GEORELIEF RECONSTRUCTION AND ANALYSIS BASED ON HISTORICAL MAPS AND AERIAL PHOTOGRAPHS

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Abstrakt

V průběhu posledního století došlo na mnoha místech k výrazné změně reliéfu vlivem lidské činnosti. Největší vliv na změnu rázu krajiny v našich podmínkách má bezesporu povrchová těžba hnědého uhlí. Vlivem těžby uhlí se odtěžilo mnoho kubických metrů zeminy, která byla opět jinde nasypána, čímž došlo k radikální změně reliéfu.

Jedním ze způsobů rekonstrukce původního rázu krajiny společně s již neexistujícím reliéfem je využití historických map a starých leteckých snímků z doby, kdy povrchová těžba uhlí v dané oblasti neexistovala, či byla pouze v počátcích. K tomuto účelu byly použity mapy III. vojenského mapování 1:25 000 po reambulanci (popřípadě před reambulací) a letecké snímky z let 1938 a 1995. Historické mapy byly georeferencovány metodou plátování s využitím velkého počtu identických bodů (ESRI 2010). U georeferencovaných map byla provedena vizuální kontrola kvality pomocí pravidelné čtvercové sítě a vizuální návaznosti na současná data. Reambulované mapy obsahují velmi dobře čitelný výškopis, který byl použit k rekonstrukci původního reliéfu a jako podkladová výšková vrstva pro ortorektifikaci leteckých snímků. Díky zpracování leteckých snímků získáme informace o výškových poměrech povrchových dolů, které jsou za normálních podmínek obtížně dostupné.

Při porovnání výškových dat získaných fotogrammetrickými metodami s výškovým rastrem získaným vektorizací vrstevnic můžeme provést analýzu přesnosti výškopisu starých map. Pomocí analýzy výpočtu objemů byl stanoven objem horniny, který byl v jednotlivých oblastech vytěžen a v jiných opět navršen. Pro velkolom Bílina se dostáváme téměř k hodnotě 1 miliardy m^3 vytěžené horniny.

Klíčová slova: rekonstrukce reliéfu, III. Vojenské mapování, letecké snímky, digitální model povrchu, analýza objemů.

Abstract

During the last century were done many significant georelief changes caused by the human activity. The biggest influence on the landscape character change within the frame of the Czech Republic has undoubtedly the brown coal opencast mining. During the mining activity were removed a lot of cubic meters of material and placed elsewhere which resulted in dramatic changes of the georelief.

One of the ways how to reconstruct the original shape of the landscape is the usage of historical maps and old aerial photographs made in the period before the dramatic georelief changes. The maps of the 3rd Military survey 1:25 000 after reambulation (partly before reambulation) and aerial photographs taken in years 1938 and 1995 were used for this purpose. Historical maps were georeferenced using the method of Coonse plating using a huge amount of identical points (ESRI 2010). The reambulated maps contain clearly readable elevation data (contour lines), which were used for reconstructing the original georelief and as well as the base elevation layer used for aerial photographs orthorectification. Thanks to processing of the aerial photographs we can obtain the Digital Surface Model of the coal mines.

Comparing the elevation data obtained by photogrammetric methods with the elevation grid constructed from vectorized contour lines we may try to evaluate the preciseness of the old maps elevation data. The volumetric analysis was used to calculate the georelief differences done during the selected years. Within the Bílina mine we almost reach the amount of 1 bilion m^3 of transferred material.

Keywords: georelief reconstruction, 3rd Military survey, aerial photographs, digital surface model, volumetric analysis.

INTRODUCTION

The area between the towns Kadaň and Duchcov (North-west Bohemia, the Czech Republic) is a part of so called Black Triangle (ECM 2010) with active coal mining activity. The Brown coal has been mined in this area for ages, but the mining has become very intense in the last 80 years. Brown coal is not located to deep in the coal basin, so the technology of open-cast mines is widely used in this area. The open-cast mining is a rather cheap technology of coal mining giving access to huge loads of brown coal, but with a destructive effect on the surrounding environment.

This region used to be focused on agriculture, with towns and little villages spread all over the basin. The coal mining followed by the heavy industry has changed the look and shape of this region a lot. The open-cast mines are covering ca 3800 ha within the Area of interest (see Fig. 5). The original landscape, including settlement, infrastructure and ecosystems has been destroyed in this area.

The purpose of this paper is to visualize the original state of the georelief and to calculate some interesting statistics using the GIS technologies. Old maps and historical aerial photographs may be a good resource for reconstructing the original state of the destructed landscape. This reconstructed georelief has a wide range of use – historical purposes, recultivations, hydrological modeling, landscape planning. Obtaining the original georelief gives us a chance to calculate how much material have been so far mined (removed) and how much have been poured into the dumps.

The georelief reconstruction requires elevation data from the period before the intensive coal mining activity. This area has been closely mapped in 1930' thanks to its geographic location (which is close to the border with Germany) and the huge brown coal reserves. The maps of the 3rd Military survey 1:25 000 of this region have been reambulated in the period 1934 – 1938 and in 1938 was the region covered with aerial photographs. The current state of the georelief within the coal mines cannot be easily obtained and the coal mining companies are not a well accessible data source at all. Here we have to use the aerial photographs for Digital Surface Model (DSM) and further on Digital Elevation Model (DTM) creation as well.

Fig. 1 Georelief change in the Basin of Most - 1960' and 2000. Štýs (2000)

DATA AND METHODS

We will work with old maps and historical/current aerial photographs. Old maps used for this project are the maps of the 3rd Military survey 1:25 000 after reambulation. Historical aerial photographs originate from the year 1938 and the recent aerial photographs from the year 1995.

Old maps

The old maps in this region were reambulated in 1930' apparently for the strategic purposes with upcoming of the 2nd World war. Elevation data are clearly readable in these maps in the form of contour lines and elevation points. These maps are covering almost the whole Area of interest with contour interval varying from 20m in flat areas to 5m in hilly areas. Only in some parts we had to use a non-reambulated map - the elevation here is expressed by the Lehman's hachure.

Hachures are an older model of representing the georelief. They show orientation of slope, and by their thickness and overall density they provide a general sense of steepness. Being non-numeric, they are less useful to a scientific survey than contours, but can successfully communicate quite specific shapes of terrain. They are a form of shading, although different from the one used in shaded maps. Hachure representation of relief was standardized by the Austrian topographer Johann Georg Lehmann in 1799. (Kennelly & Kimerling 2001)

All maps covering the Area of interest have to be georeferenced. Spline transformation implemented in ArcGIS was used to georeference the data. The spline transformation is a true rubber sheeting method and is optimized for local accuracy but not global accuracy. It is based on a spline function - a piecewise polynomial that maintains continuity and smoothness between adjacent polynomials. (ESRI 2010)

The spline transformation was chosen as it fulfills the position accuracy of the transformed requested for the DTM creation in this project. Approximately 150 to 250 identical points were chosen in each map sheet (dependently on the input data) to secure the local accuracy. The transformation accuracy has been visually tested with the MapAnalyst application (Jenny & Weber 2010) by applying a regular square network on the transformed data (see Fig. 2).

Contour lines and elevation point have been hand-vectorized and further on used for DTM creation. More complicated was to obtain the elevation data from the non-reambulated maps. Here are the contour lines created based on the Lehman's hachure.
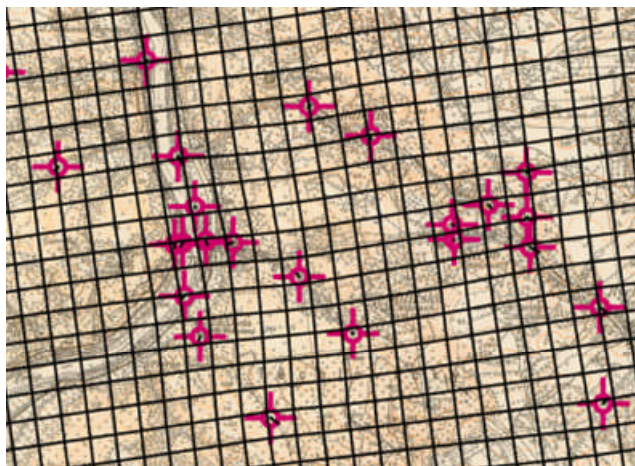
Fig. 2 Detail of the regular square network (and its distortion) applied on the transformed data

Aerial photographs

The *Area of interest* (see Fig. 5) is covered by 15 aerial photographs for the year 1995 and 17 for 1938. So far have been processed for the *Sample testing area* 5 aerial photographs for the year 1995 and 7 for 1938. All the images have at least 60% overlap.

Aerial photographs were processed using the Leica Photogrammetric Suite. The characteristics of processed images are following:

Table 1 Aerial photographs parameters

Year	1995	1938
Focal length	152.16	211.59
Scale factor	1 : 29450	Unknown (ca 1 : 18000)
Flight height [m]	4481	Unknown (ca 4000)
Resolution [DPI]	1016	1016
Resolution [μm]	25.00	25.00

The aerial photographs were processed in the standard way of photogrammetry. The images were at first tight together with 30 TIE points for each stereo-pair and then were added the Ground Control Points (GCP) covering the whole block. GCP's require georeferenced data, including the elevation information.

To create the GCP's for the year 1995 were used the standard accessible data – orthophoto available at http://geoportal.cenia.cz and ZABAGED® (ČUZK 2010) for the elevation data.

On the aerial images from the year 1938 are in the *Sample testing area* large parts of the landcape that has changed a lot. The recent data are practically useless for processing the GCP's in these areas. Here we have used partially the old maps (3rd Military survey) to locate the object on the historical aerial photographs, recent orthophoto for the surrounding areas without a significant change and the orthophoto from 1952 accessible at http://kontaminace.cenia.cz for the other areas.

The 1938 images are not of a very good visual quality. The images are noisy, scratched, and affected by the contemporary technology of creation – this affects especially the selection of GCP's and the automatic DSM creation from aerial images.

Vectorized contour lines from the maps of the 3rd Military survey were used for DTM creation – giving the Z coordinate for the GCP's. The contour interval of the 3rd Military survey maps is from 20m to 5m, depending on the slope of the terrain.

DTM interpolation was done using the Regularized Spline with Tension, implemented in GIS GRASS. See Mitas & Mitasova (1988) and (1993), Neteler (2004) for more information.

Triangulation of the aerial photographs was performed with respect to the quality of the processed images and to the minimum RMSE of the resulting data.

DTM and DSM creation

Several DTM's and DSM's were created under processing of the *Area of interest* - at first the DTM's defining the GCP's elevation and consequently the DSM derived from the aerial images. The method for processing the DTM's from ZABAGED® and 3rd Military survey contour line is described in the previous text.

We will use the following labeling for the further text:

- DTM_1936 – interpolated from the 3rd Military mapping contour lines,

- DSM_1938 – derived from the aerial photographs – year 1938,

- DSM_1995 – derived from the aerial photographs – year 1995.

DSM_1938 and DSM_1995 were created by automatic image correlation. This method is used for automatic DSM extraction from aerial images with known orientation parameters with image overlap (in our case 60%).

Produced DSM_1995 has no visible errors and is well corresponding to the aerial image. Quality of DSM_1995 can be evaluated by visual control of the DSM_1995 contour lines compared with ZABAGED® contour lines (in the areas outside the mines) – see Fig. 3.
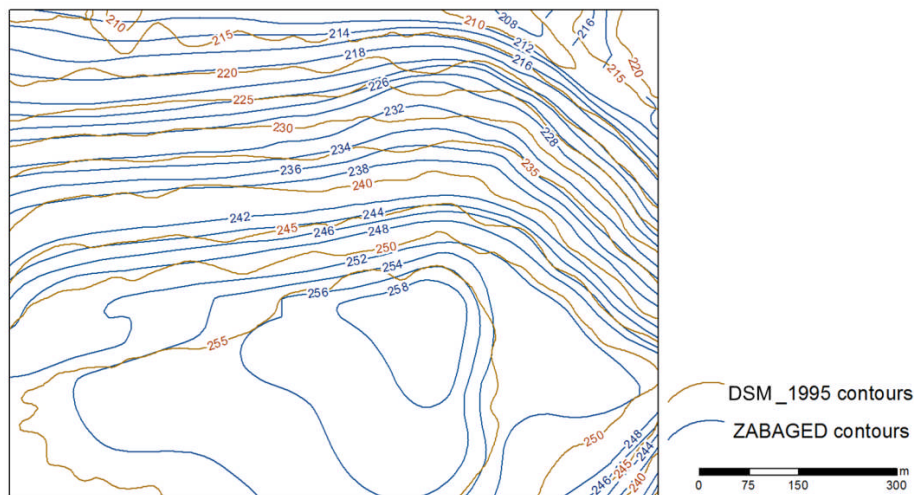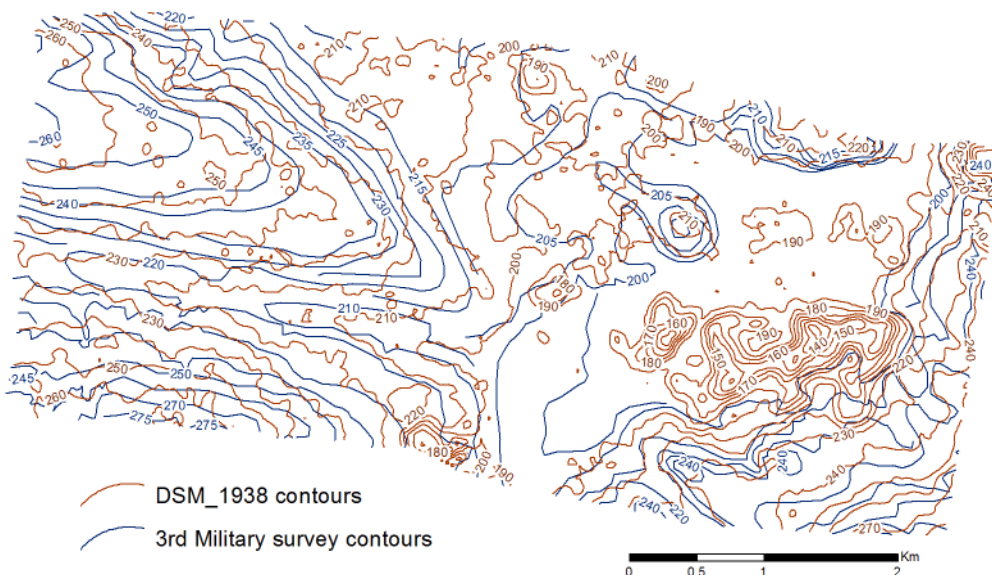
Fig. 3 Comparison of Digital Surface Model – year 1995 (DSM_1995) and ZABAGED® contour lines

The automatic DSM_1938 extraction has to deal with the following problems:

- the camera's focal length is 211.59 and the image scale is ca 1:18 000,

- old technology of original picture creation and processing,

- long term warehousing = scratched images.

All the above mentioned problems influenced the automatic image correlation and the resulting DSM is little noisy. We should apply a different data processing methodology (operator driven elevation point extraction) for the further processing of the whole *Area of interest* - especially on the crucial areas with large elevation differences. The resulting DSM_1938 was smoothed by the *mean* focal function. The result is presented on Fig. 4 – here we can compare the contour lines of DTM_1936 and DSM_1938.


Fig. 4 Comparison of Digital Terrain Model – year 1936 (DTM_1936) contour lines based on the 3rd Military survey and Digital Surface Model – year 1938 (DSM_1938) contour lines

Our area of interest is located around the town Bílina (see Fig. 5) covering the open-cast mine Bílina and the Dumb Radovesice. Processing the historical aerial photographs is problematic and thus a *Sample testing area* was defined. Here we will test the so far processed data and prepare the testing methodology for the whole Area of interest. The *Sample testing area* contains locations with active mining activity (= the material being taken away) and areas recultivated from previous mining (= filled with material).
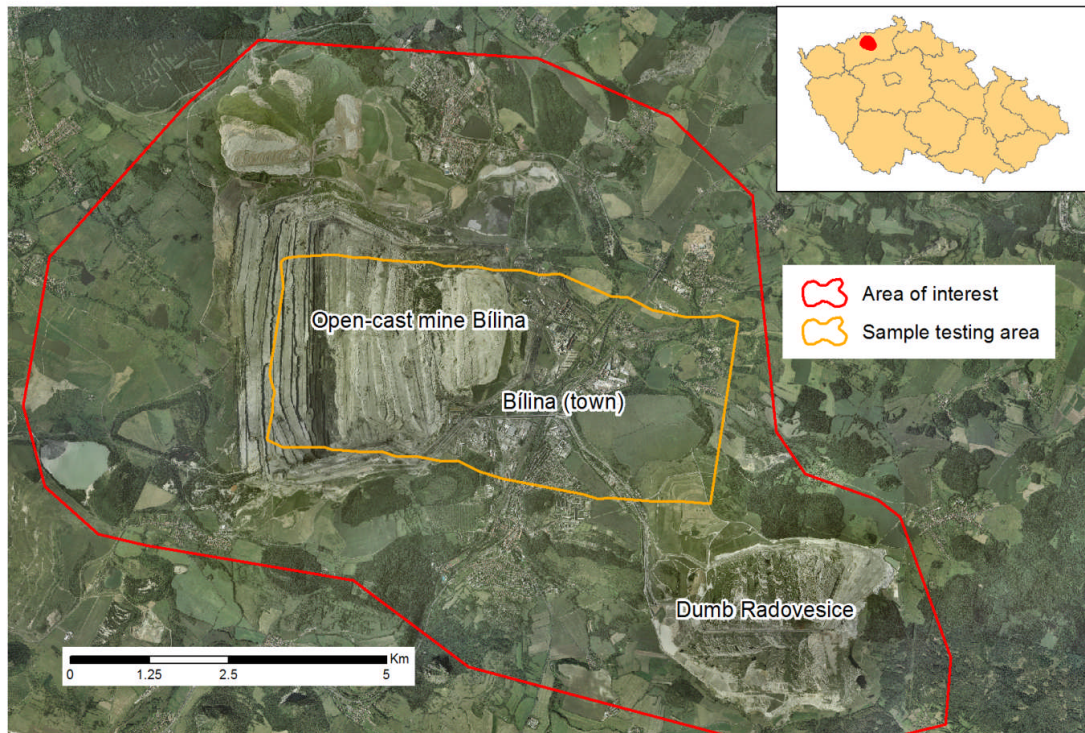
Fig. 5 The *Area of interest* overview
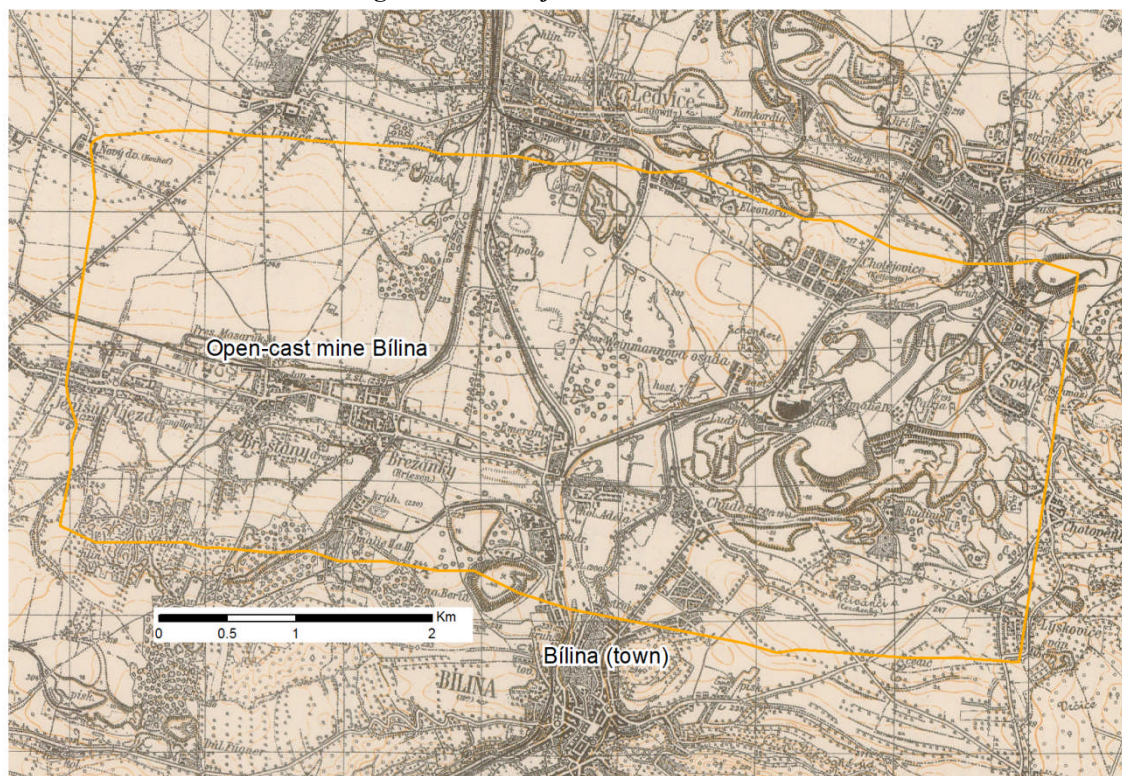
Fig. 6 Delimitation of the *Sample testing area* using the 1936 basemap

The terrain in our Sample testing area differs a lot between the year 1938 and 1995 – this is the result of mining activity, recultivations, and anthropogenic effects on the landscape (construction of houses, highway,

and industrial areas). To depict the areas with the terrain change caused by the mining activity we performed an analysis computing the differences between the DSM_1938 DTM and the DSM_1995. The result shows areas with the highest terrain change (see Fig. 7). Areas with the highest terrain change were selected based on this analysis for further testing – to obtain more precise results the "Sub-area" was delineated in the Area 2.
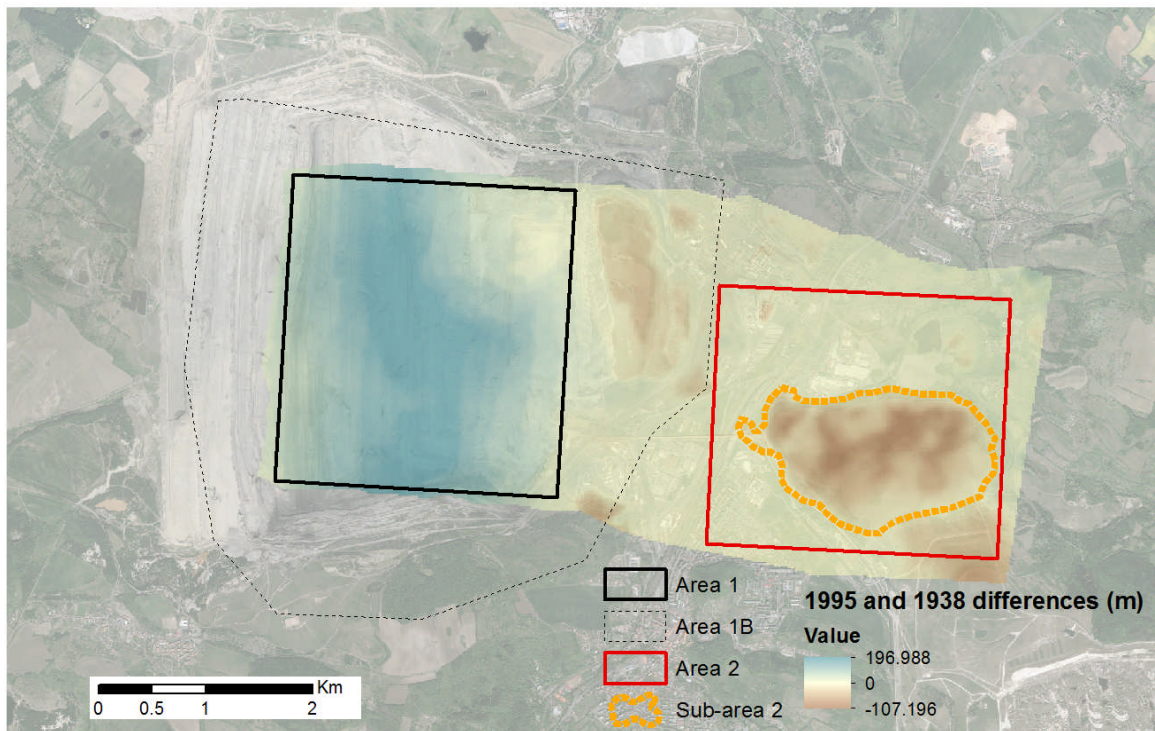

Fig. 7 Digital surface model differences (year 1938 and 1995) and areas of interest delimitation

ANALYSIS

One of the tasks of this project is to evaluate the material amount that was mined from the selected areas or transported into the dumb (deposit). The material amount is in this case equal to the volume of the upper and lower surface difference. Here we get the so called *Positive Volume (Cut)* and the *Negative Volume (Fill)*. The cut portion is the volume between the upper and lower surface when the upper surface is above the lower surface. The fill portion is the volume between the upper and lower surfaces when the upper surface is below the lower surface (see Fig. 8).

The volume calculation was performed using the double integral:

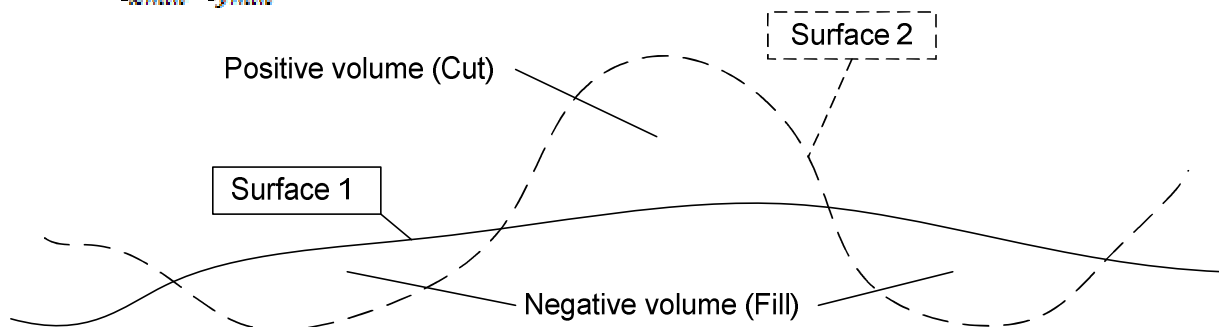$$Volume = \int_{xmin}^{xmax} \int_{ymin}^{ymax} f(x,y)dxdy.$$

Fig. 8 Principle of Positive and Negative volume

Analysis of Area 1 (open-cast mine)

The Area 1 is covering part of the open-cast mine Bílina. Only a part of the historical aerial photographs of the Area of interest has been so far processed and thus is the created DSM_1938 not covering the whole mine. In this case we will perform the calculation of the mine volume as well from the DTM_1936 – which will overgrow the Sample testing area boundaries. The volume calculation from DTM_1936 would be proximate, as the DTM was interpolated from hand-vectorized contour lines.

The total Positive Volume (Cut) of Area 1B is 44 363 951m^3 and the Negative Volume (Fill) is 930 015 080m^3. One railway transport wagon can store up to 75m^3 - this means (based on this computation) that to transport the material and coal from the Bílina mine (until the year 1995) could be used ca 12 400 200 wagons. Detailed difference grid of DTM_1936 and DSM_1995 is shown on Fig. 8. Visualization of the area is presented on Fig. 10 and Fig. 11.
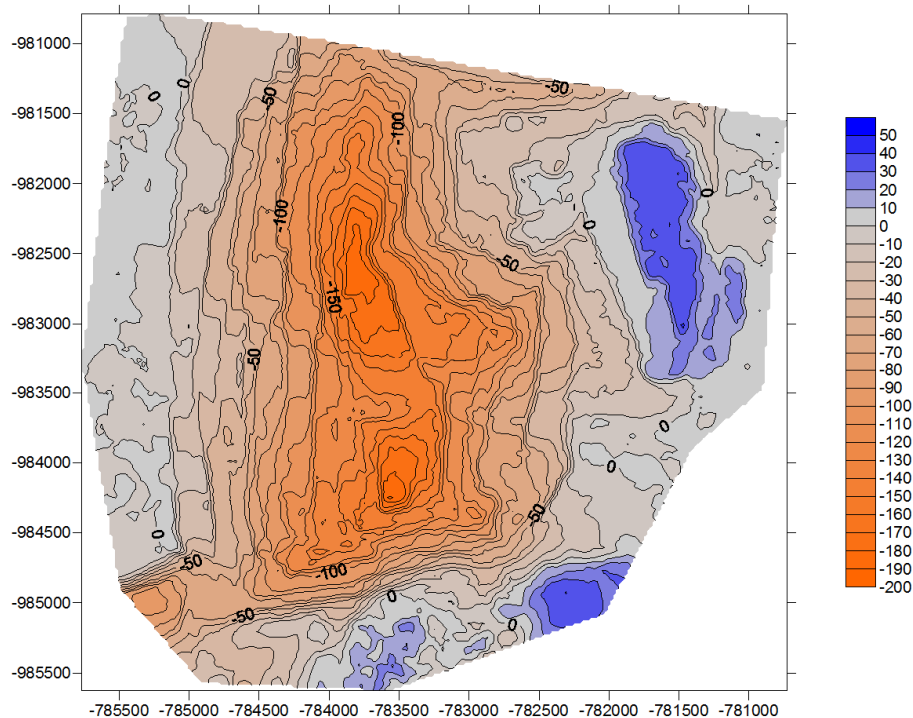
Fig. 9 Area 1B - Detailed difference grid of Digital Terrain Model – year 1936 (DTM_1936) and Digital Surface Model – year 1995 (DSM_1995)
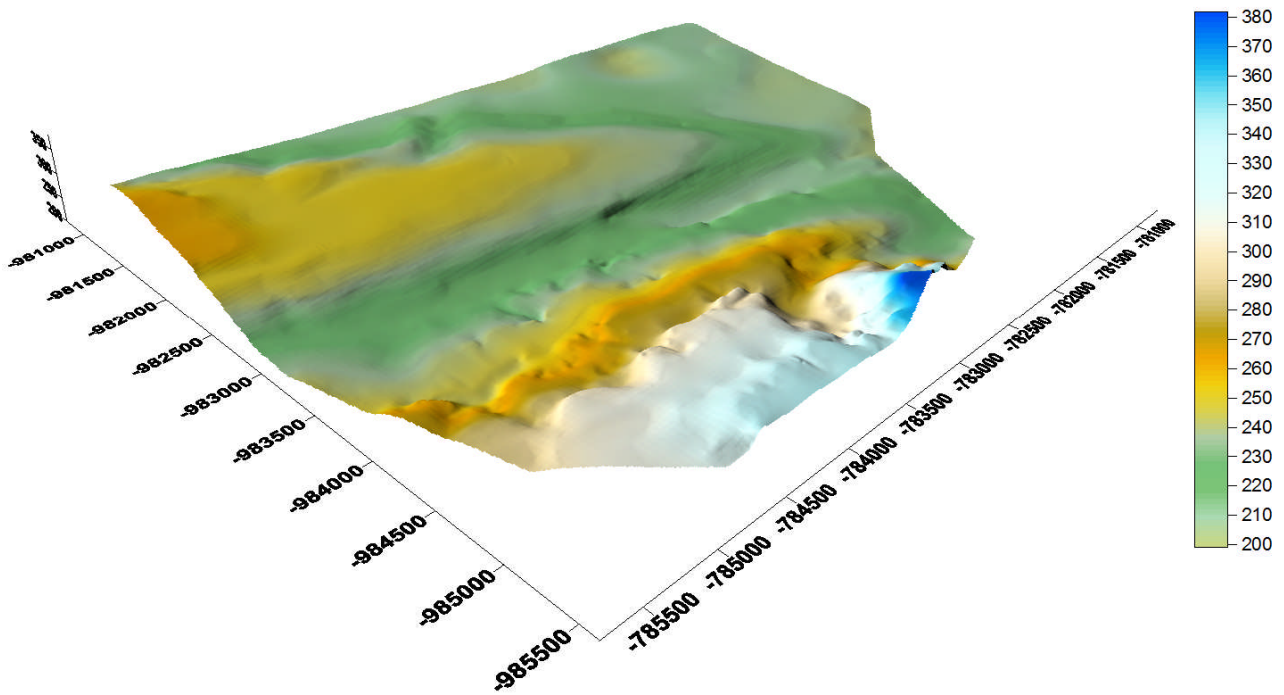
Fig. 10 Visualization of Area 1B – Digital Terrain Model – year 1936 (DTM_1936)
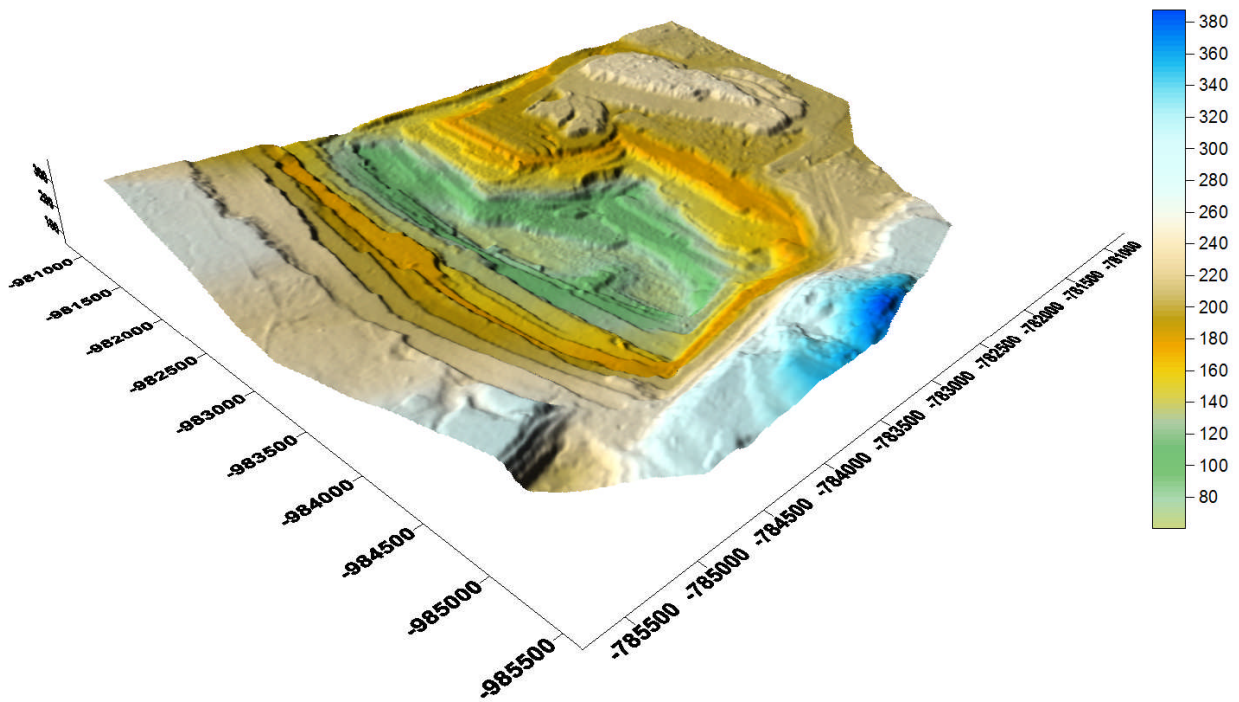

Fig. 11 Visualization of Area 1B – Digital Surface Model – year 1995 (DSM_1995)

We can compare the result of the volumetric analysis within the Area 1 using DTM_1936 and DSM_1938 in combination with DSM_1995. The DSM_1938 is more detailed but may be affected by the DSM creation method (see Fig. 12).

Calculated volumes using DSM_1938:

- Positive Volume (Cut): 487 188m^3,
- Negative Volume (Fill): 692 776 510m^3.

Calculated volumes using DTM_1936:

- Positive Volume [Cut]: 53 379m^3,
- Negative Volume [Fill]: 681 691 618m^3.
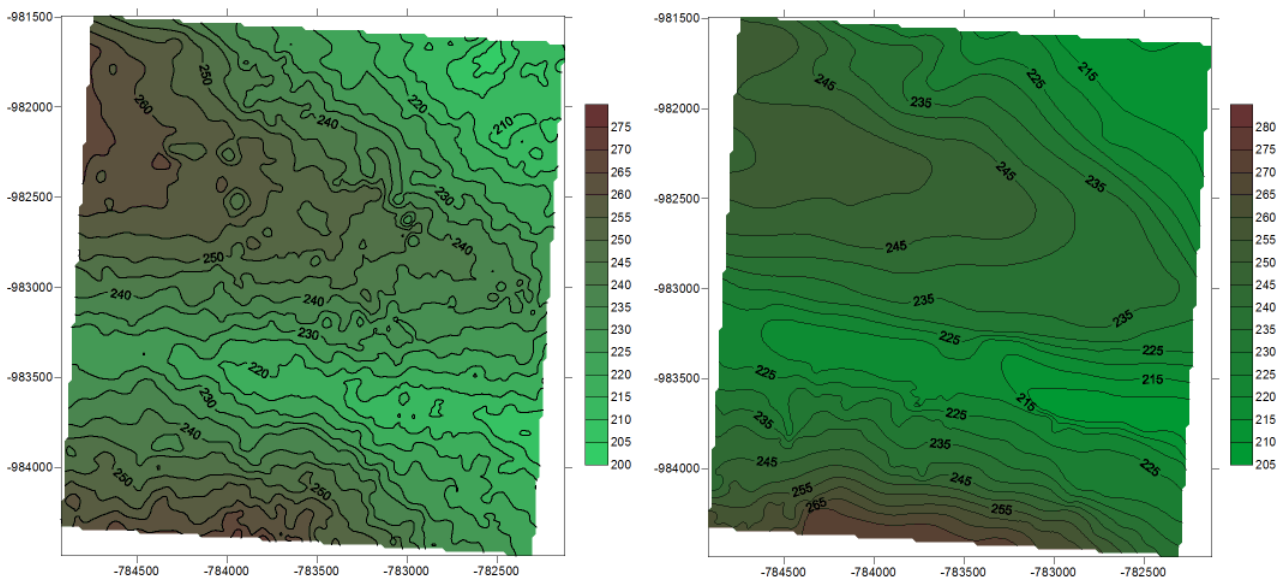
Fig. 12 Contour lines generated from Digital Surface Model – year 1936 (DSM_1938) and Digital Terrain Model – year 1936 (DTM_1936)

The contour lines generated from DSM_1938 and DTM_1936 are presented on Fig. 12. Here we may see the differences of the two datasets. The cartographically generalized contour lines from the map of the 3rd Military survey have the same trend as the contour lines generated from the DSM_1938. The DSM_1938's contour lines are more detailed in describing the terrain. The automatically generated DSM is based on a Triangulated Irregular Network and thus the contour lines should be further on cartographically generalized.

Analysis of Area 2 (recultivated mine)

Area 2 is covering a previous mine turned into forest/leisure-time recultivation (see Fig. 13 and Fig. 14). This type of recultivation is made by filling up the old mine with the material mined in an active mine or with ashes from a coal power plant. This area is fully covered by the processed new and old aerial images. The DTM_1936 was not taken into the computation, as the mine is not well described by the contour lines.

Differences of DSM_1995 and DSM_1938 are shown on Fig. 15. The volumetric analysis was performed on the Sub-area 2 as here was determined our field of interest. The total volume of added material is in this case 101 282 997m^3, which equals to ca. 1 350 440 wagons.
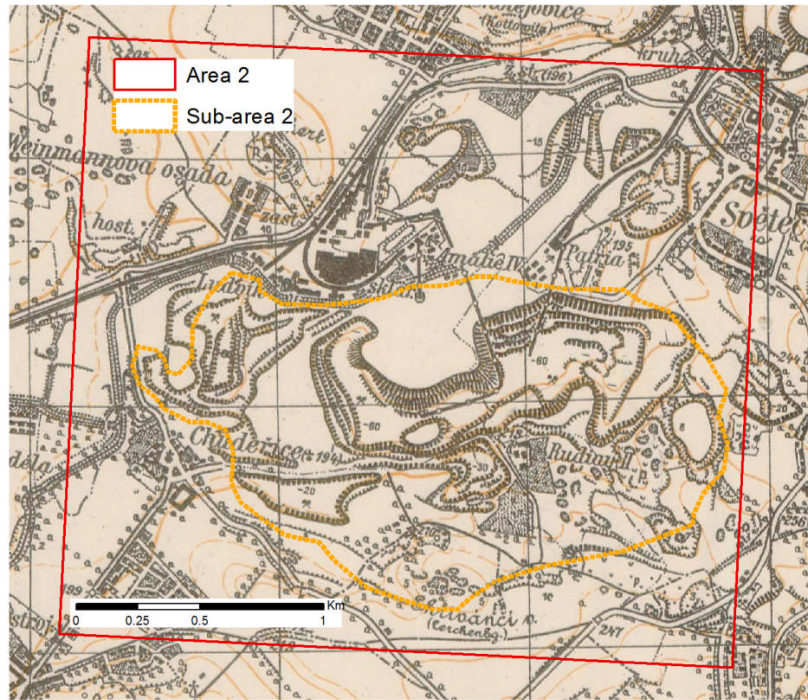
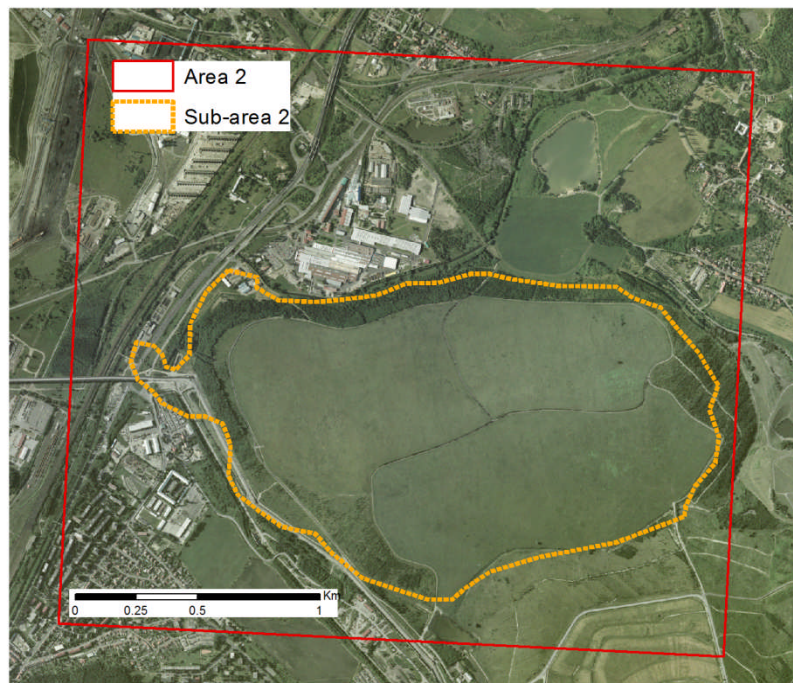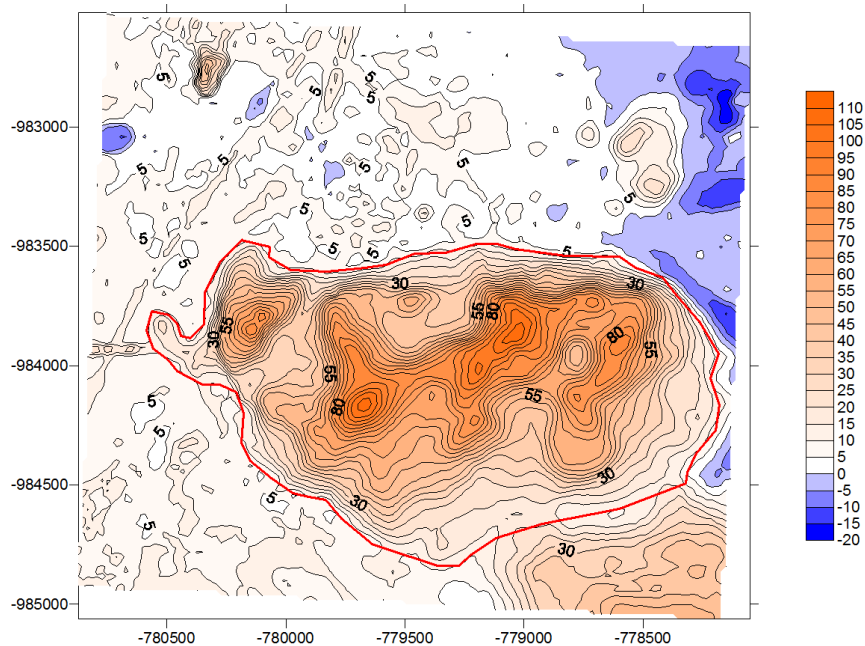**Fig. 13 The original state of Area 2 in the year 1936**

Fig. 14 The current state of Area 2 in the year 2008

Fig. 15 Differences of Digital Surface Model – year 1995 (DSM_1995) and Digital Surface Model – year 1938 (DSM_1938) with delineated Sub-area 2

CONCLUSION

In this paper are presented possibilities for reconstruction of irreversibly changed georelief, using aerial images and old maps. We have selected the Sample testing areas in the center of our study region Bílina to test the proposed methodology.

The old maps are used as a source of elevation data in areas with a large change of the landscape. In this paper were the old maps georeferenced using a spline transformation (rubber sheeting) with a huge number of identical points – 150 to 250 per map sheet. This transformation method provides sufficient accuracy for the purpose of this project. A Digital Terrain Model (DTM) was interpolated from the hand-vectorized contour lines of the 1936 map.

The historical and recent aerial photographs were photogrammetrically processed. All of the images have a 60% overlap, thus we were able to create the automatically generated Digital Surface Model (DSM) for the year 1938 and 1995. The automatic DSM creation based on pixel correlation is not producing absolutely precise results for the year 1938, as the images are scratched and influenced by the technology of original picture creation (camera's focal length 211.59mm and the image scale ca. 1:18 000). We have as well faced the problems with identifying the Ground Control Points (GCP) in areas with the large land use and georelief change. The produced DSM for the year 1995 is precise.

The amount of material that has been mined or added in the depicted areas during the period 1938 – 1995 can be computed from created DTM's and DSM's using a volumetric analysis. The material amount is 930 015 080m^3 of material mined from area 1B and 101 282 997m^3 material added into Area 2.

The results have shown that the computation may be refined by the usage of DTM's instead of DSM's - especially for the year 1938. This will require manual DTM extraction from recent and historical aerial images. This methodology will be applied of the whole Area of interest and the final result of our analysis will show us in numbers the effect of mining activity in the Bílina region.

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