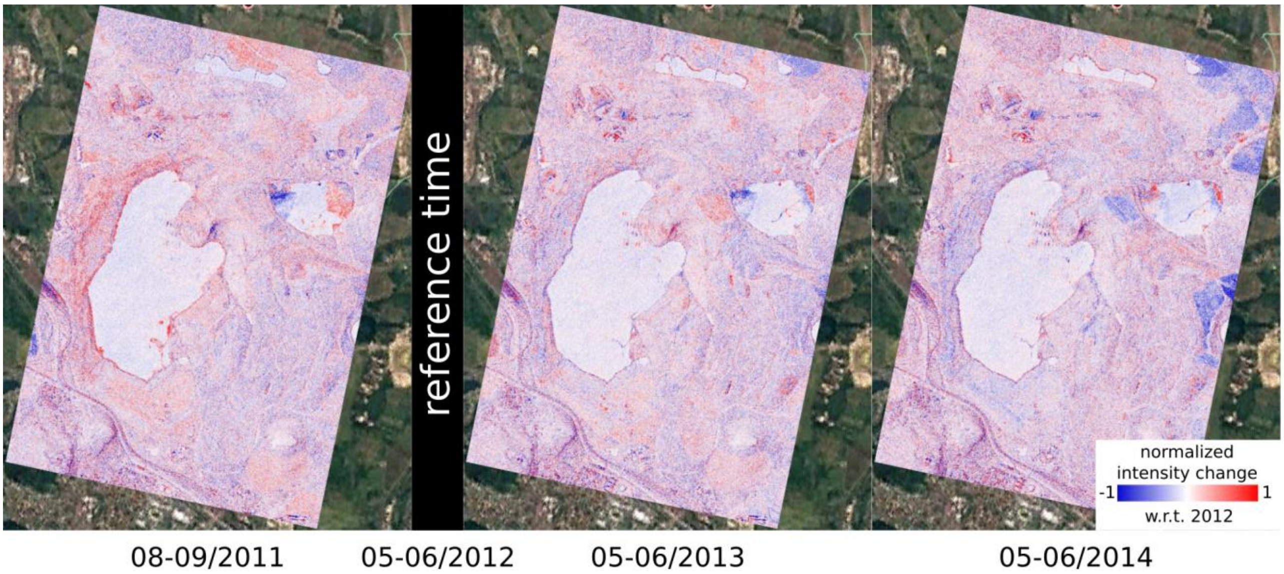

Figure 3. Normalized intensity change maps over Most lake area related to MRM from 05-06/2012 Cosmo SAR images.

A similar approach has been used for processing of Sentinel-1 images. Sentinel-1 dataset consists of ninety-four images between 10/2014 and 06/2017. By using data from springtime of 2015, 2016 and 2017 with 2015 as a reference time (data from 2014 could not be used since the area of interst was expected to be frozen). No significant and systematic development of intensity changes was found by applying the previously described differential approach and are therefore not presented in the paper as a figure. However, by comparing a MRM of Cosmo data (08/2011-06/2014) and those of Sentinel-1 (10/2014-06/2017), the growth of an average soil moisture over Most lake surroundings is clearly seen in Figure 4. Note that both datasets are taken from relatively similar direction.

5. FURTHER WORK

Complementarily, in the same territory, we are going to identify a land change based on the evaluation of selected multi-spectral raster bands from the SENTINEL-2 system. The identification of significant changes in the landscape can be accomplished, e.g. by differencing standardised differential vegetation indices obtained from pairs of multitemporal images. Other methods are based on NDVI images rationing or regression analysis.

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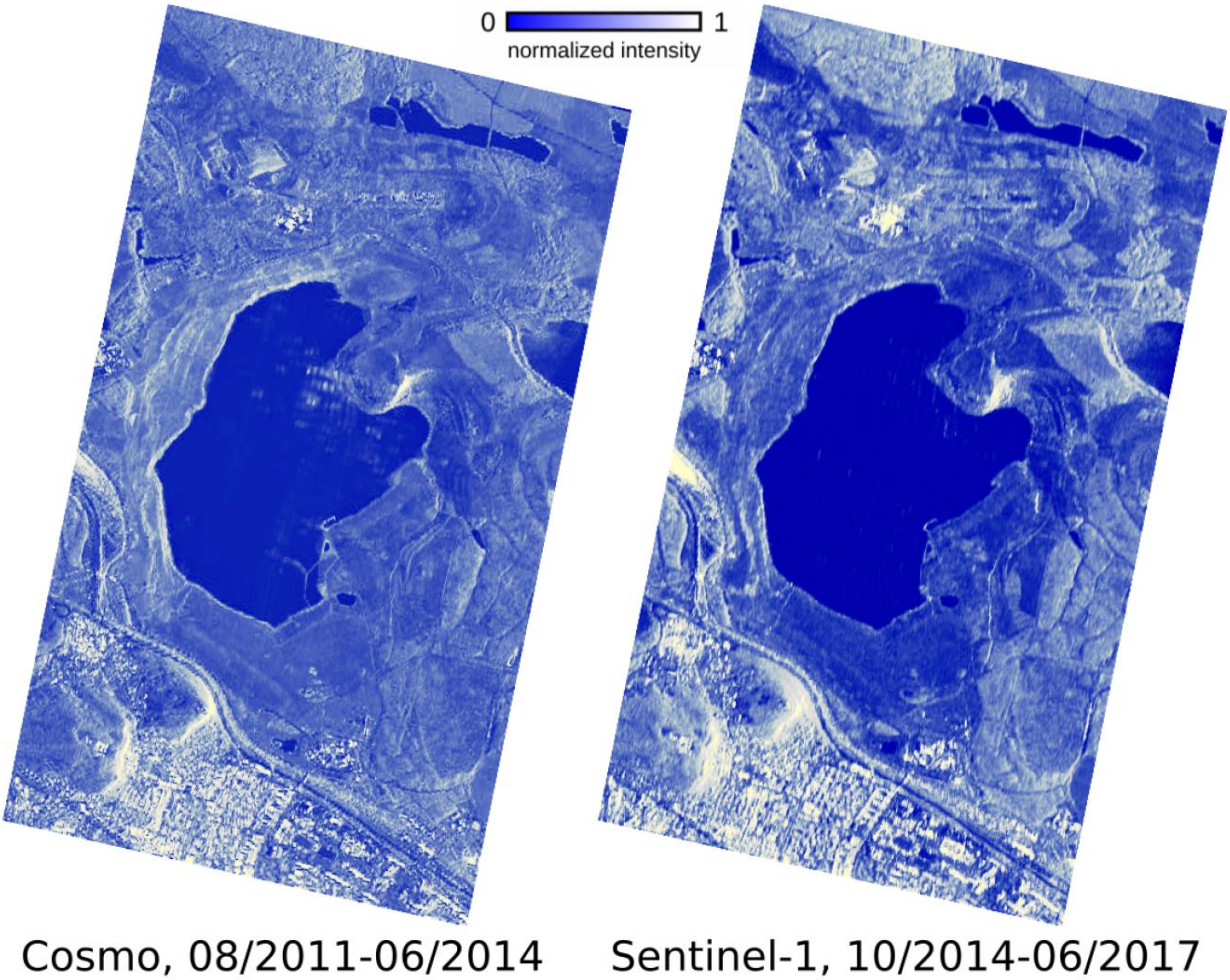

Figure 4. Two average MRMs depicting increase of soil moisture over Most lake surroundings: Cosmo MRM (left) and Sentinel-1 MRM (right).

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