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An analysis of 200-year-long changes in a landscape affected by large-scale surface coal mining: History, present and future

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ABSTRACT

We have investigated almost 200 years of landscape transformations in a traditional brown coal mining region in northwest Bohemia, Czech Republic. The investigation was focused on the central part of the North Bohemian Basin including 44 cadastral areas representing a total area of 228.48 km^2. Within this area, an analysis of land use in six different time periods (1845, 1954, 1975, 1989, 2010, 2050) was performed. The analysis therefore includes the transitory period of a boom and slow-down of surface coal mining and also provides a unique comparison with the planned future condition of the landscape after the year 2050, when the mines have been closed down and the landscape restored. Practically all available geographic data resources on land use have been used – the stable cadastre, topographic maps, current landscape mapping and aerial photographs. We differentiated twelve land-use categories. Both Friedman test and detrended correspondence analysis show significant differences in the representation of individual land-use categories and characteristics of the landscape before and during mining operations and after their discontinuance and revitalisation of spoil tips and in residual pits. For a long period of time, agricultural landscape was changed into an industrial one. The basin part of the studied territory almost completely lacks eco-stabilising features that could be used as a basis for planning of a new landscape. This is because the original landscape had been intensively used for agriculture previously, and almost one half of the territory was over-exploited and other areas were affected by operation facilities and coal processing industrial plants. With the growing number of reclamation projects, the diversity of the landscape has been increasing, as well as the proportion of ecologically valuable elements (mostly forests and water bodies), whose total area could exceed 70% of the landscape's surface in the future, approximating its characteristics to a natural landscape with a high degree of ecological stability.

1. Introduction

No other industry has raised more disputes over land use than mining (Hilson, 2002). The impact of mining on the landscape is so significant that after extracting the raw material, most developed countries embark on technically challenging reclamation projects in order to integrate this landscape, often entirely new, with the surrounding areas unaffected by mining. The aim should be to create a mosaic of areas with different functions: production (forests, agricultural land), social (tourism, new constructions) and non-production (where the dominant functions may be aesthetic or that of nature preservation, among others). Revitalization strategies take into account the history of the affected landscape, specifically when the aim is to achieve a landscape with full ecological function (Demirel, Emil, & Duzgun, 2011).

The changes in landscape structure induced by surface coal mining are enormous. Open cut mining is one of the landscape-altering activities of human history, producing large irreversible (permanent) changes to landscape (Dulias, 2010; Slonecker & Benger, 2001). They can be observed by means of qualitative changes (land-use) and changes of landscape heterogeneity attributes (Sklenička, 2002). By analysing these changes, it is possible to identify parts of stable landscape structures unaffected by significant changes that may be used as a basis for creation of territorial systems of ecological stability (Sklenička & Charvátová, 2003), which are the main resource of species necessary for repopulation of reclaimed spoil heaps and mines with wild-living animals and wild-growing plants, particularly in territories affected by large-

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scale mining. The alternation of landscape affected by mining was studied in detail in Eastern Germany (e.g. Larondelle & Haase, 2012; Lautenbach, Kugel, Lausch, & Seppelt, 2011), West Bohemia (Skaloš et al., 2015) or Central India (Malaviya, Munsi, Oinam, & Joshi, 2010).

Information on land-use may be acquired directly by terrain mapping, or indirectly using remote land sensing methods and maps. Modern satellite remote sensing is a good control tool for monitoring of the reclamation activities (Schmidt & Gleaesser, 1998). Long-term transformations of land use can be analysed by means of a wide range of historic data sources, such as satellite photographs (Antwi, Krawczynski, & Wiegleb, 2008; Antwi, Boakye-Danquah, Asabere, Takeuchi, & Wiegleb, 2014; Brink & Eva, 2009; Brom, Nedbal, Procházka, & Pecharová, 2012; Latifovic, Fytas, Chen, & Paraszczak, 2005; Nagendra, Munroe, & Southworth, 2004), historical aerial photographs and historical maps (Kadmon & Harari-Kremer, 1999; Cousins, 2001; Skaloš & Engstová, 2010; Skaloš & Kašparová, 2012; Skaloš et al., 2011, 2012a,b, 2015). For the Czech Republic, several resources of historical maps are available, allowing us to analyse the development of the landscape over the past 200 years and more (Trpáková, 2009). The three-phase military mapping and stable cadastre maps (Brůna et al., 2002; Brůna & Křováková, 2005) allow us to visually interpret landscape development approximately from the mid-18th to the end of 19th century. The historical images of 20th century landscape may be retrieved from aerial photographs taken in irregular intervals for military purposes of the Czech state since the end of 1930's at a scale of 1:25 000. First aerial photographs were taken in the years 1936–1938 but did not cover the whole Czech territory due to the outbreak of World War II. A systematic aerial mapping was resumed not before 1946 (Struha, 1998). The land survey images were classified by a topographer in the field (Raděj, 2001), and thus we acquired a high quality collection of maps with detailed topographic and hypsographic data.

The aim of this study is to (1) analyse, based on the information from the stable cadastre and military topographic maps, the changes in the use of a landscape that has been continuously affected by underground and surface mining and often also by the related industry for over 150 years, and evaluate the planned outcome of revitalisation of the landscape currently used for mining. Documenting the development of mining landscape in a time span of more than 200 years (1845–2050), our study focuses mainly on the (2) cumulative effect of mining industry on the landscape (3) changes in landscape diversity, (4) representation of stable landscape structures and (5) other ecologically valuable features (landscape stability).

2. Methods

2.1. Study area

The studied territory is situated in the central part of the Most Basin in north-west Bohemia, about 80 km northwest of Prague (Fig. 1). The brown coal basin represents the central part of the studied territory, with elevation ranging from 240 to 400 m a.s.l., 450–550 mm of rainfall, and mean temperature of 8–9 °C (Quitt, 1971). The northern part includes the southernmost bottom of the Krušné hory (Ore Mountains) (slightly colder, covered with forests), while in its southern part the basin is gradually replaced by the hilly and warm region of České středohoří (Central Bohemian Uplands) with the town of Most, whose historical part had to be torn down to give way to mining and the inhabitants were gradually relocated to an entirely new town. The central part of the Most Basin represents a territory which was affected by surface coal mining at the most extensive way in contrast to other mining areas in the Northern Bohemia that is why this territory was chosen as a study area.

Until the first half of 19th century the studied territory, with a total area of 228.488 km^2, was covered mostly with plain wetlands, which is reflected in the names of many local villages. The wetlands were replaced with agricultural land, and approximately from the first half of the 20th century the landscape began to transform due to the fast development of surface coal extraction. At present, the territory is divided into 44 cadastres significantly affected by mining (Fig. 1). There are two active large superficial mines, one recently flooded residual pit, several residual pits after small-quarry extraction and a number of external spoil heaps of different parameters.

2.2. Processing of map resources

The analysis of the long-term development of the landscape in the studied area is based on the situation in six time periods: 1845, 1954, 1976, 1988, 2010, and after 2050. Except for the year 1845, a digital map of the territory was created for each time period in the Geographic Information System (GIS) (supplement).

The basic analysis of landscape transformations was conducted based on military topographic maps with measuring scale of 1:25 000 (the maps from actualised aerial photography come from the period **1954/1955, 1976** and from **1988/1989**). The Czech Military Geographic and Hydrometeorological Office in Dobruška provided us with nine map sheets covering the entire studied area (original mapping in the 1942 (S-42) coordinate system, renewed maps from later periods in the 1952 (S-52) coordinate system).

A continuous raster map in S-JTSK was created for each period by georeferencing of the map sheets (TIFF, 300 dpi) using the ArcMap 10.1. program (ESRI) in GIS. The obtained maps were subsequently vectorised. An attribute table was created, specifying the details for each vectorised polygon, including the identification with the relevant cadastral area, land-use category and square area. A total of 24 land-use types could be distinguished in 12 basic categories (Table 1). The categories of arable land, difficult to identify as they are not marked by any sign in the map and form part of the white background, were verified on aerial photographs (available online in the GIS for the northern part of the city of Most, http://gis.mesto-most.cz/mostdominulosti/).

To compare the land-uses identified in military topographic maps with the situation in a more remote past, we used Imperial Imprints of the Stabile Cadastre of Bohemia coming from the period **1824–1843** (SALSC, 2010). These archival maps contain not only map sheets, but they are complemented by land use acreage sheets. Thus, no processing of map sheets is needed.

To compare the historic image of the landscape in the studied area with the present situation, we used digital data from the current landscape mapping carried out in **2010** within the research project of the Ministry of Education, Youth and Sports No. 2B08006 (Kašparová, Pecharová, Justová, & Gillarová-Hrajnohová, 2012). Individual landscape features were classified according to Bodlák and Vinciková (2008), adding several specific categories. In total we defined 50 types of land-use.

The land-use classifications used in the imperial prints of the stable cadastre and in the mapping of contemporary landscape had to be adapted and unified to correspond to the land-use classification derived from military topographic maps (Table 1).

The last evaluated time period is the future condition of the landscape **after discontinuance of mining**. For this purpose, we combined the data from the landscape mapping carried out in 2010 with digital maps created as part of the summary plans for recovery and revitalisation of the two active large-scale quarries indicating what the area of the quarry is supposed to look like after the mining