Multitemporal aerial image analysis for the monitoring of the processes in the landscape affected by deep coal mining

Renata Popelková* and Monika Mulková

Department of Physical Geography and Geocology, Faculty of Science, University of Ostrava, Chittussiho 10, 710 00 Ostrava, Czech Republic
*Corresponding author, e-mail address: Renata.Popelkova@osu.cz

Abstract
In the last seventy years aerial images have represented an important source of information on land cover on a detailed scale. The paper deals with the usage of aerial photographs in the study of landscape changes produced by deep coal mining. The authors show the possibilities of multitemporal land cover analysis in the Ostrava-Karviná mining district analysing a series of aerial photographs covering the period from the second half of the 20th century to the beginning of the 21st century. The paper highlights not only the specific features of deep coal mining displays on aerial images, but it also points to the necessity of understanding the fundamental processes that are related to the land cover changes. On the base of the multitemporal analysis the authors defined seven basic processes that reflect the trends in the landscape changes in the area of interest.

Keywords: Land cover, aerial photographs, multitemporal analysis, landscape changes, Ostrava-Karviná mining district.

Introduction
An increased study of the landscape changes in the Czech Republic has been noted since the 1980s, mainly in relation to the agricultural landscape affected by the loss of agricultural land. Since the 1990s the research in land use has become even more intensive thanks to both the urgent nature of the topic and a very large contribution of geoinformation technologies that facilitated new methods of work and interpretation. The research focused on long-term changes in the macrostructure of the Czech Republic landscape [Bičík et al., 1996; Bičík, 1997; Jeleček, 2002]. In recent years an increased attention has also been paid to the post-industrial landscape of the Czech Republic [Kolejka, 2012; Kolejka et al., 2013; Kolejka and Klimánek, 2014; Kolejka and Klimánek, 2015]. In the period of the industrialisation specific landscape changes were often related to the areas of mining and quarrying, mainly mining districts. In order to study landscape changes in these areas the usage of aerial photographs brings numerous benefits. The fact that aerial images capture the complete view of the landscape in a given moment and on a detailed
scale makes it possible to employ them in the complex study of landscape changes that took place in the 20\textsuperscript{th} and 21\textsuperscript{st} centuries. The possibility to analyse a longer period than that offered by satellite images provides a broader information base for (i) the calculation of landscape metrics, (ii) identification of landscape processes and (iii) performance of a wide range of subsequent analyses. Analysing aerial and satellite images allows the study of land cover changes [Oťahel and Feranec, 1999; Kučera and Guth, 1999; Feranec et al., 2000, 2002, 2010], modelling of land cover spatial variability [Cooper and Loftus, 1998] or quantification of the impact of land use changes on the landscape [Plieninger, 2006]. Studying the changes in land cover and landscape pattern using aerial images was the research object of Coppedge et al. [2001] who also studied the possibilities of the quantification of landscape changes dynamics. Historical aerial photographs were used to detect land use and land cover changes also by Bracchetti et al. [2012], Teferi et al. [2013], Mallinis et al. [2014], Lieskovský et al. [2015], and Svenningsen et al. [2015]. Historical aerial photographs were also used in order to identify landfill sites, mines or lagoons and to date and identify the source of contaminants for the purpose of judicial investigation [Grip et al., 2000]. The quantification of land cover changes along with the research of landscape changes using aerial images was further dealt with by Moreira et al. [2001], Petit and Lambin [2002] and others. Aerial photographs were used by Cebecauerová and Cebecauer [2006] to study the changes in the landscape of the Slovak Republic changes. Other studies that analysed landscape changes on the basis of aerial images include: Kadmon and Harari-Kremer [1999], Cousins [2001], Fensham and Fairfax [2003], Narumalani et al. [2004], Arroyo-Mora et al. [2005], Bergen et al. [2005], Rocchini et al. [2006] and Wentz et al. [2006].

Considering relatively high dynamics of anthropogenically conditioned landscape changes in mining areas, aerial photographs represent a valuable source of information on the landscape state in a given moment, in a non-generalised form, and on a detailed scale. More often aerial images are used to study the opencast mining of coal and other minerals. Within the research of the changes in mining landscape, aerial images were used to monitor the landscapes that had been heavily affected by opencast lignite mining and intensive agriculture [Herzog et al., 2001]. Lausch and Herzog [2002] dealt with the suitability of landscape metrics for landscape monitoring on an example of opencast coal mining in eastern Germany using topographic maps and aerial and satellite photographs. LANDSAT satellite images were used by Fernández-Manso et al. [2012] to detect land use/land cover changes in opencast coal mining areas on a global scale and by Townsend et al. [2009] in central Appalachian Mountain region of the Eastern United States. Using large scale vertical aerial photographs, Santo and Sánchez [2002] studied the development of sand extraction and its impact on the landscape in the Paraíba do Sul River over the period of 35 years. Aerial photographs were used by Sklenička and Lhota [2002] to study land reclamation in Chabaňovice in the northern Bohemia brown coal basin and by Soriano and Simón [2002] and Stiros [2001] to detect ground subsidences. The authors of this article have long dealt with the monitoring, interpreting and visualisation of spatial-temporal changes in the landscape affected by deep coal mining in the Ostrava-Karviná mining district [Mulková and Popelková, 2008; Mulková et al., 2012, 2016].
Study area
In order to show the possibilities of the multitemporal analysis of the land cover in the region of deep coal mining, the main hard coal field in the territory of the Czech Republic has been selected: Ostrava-Karviná mining district (OKMD) containing 90% of the country’s hard coal reserves. The district comprises four partial basins: Ostrava Basin, Petřvald Basin, Karviná Basin and Frenštát Basin. In terms of mineral extraction, the first three basins were long actively exploited. However, coal has never been mined in the Frenštát basin. Hard coal started to be extracted in the OKMD at the end of the 18th century, while intensive mining dates back to the second half of the 19th century and the beginning of the 20th century. Since the 1990s coal mining activities have gradually been reduced. Nowadays, mining only takes place in four mines of the Karviná Basin.

With respect to the geomorphologic division of the Czech Republic, the area of interest belongs to the Ostrava Basin characterised by slightly undulated uplands and alluvial plains [Bina and Demek, 2012]. Flat, erosion-accumulation or accumulation landscape established on Quaternary sediments of various origins (loess loams, gravels and sands) has been altered due to deep black coal mining, industry and urbanisation. Waste heaps, submerged ground subsidences and tailings ponds have become the main anthropogenic landforms that cannot be missed.

The cadastral areas of the Ostrava, Petřvald and Karviná Basins, which have thoroughly been analysed within the OKMD landscape changes are listed in the Table 1.

Table 1 - Selected cadastral areas of the Ostrava, Petřvald and Karviná Basins. ID is identifier of the cadastral area (also used in Fig. 1).

| Ostrava Basin | Petřvald Basin | Karviná Basin |
|---------------|----------------|---------------|
| ID | Cadastral area | ID | Cadastral area | ID | Cadastral area |
| 1 | Nová Ves near Ostrava | 14 | Radvanice | 18 | Orlová |
| 2 | Mariánské Hory | 15 | Rychvald | 19 | Lazy near Orlová |
| 3 | Zábřeh-Hulváky | 16 | Petřvald near Karviná | 20 | Doubrava near Orlová |
| 4 | Zábřeh-VŽ | 17 | Poruba near Orlová | 21 | Karviná-Doly |
| 5 | Přívoz | | 22 | Dolní Suchá |
| 6 | Moravian Ostrava | 23 | Prostřední Suchá |
| 7 | Vítkovice | 24 | Horní Suchá |
| 8 | Hrušov | 25 | Staré Město near Karviná |
| 9 | Muglinov | 26 | Karviná-město |
| 10 | Heřmanice | 27 | Darkov |
| 11 | Silesian Ostrava | 28 | Stonava |
| 12 | Kunčičky |
| 13 | Michálkovic |

The total study area makes 60.83 km² within the Ostrava Basin is, 43.46 km² within the Petřvald Basin and 92.87 km² within the Karviná Basin. A total of 28 cadastral units (Fig. 1) cover the territory of 197.16 km² forming the area of interest of this article.
Figure 1 - Localization of the Ostrava-Karviná mining district (OKMD) and selected cadastral areas within the Czech Republic.

Materials and methods

Aerial photographs

In order to perform quantitative and qualitative evaluation of spatial-temporal changes in the study area, we used series of aerial images from the second half of the 20th century and the beginning of the 21st century. The oldest aerial photographs used in this study are from the period of 1947-1949, i.e. the period just before the collectivisation of agriculture and the main phase of socialist industrialisation. This period is covered by 95 black and white photographs at a scale of 1:11 000. Other black and white photographs, whose total number
is 56 and whose scale ranges between 1:15 000 and 1:20 000, are from the period of 1971-1975. The aerial images from the 1940s and 1970s were provided by the Office of Military Geography and Hydrometeorology in Dobruška disposing of the largest archive of aerial photography in the Czech Republic. The archive contains approximately 900 000 mainly black and white aerial images of various scales and formats from the territory of the Czech Republic starting with the year 1936 up to the present [Stehlik, 2004]. The scale ranges from 1:3 000 to 1:40 000.

Finally, it is the year 2009 when the landscape already substantially reflects the transformation processes connected to the changes in the society and economy following the so-called Velvet Revolution. An orthophoto from the year 2009 was in ArcGIS software displayed from ArcGIS Server of the State Administration of Land Surveying and Cadastre in the S-JTSK system of coordinates. The orthophoto pixel size is 0.25 m.

**Data processing**

The processing of aerial images from the area affected by deep coal mining is accompanied by specific features that have an impact on the geometric correction of images and their visual photointerpretation. Figure 2 shows the generalized workflow. Contact copies of black and white aerial images were scanned in the resolution 600 dpi. Geometric correction of the images was subsequently performed in the PCI Geomatica OrthoEngine 9 software. A suitable mathematical model was selected on the basis of the availability of the digital terrain model and data from the camera calibration protocol. The oldest archive images lacked some data from the camera calibration protocols. In relation to deep coal mining, the relief of the study area has been transformed by subsidences as a result of undermining. The width of the subsidences reaches more than 30 m in the Karviná part of the OKMD. The volume of ongoing changes in the hypsography has not been recorded in maps since the 1950s with an exception of the State Maps of the scale 1:5 000 capturing the hypsography to the year 1951 but failing to cover the entire territory of the Czech Republic. For these above mentioned reasons, there was no possibility to base the transformation of archive aerial images on a digital terrain model that would be relevant for individual years of imaging.

Geometric correction was then performed on the basis of polynomial transformation, in which case the images are not connected by tie points. The mathematical model and resulting errors were calculated for each image. Zala and Barrodale [1999] found out that 2D polynomial transformation was unsuitable for geometric corrections as it brought errors into images, especially the peripheral parts. However, applying polynomial transformation in the case of the OKMD proved to be fully sufficient for the analyses of landscape changes on a detailed scale. When verifying the transformation accuracy by putting transparent map rasters over geometrically corrected images, no deviations were identified that would further affect visual photointerpretation and subsequent overlay analyses.
Figure 2 - The generalized workflow.
The accuracy of the mathematical model and therefore the result of the geometric correction depend on the quality of ground control points (GCPs). The number, configuration and type of GCPs affect the accuracy of the polynomial transformation [Hughes et al., 2006]. As it can be difficult to localise GCPs in mining areas, the users are often confronted with the usage of optimal number, type and configuration of suitable points. Identical points are usually lost as a consequence of ground subsidence (Fig. 3). Ideally, we used the bases of buildings as GCPs, the number of which gradually decreased on newer images due to demolitions of buildings. In some cases the centres of crossroads were used to ensure even distribution of points on images. For the transformation of the study area aerial photographs, target coordinates of the GCPs were taken from the map sheets of the State map at a scale 1:5000 from the 1950s and a State map derived 1:5000. The mean squared error should be within the resolution of a pixel or less, taking into account the image resolution, required accuracy of the target transformed image and accuracy of the source of target coordinates for the collection of GCPs. While transforming the aerial photographs into the S-JTSK coordinate system, it was problematic to get the RMS value equal to 0.5 m (according to the given pixel size of the transformed image) in all images, mainly due to missing GCPs. Although the RMS reached 3 m in some cases, no significant shifts or deformations of the geometrically corrected image occurred that would threaten the application of the data in the mapping of the landscape changes. In the case of archive aerial images, such RMS values can thus be considered sufficient for the subsequent multitemporal analyses of landscape changes, after image deformities have been ruled out by means of visual inspection. Having carried out the geometric correction, we connected individual aerial photographs into a mosaic for the partial sections of the study area.

Visual photointerpretation was chosen as the method assessing the spatial-temporal changes in the land cover of the study area. The photointerpretation is based on visual perception related to the awareness of the objects and phenomena of the outside world [Ciolkosz et al., 1999]. Therefore, photointerpretation is based on (i) the concurrence of analysis and synthesis, (ii) comparison, (iii) deductive and inductive reasoning to develop a conclusion, and (iv) analogy. The appearance and features of objects identified in the photographs are described using interpretation signs. We used direct photointerpretation signs (shape, size, tone or colour, object texture and structure) and indirect photointerpretation signs (shade, location and relations to other objects in the photograph). Experienced interpreters make use of such interpretation elements that are based on the experience related to the objects’ real form. On the basis of the presence of certain elements and signs, such interpreters are able to deduce the objects and phenomena that are not primarily contained in the photographs.

The images capturing coal mining affected landscape are characterised by specific features also in connection with visual photointerpretation. With regard to considerable landscape changes in the study area, we opted for the image photointerpretation starting with the latest and finishing with the oldest images. The interpretation of older images required the use of supporting data (text sources of information and maps) in doubtful cases.
Figure 3 - The example of ground control points loss due to mining subsidence.
The relation between the object appearance in an image and its real appearance is expressed by the photointerpretation key [Čapek, 1978]. We created a selective photointerpretation key for the visual photointerpretation of the land cover of mining area. The selective key, which is made by commented image cut-out segments showing an object or a phenomenon, is used for direct visual comparison with the interpreted image; what is selected is the pattern that is closest to the pattern on the image. Appendix 1 shows those parts of the photointerpretation key that are related to the land cover categories connected with deep coal mining (presented in bold letters in Tab. 2).

Table 2 - Selected land cover (LC) categories. Deep mining related LC categories are presented in bold letters.

| Main CLC categories | Selected land cover categories |
|---------------------|--------------------------------|
| 1 Artificial surfaces | 111 Continuous urban fabric |
|                     | 112 Discontinuous urban fabric |
|                     | 121 Industrial and commercial units |
|                     | 122 Road and rail network and associated land |
|                     | 131 Mineral extraction sites |
|                     | 132 Dump sites |
|                     | 133 Waste heaps |
|                     | 141 Allotments |
|                     | 142 Sport and leisure facilities |
|                     | 143 Green urban areas |
|                     | 161 Reclamation areas |
|                     | 162 Handling areas |
|                     | 163 Dry tailings ponds |
|                     | 164 Other vegetation-free areas |
| 2 Agricultural areas | 210 Arable land |
|                     | 222 Fruit trees and berry plantations |
|                     | 231 Pastures and meadows |
|                     | 242 Complex cultivation patterns |
| 3 Natural and semi natural areas | 310 Forests |
|                     | 320 Trees, scrub and/or herbaceous vegetation associations |
| 5 Water bodies | 511 Water courses |
|                     | 512 Water bodies |
|                     | 513 Submerged ground subsidences |
|                     | 514 Tailings ponds |

Primary displays of deep coal mining activities are connected with the following land cover categories: waste heaps, ground subsidences, tailings ponds and handling areas [Mulková and Popelková, 2013]. Areas of subsurface mining (mineral extraction sites category) can as well be identified, namely based on the presence of mine buildings and structures. Secondary displays of deep coal mining are related to the following land cover categories:
reclamation areas, dry tailings ponds, embankments (contained in the category of road and rail network and associated land) and vegetation-free surfaces.

Land cover categorisation was derived from the EU initiated CORINE Land Cover (CLC) Legend [Feranec and Oťaheľ, 2001; European Environment Agency, 2005] and processed for the scale 1:100 000. With respect to selected localities and mapping at a more detailed 1:5 000 scale, the CLC legend was appropriately modified in such a way that some categories were added, left out or united (Tab. 2). The third main CLC category Forest and seminatural areas was retitled to Natural and semi-natural areas as forest areas can also be semi-natural [Popelková, 2009].

Land cover in individual years was obtained by means of vectorisation in ArcGIS software at a scale 1:5000 on the basis of visual photointerpretation of aerial photographs. The minimum area of the vectorised polygon was 625 m². For each territory a geodatabase was created that contained two datasets (Feature Datasets) for individual years and these further contained land cover layers. Land cover vectorisation was performed in one layer for each year and each cadastral area. A total of 84 land cover layers were created. Verification was conducted in connection with each layer whether important topology rules had been followed, particularly whether there were no voids between adjacent polygons. Land cover map for each year was created (Fig. 4). With regard to subsequent detection of LC changes using overlay analyses, it is necessary to maintain the mutual positional accuracy of individual layers in order not to distort the results of the analyses due to potential geometric inaccuracies in transformed input data.

Figure 4 (Continued on the next page) - The landscape of Ostrava-Karviná mining district in the year 1947 (the upper map) and in the year 2009 (the lower map).
Processes of landscape changes
The multitemporal analysis of aerial and satellite images does not only allow to perform a simple analysis of a certain landscape change in time but it mainly enables to synthesise the knowledge and to create a typology of landscape changes in time. Using the multitemporal analysis, we can reach the understanding of the main processes that are connected to the landscape changes. Defining the processes in the landscape enables a generalised look at the landscape changes.

On the basis of the performed multitemporal analysis of land cover vector layers, we determined seven basic processes that indicate the trends in the development of the OKMD landscape.

The description of these processes is based upon the methodology of a BIOPRESS international project and on the results of the so far published peer studies working with the evaluation of the CORINE Land Cover databases [Feranec and Ot‘ahel‘, 2001; Biopress, 2008]. Therefore, these processes primarily assess the quantitative changes between individual categories land cover.
Table 3 - Processes of the landscape changes in the studied area and their characteristics.

| Process               | Characteristics of the direction of the change within the relevant land cover category                                                                 |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Urbanisation          | agricultural areas, natural and semi natural areas, water bodies → artificial surfaces                                                              |
| Abandonment           | artificial surfaces, agricultural areas, forests, water bodies → scrub and/or herbaceous vegetation associations                                     |
| Intensification of agriculture | artificial surfaces, fruit trees and berry plantations, pastures, complex cultivation patterns, natural and semi natural areas, water bodies → arable land |
| Deforestation         | forests → artificial surfaces, agricultural areas, scrub and/or herbaceous vegetation associations, water bodies                                    |
| Afforestation         | artificial surfaces, agricultural areas, scrub and/or herbaceous vegetation associations, water bodies → forests                                      |
| Flooding              | artificial surfaces, agricultural areas, natural and semi natural areas → water bodies                                                              |
| Drainage              | water bodies → artificial surfaces, agricultural areas, natural and semi natural areas                                                               |

Table 3 presents the main CORINE Land Cover classes of the first stage of the CLC hierarchy. The inclusion of selected land cover categories into individual main CLC categories is presented in Table 2.

The process of urbanisation is used here to describe the increase of artificial surfaces on the expense of agricultural areas, natural and semi natural areas and water bodies. The process of intensification of agriculture is used to denote the transformation of all the categories of land cover to arable land. Therefore, the process of intensification is understood as the intensification of agriculture in an extensive way, i.e. by increase in the area of arable land. We leave aside the intensification of agriculture through the restructuralisation of the land fund and through the application of new farming systems and the processes of innovation (fertilisation, application of chemicals in agriculture, melioration, etc.). The process of afforestation denotes a transformation of agricultural and other areas into natural and semi natural forest areas. The process of deforestation is the opposite process within which forests are lost as they are transformed into other types of land cover. In line with the BIOPRESS methodology, the process of abandonment can be described as the transformation of artificial areas, agricultural areas and also forests and water areas into the category of scrub and/or herbaceous vegetation associations. The category of scrub and/or herbaceous vegetation associations is defined as grasslands not used in agriculture with scattered shrubs or solitaire trees, shrubs, vegetation typical of water courses or communications and hedgerows. The process of abandonment can occur on untreated or unused areas which get spontaneously covered with self-seeded vegetation. Flooding is defined as an occurrence of water bodies in areas where water bodies had not been present before. Therefore, it encompasses all transformation in the categories of artificial areas, agricultural areas and natural and semi natural areas into the category of water bodies. The process of drainage is a process within which water bodies and water courses pass into another land cover category [Mulková et al., 2012].
Results and discussion
The multitemporal analysis of land cover in individual studied years made it possible to determine the type, size and spatial layout of processes. After we had performed the analytical operations, we could identify the proportionate representation of land changes and the processes behind these changes (Tab. 4).

Table 4 - Proportionate representation of changes caused by processes in selected localities of the studied area.

| Process                  | Karviná area | Petřvald area | Ostrava area |
|--------------------------|--------------|---------------|--------------|
|                          | 1947-1971    | 1971-2009     | 1947-1975    | 1975-2009     | 1949-1972    | 1972-2009     |
| urbanisation             | 15.51        | 11.34         | 12.70        | 10.83         | 18.04        | 12.87         |
| afforestation            | 3.42         | 11.17         | 5.61         | 10.58         | 3.24         | 5.02          |
| abandonment              | 13.03        | 18.88         | 11.41        | 9.15          | 15.46        | 11.04         |
| intensification of agriculture | 14.25   | 5.70          | 14.05        | 6.43          | 5.29         | 0.69          |
| flooding                 | 5.78         | 2.14          | 1.17         | 0.78          | 2.55         | 0.36          |
| deforestation            | 3.23         | 2.75          | 3.19         | 2.84          | 1.05         | 1.33          |
| drainage                 | 0.55         | 2.72          | 0.75         | 0.49          | 1.25         | 1.35          |

It was mainly the process of urbanisation (Fig. 5) that was strongly represented in the whole studied area and that exceeded 10% of the extent of the studied area in all observed periods. Further, urbanisation represents the strongest landscaping process in almost all parts of the OKMD and in almost all the periods. The only exceptions were the Karviná part between 1971 and 2009 and also the Petřvald part between 1947 and 1975. In the Karviná part (between 1971 and 2009) the process of abandonment was more intensive then urbanisation. In the Petřvald part (between 1947 and 1975) the intensification of agriculture prevailed over urbanisation. When we compare individual parts, we can conclude that urbanisation affected most the Ostrava part of the OKMD; it was less prominent in the Karviná part and least prominent in the Petřvald part.

Urbanisation reached the highest peak in the Ostrava part of the OKMD between 1949 and 1972. As a result of urbanisation the highest decrease in agricultural areas was observed, i.e. 630.3 ha complex cultivation patterns (10.4% of the area) and 154 ha of arable land (2.5%). Artificial surfaces were extended to those areas where scrub and/or herbaceous vegetation associations used to be (181 ha, 3%) before.
Apart from the process of urbanisation, also the process of abandonment hit the landscape of the Ostrava-Karviná mining district strongly since it affected primarily agricultural areas and urban fabric (Fig. 6). This process was connected largely with the effect of ongoing black coal extraction and its negative impacts. These became evident in the devastation of urban fabric and in the economy of the used land. The process of abandonment extended over 9% of the studied area in all its parts and in all observed periods. It was most intensive in the Karviná part of the OKMD in 1971-2009 when it exceeded 19% of its total area. This
fact was clearly connected to the impacts of socialist industrialisation upon the landscape of the coalfield. Further, the process of abandonment became strongly apparent in the Ostrava part of the OKMD between 1949-1972 when it hit 15% of the area and in the Karviná part in 1947-1971 when it hit 13% of the area.

The process of intensification of agriculture (Fig. 7) was typical of the period of 1947-1971. The first main reason behind this was the collectivisation of the 1950s when tiny fields, pastures and permanent crops were united into large fields of arable land. The other reason was the stress upon extending the land fund and its intensive use. It was during this period
when the intensification of agriculture reached its maximum level in all the studied areas. It was more pronounced in the Karviná and Petřvald parts of the OKMD where it occurred on 14% of the territory. It only concerned 5% of the area in the Ostrava part and this fact is closely connected to the urbanised and industrialised character of the Ostrava part of the OKMD. As for the Petřvald part, the intensification of agriculture was the most significant process here between 1947 and 1975 and it occurred on 610.7 ha (14.1%) of the area. As far as the Karviná part is concerned, the process of intensification of agriculture was the second most significant process after urbanisation and it affected the area of 1323.8 ha (14.3%). Complex cultivation patterns with the area of 1209.7 ha (13%) were affected most.

Figure 7 - Example of the process of intensification of agriculture in the north-western part of Stonava. The upper photo: complex cultivation patterns in 1947. The lower photo: the same area with fields of arable land in 1971.

The process of deforestation (Fig. 8) reaches higher values (c. 3% of the studied area) in the Karviná and Petřvald parts in both the studied periods but slightly higher values in the
period 1947-1971. This period witnessed the substitution of forests with trees, scrub and/or herbaceous vegetation associations in the Karviná part to 190.5 ha (2.1% of the total area) and in the Petřvald part to 104.4 ha (2.4% of the total area). In both above mentioned parts of the OKMD forests are substituted by trees, scrub and/or herbaceous vegetation associations also in the following (1971-2009) period.

In fact, forests only spread in all the studied areas in the last third of the 20\textsuperscript{th} century. The process of afforestation (Fig. 9) is more visible both in the Karviná part (11.2% of the
territory), and in the Petřvald part (10.6%). This process also reached its maximum in the Ostrava part between 1972 and 2009 but it was apparent only on 5% of the studied area. We can say that forests spread primarily into areas covered with solitaire trees, scrub and/or herbaceous vegetation associations. This phenomenon concerned 6% of the territory (556.9 ha) in the Karviná part, 6.8% of the territory (294.9 ha) in the Petřvald part and 3.1% of the total territory (189.2 ha) of the Ostrava part. Afforestation hit considerably also agriculture areas in all the studied parts: the Karviná part 2.5% of the territory (234.2 ha), the Petřvald part 2.6% (111.9 ha) and the Ostrava part 0.8% (46.9 ha). In the Karviná part, forests extended also into areas emerging after pulled down residential areas (127.5 ha; 1.4%). As for other observed areas, the process of afforestation was more obvious only in the Petřvald part of OKMD between 1947 and 1975 when it affected 5.6% of the total territory. During this period 110.9 ha (2.6%) of scrub and/or herbaceous vegetation association turned into forests and following that another 100.7 ha of agricultural areas (2.3%).

Figure 9 (Continued on the next page) - Example of the process of afforestation in the western part of Doubrava. The upper photo: the area covered with scrub and/or herbaceous vegetation associations in 1971, the lower photo: the same area with forests in 2009.
The process of drainage (Fig. 10) played only a less significant role in the changes of the landscape as far as the size of affected localities is concerned, except for some areas and some periods. Despite that, the emergence of specific anthropogenic forms of relief in the landscape of the OKMD, primarily submerged ground subsidences and tailings ponds, is connected exactly to this process. The process of drainage was most intense in the Karviná part of the OKMD between 1947 and 1971 when it affected 5.8% of the territory. This corresponds to the increasing influence of black coal and also to the effort to establish new water bodies (Fig. 11). Out of 537.2 ha of newly emerged water bodies, approximately 150 ha belonged to ponds that were created in the northern part of Staré Město, mainly on arable land. Tailings ponds newly emerged on the area of 277.1 ha (3%) and they were created on former agricultural areas (174.6 ha, 1.9%), out of which 97.5 ha were created by complex cultivation patterns and less than 40 ha by arable land as well as pastures. The area of newly occurring submerged ground subsidences was 72.5 ha (0.8%). Mainly complex cultivation patterns with the area of 36.3 ha were flooded.
Figure 10 - Example of the process of drainage in the south-western part of Orlová. The upper photo: submerged ground subsidences in 1971, the lower photo: the same area with natural and semi natural areas in 2009.
Figure 11 - Example of the process of flooding in the south-eastern part of Doubrava. The upper photo: discontinuous urban fabric and agricultural areas in 1947, the lower photo: the same area with tailings ponds and submerged subsidences in 1971.
The process of drainage comprises a transformation of water bodies into other areas but adjustments to river beds play their role here too. The process of drainage became evident most significantly in the whole studied area between 1971 and 2009 the Karviná part. It had an effect on 2.7% of the territory. Between 1971 and 2009 mainly tailings ponds in Karviná-Doly, Doubrava, Lazy and Prostřední Suchá disappeared due to a decrease in coal extraction in the Karviná part of the OKMD. Some submerged ground subsidences were redeveloped during this stage (e.g. in Stonava, Karviná-Doly and Orlová). The strongest process that we could observe in the whole area of the Ostrava-Karviná mining district was the process of urbanisation. We use the term urbanisation to describe an increase in both continuous and discontinuous urban fabric, industrial areas and also transport infrastructure. From the spatial point of view, the Ostrava part of the Ostrava-Karviná mining district was most strongly affected by this process. This part also became exceptionally industrialised and urbanised. From our analyses we can also conclude that the process of urbanisation affected primarily arable land, pastures and meadows and partly also forests in the Ostrava-Karviná mining district. Only from the 1970s it was present more often also in unused natural and semi natural areas covered with solitaire trees, scrub and/or herbaceous vegetation associations. The second most prominent process that characterised the development in the local landscape was the process of abandonment. We use this term to describe a process within which residential areas, industrial units, agricultural areas, forests or water bodies change into natural and semi natural areas represented by solitaire trees, scrub and/or herbaceous vegetation associations. This process usually occurs in disused areas which get spontaneously covered with self-sowing vegetation. As far as the Ostrava-Karviná mining district is concerned, the process of abandonment affected agricultural areas and original urban fabric. In the study area, the process of abandonment did not take place due to lack of profit from agriculture but it was enforced by the devastation of the land fund (ground subsidences, its contamination, etc.). Similar to the case of urban fabric, also residential areas were abandoned due to ground subsidences. The process of abandonment was strongly manifested mainly in the Karviná part where it gradually increased its intensity during the 20th century. The process of abandonment was connected to the dynamics in coal extraction development. Between 1947 and 1971 13% of the territory became abandoned and between 1971 and 2009 even 19% of the Ostrava-Karviná mining district was abandoned. From the mid-1950s the process more and more significantly affected abandoned and pulled down urban fabric. This was connected to the devastation of a part of the original settlement. The process reached its peak in the Ostrava part between 1949-1971 when it affected mostly plots that had been used in agriculture before and to a limited extent it affected urban fabric too. In the Petřvald part its development resembled the Ostrava part but its intensity was weaker and its character slightly different. The process has an ambivalent character with respect to the development of the landscape. It can bring both positive trends (in the studied coalfield it is mainly a result of biological reclamation) and also negative trends (appearance of extensive unused areas, i.e. brown fields). The process of intensification of agriculture was rather significant in the landscape of the Ostrava-Karviná mining district but our analysis recorded its more intensive course only between 1947-1971. However, in this case it concerns mainly the indication of changes in the structure of agricultural land influenced by collectivisation which affected the parts of
Karviná and Petřvald. If we wish to include the overall representation of agricultural land into our analysis, then the process of intensification of agriculture will only appear as weak. Compared to the increase in arable land, the area of complex cultivation patterns (including also a considerable area of scattered arable land) dropped significantly, which indicates a trend towards deagrarisation.

During the second half of the 20th century the process of deforestation got considerably weaker compared to the pace of this process in previous years. The districts of Ostrava and Karviná showed the lowest afforestation in the total territory of Czechoslovakia in the 1970s. Good quality forest cover cannot be really found in the study area during this period. Only worse quality natural and semi natural areas spread.

In the last third of the 20th century this trend started to revert. The process of afforestation, which had only been marginal in the landscape development in the studied coalfield in previous decades, started to manifest itself rather strongly in the Karviná and Petřvald parts. Forests spread primarily in the areas previously affected by abandonment. These areas were covered by trees, scrub and/or herbaceous vegetation associations. Alternatively forests spread also in agricultural areas and on locations after residential areas had been pulled down in the Karviná part. The Ostrava part was affected by afforestation only marginally, as compared to Petřvald and Karviná parts. Therefore, the Ostrava region remained to be an area with relatively low afforestation.

The topic of changes in water courses and water bodies in the Ostrava-Karviná mining district is connected to two last described processes: drainage and flooding. From the second half of the 20th century the process of flooding became more pronounced. This was connected mainly to more intensive coal extraction and emergence of specific mining related landforms: submerged ground subsidences and tailings ponds - mainly in the Karviná part. In the last third of the 20th century, mainly from the 1990s onwards, numerous submerged ground subsidences and tailings ponds were reclaimed, which strengthened the process of drainage too.

**Conclusion**

In comparison with satellite images, historical aerial images represent a convenient source of information for the study of changes in the landscape affected by deep hard coal mining with regard to space and a long time period. However, high dynamics in mining landscape development becomes reflected in geometric correction of archive images that gets complicated as a result of non-existing digital terrain model that would be relevant to the date of imaging and decreasing number of suitable ground control points towards the present day due to territory undermining.

With regard to the speed of land cover evaluation on the basis of archive aerial images, another limitation can be the impossibility to use the methods of automatic classification that are based on the spectral behaviour of objects. Considering the features of archive aerial images, the pixel value does not have to represent a characteristic spectral attribute of an object. Furthermore, similarity in the spectral behaviour within many land cover categories makes clear identification impossible and does not allow to include a part of images into given land cover categories at a detailed mapping scale. However, in order to evaluate mining related landscape changes, it is necessary to carry out correct interpretation of land cover categories connected to this anthropogenic activity. Therefore,
CORINE Land Cover categories were supplemented with categories related to primary and secondary displays of deep hard coal mining. The interpretation of aerial images can be facilitated by photointerpretation keys that help to identify specific land cover categories. A photointerpretation key was created for individual land cover categories. The categories related to the displays of deep hard coal mining are presented in Appendix 1. This selective photointerpretation key can also be used in other areas affected by deep mining.

The multitemporal analysis of the land cover in the Ostrava-Karviná mining district detected seven basic processes that point to the directions, intensity and speed of landscape changes in individual studied periods. They are the processes of urbanisation, intensification of agriculture, afforestation, deforestation, flooding and drainage. These processes hit individual parts of the coalfield with a different intensity and at different times.

Generally, processes affected the largest area in the Karviná part of the OKMD, namely 56% in the period 1947-1971, and 54.7% in 1971-2009. More than 40% of the territory was affected by the processes in the Petřvald and Ostrava parts, while the Petřvald part shows slightly higher values. In the Ostrava part of the period of 1972-2009 the processes affected 33.2% of the territory, which represents the lowest value within the OKMD.

Based on the performed analyses, we can present several essential findings concerning the development of the Ostrava-Karviná mining district. Although anthropogenic activities affected the local landscape in a radical way, land changes did not occur in all the parts of the coalfield with the same intensity. This fact was caused by a combination of natural (mainly geological), social and historical conditions. On the basis of the analysis of the land cover development, we could identify specific landscape development within each of the three so far actively used coalfields of the Ostrava-Karviná mining district, i.e. the Ostrava basin, the Petřvald basin and the Karviná basin.

Different geological conditions between the Ostrava and Karviná parts led to different manifestations of the mining activity in the landscape. In the Ostrava part with a lower thickness of mining seams, mining damage did not occur to such an extent as in the case of the Karviná area. The Ostrava area can be described as a landscape affected by mining and industry but with a maintained residential purpose. As for the Karviná area, this is characterised by its mining landscape where original housing estates disappeared in many places to be replaced with mostly semi-natural areas of trees, scrub and/or herbaceous vegetation associations.

Acknowledgements
The contribution was created on the basis of the grant project solution: GAČR P410/12/0487 “The process of industrialization and landscape changes in the Industrial Zone of Ostrava in the nineteenth and twentieth century”.

References
Arroyo-Mora J.P., Sanchez-Azofeifaa G.A., Rivarda B., Calvob J.C., Janzen D.H. (2005) - Dynamics in landscape structure and composition for the Chorotega region, Costa Rica from 1960 to 2000. Agriculture, Ecosystems and Environment, 106: 27-39. doi: http://dx.doi.org/10.1016/j.agee.2004.07.002.

Bergen K.M., Brown D.G., Rutherford J.F., Gustafson E.J. (2005) - Change detection with heterogeneous data using ecoregional stratification, statistical summaries and a land
allocation algorithm. Remote Sensing of Environment, 97: 434-446. doi: http://dx.doi.org/10.1016/j.rse.2005.03.016.

Bičík I. (1997) - Land Use in the Czech Republic 1845-1948-1990. Methodology, Interpretation, Contexts. Acta Universitatis Carolinae, Geographica, 32: 255-263.

Bičík I., Götz A., Jančák V., Jeleček L., Mejsnarová L., Štěpánek V. (1996) - Land Use / Land Cover Changes in the Czech Republic 1845-1995. Geografie, Sborník ČGS, 101 (2): 92-109.

Bina J., Demek J. (2012) - Znížin do hor: geomorfologické jednotky České republiky. Academia, Praha, pp. 343.

Biopress (2008) - Linking Pan-European Land Cover Change to Pressures on Biodiversity. Available on line at: http://www.creaf.uab.es/biopress/index2.htm. (Quoted 20 June 2008).

Bracchetti L., Carotenuto L., Catorci A. (2012) - Land-cover changes in a remote area of central Apennines (Italy) and management directions. Landscape and Urban Planning, 104 (2): 157-170. doi: http://dx.doi.org/10.1016/j.landurbplan.2011.09.005.

Cebecauerová M., Cebecauer T. (2006) - Vývoj krajinné pokrývky v južnej části Záhorskej nížiny a Malých Karpát v období 1954-1992. GEOInformations, pp. 67-74.

Ciolkosz A., Miszalski J., Olędzki J. R. (1999) - Interpretacja zdjęć lotniczych. PWN, Warszawa, pp. 458.

Cooper A., Loftus M. (1998) - The application of multivariate land classification to vegetation survey in the Wicklow Mountains, Ireland. Plant Ecology, 135 (2): 229-241. doi: http://dx.doi.org/10.1023/A:100970211061.

Coppedge B.R., Engle D.M., Fuhlendorf S.D., Masters R.E., Gregory M.S. (2001) - Landscape cover type and pattern dynamics in fragmented southern Great Plains grassland, USA. Landscape Ecology, 16 (8): 677-690. doi: http://dx.doi.org/10.1023/A:1014495526696.

Cousins S.A.O. (2001) - Analysis of land-cover transitions based on 17th and 18th century cadastral maps and aerial photographs. Landscape Ecology, 16 (1): 41-54. doi: http://dx.doi.org/10.1023/A:1008108704358.

Čapek R. (1978) - Dálkový průzkum a fotointerpretace z hlediska geografie. 1. díl. SPN, Praha, 164 pp.

European Environment Agency (2005) - Remote Sensing in History. Available online at: http://observe.arc.nasa.gov/nasa/exhibits/history/history_1.html. (Quoted 30 June 2005).

Fensham R.J., Fairfax R.J. (2003) - A land management history for central Queensland, Australia as determined from land-holder questionnaire and aerial photography. Journal of Environmental Management, 68 (4): 409-420. doi: http://dx.doi.org/10.1016/S0301-4797(03)00110-5.

Feranec J., Oťahel J. (2001) - Krajinná pokrývka Slovenska. Veda, Bratislava, 122 pp.

Feranec J., Šúri M., Cebecauer T., Oťahel J. (2002) - Methodological aspects of landscape changes detection and analysis in Slovakia applying the CORINE land cover databases. Geografický časopis, 54 (3): 271-288.

Feranec J., Šúri M., Oťahel J., Cebecauer T., Kolář J., Soukup T., Zdeňková D., Waszmuth J., Vâjdeac V., Vijdeac A.M., Niticae C. (2000) - Inventory of major landscape changes in the Czech Republic, Hungary, Romania and Slovak Republic 1970s-1990s. International Journal of Applied Earth Observation and Geoinformation, 2 (2): 129-139. doi: http://
dx.doi.org/10.1016/S0303-2434(00)85006-0.
Feranec J., Jaffrain G., Soukup T., Hazeu G. (2010) - Determining changes and flows in European landscapes 1990-2000 using CORINE land cover data. Applied Geography, 30 (1): 19-35. doi: http://dx.doi.org/10.1016/j.apgeog.2009.07.003.
Grip W.M., Grip R.W., Morrison R.D. (2000) - Application of Aerial Photography and Photogrammetry in Environmental Forensic Investigations. Journal of Environmental Forensics, 1 (3): 121-129. doi: http://dx.doi.org/10.1006/enfo.2000.0014.
Herzog F., Lausch A., Müller E., Thuik H.H., Steinhardt U., Lehmann S. (2001) - Landscape metrics for assessment of Landscape destruction and rehabilitation. Environmental Management, 27 (1): 91-107. doi: http://dx.doi.org/10.1007/s002670010136.
Hughes M.L., McDowell P.F., Marcus W.A. (2006) - Accuracy assessment of georectified aerial photographs: Implications for measuring lateral channel movement in a GIS. Geomorphology, 74 (1-4): 1-16. doi: http://dx.doi.org/10.1016/j.geomorph.2005.07.001.
Jeleček L. (2002) - Historical development of society and LUCC in Czeochia 1800-2000. Major societal driving forces of land use changes. In: Land Use/Land Cover Changes in the Period of Globalization, Bičík I. (Ed), Prague, pp. 44-57.
Kadmon R., Harari-Kremer R. (1999) - Studying Long-Term Vegetation Dynamics Using Digital Processing of Historical Aerial Photographs. Remote Sensing Environment, 68 (2): 164-176, doi: http://dx.doi.org/10.1016/S0034-4257(98)00109-6.
Kolejka J., Klímanek M. (2015) - Identification and Typology of Czech Postindustrial Landscapes on National Level Using GIS and Publicly Accessed Geodatabases. Ekológia, International Journal for Ecological Problems of the Biosphere, 34 (2): 121-136. doi: http://dx.doi.org/10.1515/eko-2015-0013.
Kolejka J., Klímanek M. (2014) - The process of transition from industrial to post-industrial society identified in land use and land cover data: Case of the Czech Republic. In: Land Use/Cover Changes in Selected Regions in the World, Bičík I., Himiyama Y., Feranec J., Kupková L. (Eds), Volume IX, Asahikawa, pp. 95-104.
Kolejka J., Klímanek M., Martinát S., Ruda A. (2013) - Delineation of post-industrial landscapes of the Upper-Silesian corridor in the Basin of Ostrava. Environmental and Socio-economic Studies, 1 (3): 21-34. doi: http://dx.doi.org/10.1515/environ-2015-0016.
Kolejka J. (2012) - Post-Industrial Landscape - Return to Rural Affairs?, Rural Studies, 27 (1): 113-133.
Kučera T., Guth J. (1999) - Stabilization of the natural landscape in the Bohemian Forest frontier area (Czech Republic/Germany) abandoned for 40 years. Proceedings of the CZ-IALE conference, Present and Historical Nature-Culture Interactions in Landscapes (Experiences for the 3rd Millenium), Nature and culture in landscape ecology (experience for the 3rd millenium), Karolinum Press, Prague, pp. 183-190.
Lausch A., Herzog F. (2002) - Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. Ecological Indicators, 2 (1-2): 3-15. doi: http://dx.doi.org/10.1016/S1470-160X(02)00053-5.
Lieskovský J., Bezák P., Špulerová J., Lieskovský T., Koleda P., Dobrovodská M., Burgi M., Gimmi U. (2015) - The abandonment of traditional agricultural landscape in Slovakia - Analysis of extent and driving forces. Journal of Rural Studies, 37: 75-84. doi: http://dx.doi.org/10.1016/j.jrurstud.2014.12.007.
Fernández-Manso A., Quintano C., Roberts D. (2012) - Evaluation of potential of multiple
endmember spectral mixture analysis (MESMA) for surface coal mining affected area mapping in different world forest ecosystems. Remote Sensing of Environment, 127: 181-193. doi: http://dx.doi.org/10.1016/j.rse.2012.08.028.

Mallinis G., Koutsias N., Arianoutsou M. (2014) - Monitoring land use/land cover transformations from 1945 to 2007 in two peri-urban mountainous areas of Athens metropolitan area, Greece. Science of the Total Environment, 490: 262-278. doi: http://dx.doi.org/10.1016/j.scitotenv.2014.04.129.

Moreira F., Rego F.C., Ferreira P.G. (2001) - Temporal (1958-1995) pattern of change in cultural landscape of northwestern Portugal: implications for fire occurrence. Landscape Ecology, 16 (6): 557-567. doi: http://dx.doi.org/10.1023/A:1013130528470.

Mulčková M., Popelková R. (2008) - Cultural and Mining Landscapes: Different Changes and Different Methods to Evaluate the Landscape Development. In: Geography in Czechia and Slovakia, Theory and Practice at the Onset of 21st Century, Brno, pp. 153-159.

Mulčková M., Popelková R., Popelka P. (2012) - Landscape changes in the central part of the Karviná region from the first half of the 19th century to the beginning of the 21st century. Ekológia. International Journal for Ecological Problems of the Biosphere, 31 (1): 75-91. doi: https://doi.org/10.4149/ekol_2012_01_75.

Mulčková M., Popelková R. (2013) - Displays of hard coal deep mining in aerial photos. Acta Universitatis Carolinae - Geographica, 48 (1): 25-39. doi: http://dx.doi.org/10.14712/23361980.2015.8.

Mulčková M., Popelková R., Popelka P. (2016) - Black Land: The Mining Landscape of the Ostrava-Karviná Region. In: Landscapes and Landforms of the Czech Republic, Hradecký J., Pánek T. (Eds), Springer International Publishing, pp. 319-332. doi: http://dx.doi.org/10.1007/978-3-319-27537-6_25.

Narumalani S., Mishra R.D., Rothwell R.G. (2004) - Change detection and landscape metrics for inferring anthropogenic processes in the greater EFMO area. Remote Sensing of Environment, 91: 478-489. doi: http://dx.doi.org/10.1016/j.rse.2004.04.008.

Oťahel J., Feranec J. (1999) - Landscape structure analysis in environmental planning: Case study - Part of Liptov (Slovakia). In: Proceedings of the CZ-IALE conference, Present and Historical Nature-Culture Interactions in Landscapes (Experiences for the 3rd Millenium), Nature and culture in landscape ecology (experience for the 3rd millenium), Karolinum Press, Prague, pp. 155-169.

Petit C.C., Lambin E.F. (2002) - Impact of data integration technique on historiclal land-use/land-cover change: Comparing historical maps with remote sensing data in the Belgian Ardennes. Landscape Ecology, 17 (2): 117-132. doi: http://dx.doi.org/10.1023/A:1016599627798.

Popelka P., Popelková R., Mulčková M. (2015) - Hlavní tendence ve vývoji krajiny ostravsko-karvinského revíru v 19. a 20. století. Časopis Maticy moravské, 134: 435-463.

Popelková R. (2009) - Retrospektivní analýza vývoje krajiny s využitím geoinformačních technologií. Ph.D. thesis, Vysoká škola báňská – Technická univerzita Ostrava, Hornicko-geologická fakulta, Institut geoinformatiky, Ostrava, 168 pp.

Plieninger T. (2006) - Habitat loss, fragmentation, and alteration - Quantifying the impact of land-use changes on a Spanish dehesa landscapes by use of aerial photography and GIS. Landscape Ecology, 21: 91-105. doi: http://dx.doi.org/10.1007/s10980-005-8294-1.
Rocchini D., Perryb G.L.W., Salernoa M., Maccherinia S., Chiaruccia A. (2006) - Landscape change and the dynamics of open formations in a natural reserve. Landscape and Urban Planning, 77 (1-2): 167-177. doi: http://dx.doi.org/10.1016/j.landurbplan.2005.02.008.

Santo E.L., Sánchez L.E. (2002) - GIS applied to determine environmental impact indicators made by sand mining in a floodplain in southeaster Brazil. Environmental Geology, 41 (6): 628-637. doi: http://dx.doi.org/10.1007/s002540100441.

Skleníčka P., Lhota T. (2002) - Landscape heterogenity - a quantitative criterion for landscape reconstruction. Landscape and Urban Planning, 58 (2-4): 147-156. doi: http://dx.doi.org/10.1016/S0169-2046(01)00217-1.

Soriano M.A., Simón J.L. (2002) - Subsidence rates and urban damages in alluvial dolines of the Central Ebro basin (NE Spain). Environmental Geology, 42 (5): 476-484. doi: http://dx.doi.org/10.1007/s00254-001-0508-5.

Stehlík P. (2004) - Letecké měřické snímkování. Vojenský geografický obzor, 1: 33-37.

Stiros C.S. (2001) - Subsidence of the Thessaloniki (northern Greece) coastal plain, 1960-1999. Engineering Geology, 61 (4): 243-256. doi: http://dx.doi.org/10.1016/S0013-7952(01)00027-8.

Svenningsen S.R., Brandt J., Christensen A.A., Dahl M.C., Dupont H. (2015) - Historical oblique aerial photographs as a powerful tool for communicating landscape changes. Land Use Policy, 43: 82-95. doi: http://dx.doi.org/10.1016/j.landusepol.2014.10.021.

Teferi E., Bewket W., Uhlenbrook S., Wenninger J. (2013) - Understanding recent land use and land cover dynamics in the source region of the Upper Blue Nile, Ethiopia: Spatially explicit statistical modeling of systematic transitions. Agriculture, Ecosystems and Environment, 165: 98-117. doi: http://dx.doi.org/10.1016/j.agee.2012.11.007.

Townsend P.A., Helmers D.P., Kingdon C.C., McNeil B.E., de Beurs K.M., Eshleman K.N. (2009) - Changes in the extent of surface mining and reclamation in the Central Appalachians detected using a 1976-2006 Landsat time series. Remote Sensing of Environment, 113 (1): 62-72. doi: http://dx.doi.org/10.1016/j.rse.2008.08.012.

Wentz E.A., Stefanov W.L., Gries C., Hope D. (2006) - Land use and land cover mapping from diverse data sources for an arid urban environments. Computers, Environment and Urban Systems, 11 (2): 211-227. doi: http://dx.doi.org/10.1023/A:1018928026708.

Zala C.A., Barrodale I. (1999) - Warping aerial photographs to orthomaps using thin plate splines. Advances in Computational Mathematics, 11 (2): 211-227. doi: http://dx.doi.org/10.1023/A:1018928026708.
Appendices

Appendix 1 (Continued on the next page) - Photointerpretation key.

| Land cover category               | Black and white aerial image | Coloured aerial image | Characteristics                                                                                                                                 |
|----------------------------------|------------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Road and rail network and associated land | ![Image]                   | ![Image]              | If some areas have been undermined, embankments are created to level surface deformations that damage communications. High embankments of up to a few meters are built due to the modification of the roads. The types of embankments that manifest themselves as lines and are easily identifiable in aerial photos involve railway and road embankments as well as embankments of engineering networks. |
### Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category                        | Black and white aerial image                                                                 | Coloured aerial image                                                                 | Characteristics                                                                                                                                                                                                 |
|--------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineral extraction sites                   | ![Black and white image](image1.png)                                                        | ![Coloured image](image2.png)                                                            | Individual mine buildings including winding towers and other mining-related buildings can be identified in aerial photographs.                                                                                 |

![Image](image3.png)
Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Coloured aerial image | Characteristics |
|---------------------|------------------------------|-----------------------|-----------------|
| Waste heaps         | ![Image 1](image1.png)       | ![Image 2](image2.png) | Convex landforms (area can reach from a few areas to tens of hectares) generally found in the proximity of mine buildings. They originate as a result of the deposition of extracted coal waste during deep coal mining. Active waste heaps in the photos represent vegetation-free surfaces with clearly visible contours. |
Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Coloured aerial image | Characteristics |
|---------------------|------------------------------|-----------------------|-----------------|
| Reclamation areas   | ![Reclamation areas](image1)  | ![Reclamation areas](image2) | Make up a component of reclamation construction sites. They are characterised by temporary convex landforms in a shape of low flat waste banks. The photos facilitate easy interpretation of new reclamation areas in the form of bare surfaces. Unlike waste heaps, reclamation areas can be found relatively far from mine buildings. In many cases, visual photointerpretation needs to be carried out with the use of supporting data in order to avoid confusion with waste heaps. |
### Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Coloured aerial image | Characteristics |
|---------------------|-----------------------------|-----------------------|------------------|
| Handling areas      | ![Black and white image](image1.png) | ![Coloured image](image2.png) | Generally found in the proximity of mine buildings, tailings ponds or waste banks. They are anthropogenic levels and terraces of various shapes and sizes including access roads. They are detected in aerial photos as bare surfaces, either convex or concave, serving as manipulation areas for e.g. transport. |

---

Continue the table as needed.
Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Coloured aerial image | Characteristics |
|---------------------|------------------------------|-----------------------|-----------------|
| Dry tailings ponds  | ![Black and white image](image1) | ![Coloured image](image2) | Shallow concave vegetation-free landforms that appear in the landscape after the termination of sludge management activities. Dry tailings ponds can be identified in aerial photos on the basis of their shape that usually remains preserved after the life of the ponds has come to the end. Clear-cut interpretation is facilitated by the comparison of time series of aerial photos. |
## Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Coloured aerial image | Characteristics |
|---------------------|-----------------------------|----------------------|-----------------|
| Other vegetation-free areas | ![Black and white image](image1) | ![Coloured image](image2) | Most often related to bare surfaces appearing particularly after the demolition of buildings. |

Other vegetation-free areas are typically seen as bare surfaces, often indicating areas that have been recently cleared or disturbed. This could be due to natural events, such as fires, or human activities, such as construction or clearing for new development.

### Other vegetation-free areas

- **Characteristics:**
  - Most often related to bare surfaces appearing particularly after the demolition of buildings.

The images above illustrate examples of other vegetation-free areas, showing the contrast between black and white and coloured aerial images. The coloured image provides a clearer distinction between different types of surfaces, aiding in the interpretation of the landscape.
### Appendix 1 (Continued from preceding page and on the next page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Colour aerial image | Characteristics |
|---------------------|------------------------------|---------------------|-----------------|
| Submerged ground subsidences | ![Black and white image](image1.png) | ![Colour image](image2.png) | Ground subsidences originate as a result of surface subsidence above mined-out space. It concerns flat subsidences (size depends on geological conditions, tectonics and the area and thickness of coal seams). The subsidences can be filled with water. Clear-cut interpretation is particularly that of submerged ground subsidences that represent secondary mining displays and largely participate in the formation of water bodies. Unlike other water surfaces, they usually have an irregular broken shape. |
|                      | ![Black and white image](image3.png) | ![Colour image](image4.png) | |
|                      | ![Black and white image](image5.png) | ![Colour image](image6.png) | |

---

Popelková and Mulková  Multitemporal aerial image analysis in the coal mining landscape
### Appendix 1 (Continued from preceding page) - Photointerpretation key.

| Land cover category | Black and white aerial image | Coloured aerial image | Characteristics |
|---------------------|------------------------------|-----------------------|-----------------|
| Tailings ponds      | ![Black and white image](image) | ![Coloured image](image) | Natural or excavated basin, serves for permanent or temporary storing of hydraulically transported tailings. It particularly concerns water surfaces of a regular, often geometric, shape in the proximity of mine buildings. |