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Denudacja antropogeniczna na obszarach górniczych

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SPIS TREŚCI

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Anthropogenic Denudation in Mining Areas on the Example of the Upper Silesian Coal Basin

Summary

The Upper Silesian Coal Basin (USCB) is one of the oldest and largest mining areas in Poland as well as in Europe. Intense extraction of hard coal, stowing sands, zinc and lead ores, and rock resources caused such extensive transformations of landscape that it can be considered a model anthropogenic relief. This dissertation attempts at a synthesis of these transformations, using uniform research methods for the whole study area. Our main objectives are as follows: 1/ to recognize anthropogenic forms of relief related to mining activity and present them from a spatial, genetic and age perspective, 2/ to determine the changes in the morphometric characteristics of relief and the conditions for matter movement in open systems (catchments) and closed systems (closed basins), caused by the extraction of mineral resources, and 3/ to estimate the size of anthropogenic denudation using varied methods based on such factors as the volume of extraction, a morphometric analysis, a study of sediments in closed basins, and through observation and direct measurements.

The research spans a short period of time (100-250 years); *sensu lato* it encompasses the area of almost entire Upper Silesian Coal Basin (4,540 km^2, Fig. 1), *sensu stricto* it includes 3 geological zones (Fig. 7) and 25 geomorphological units within the range of 63 hard coal mines (2,838 km^2, Fig. 2, 6, photo 3). The geological zones, here called – Carboniferous, Triassic and Miocene, in broad outline, refer to the occurrence of deposits of older, Pre-Quaternary substratum (Fig. 7). The Carboniferous zone (516 km^2) includes areas whose substratum was deeply drained as a result of intense hard coal mining. In a landscape characterised by moderate relief and strong urbanisation, there are noticeable sandstone horsts of tectonic origin, occasionally overlaid with „caps" of the Triassic rocks split by tectonic and erosional-denudational depressions (Fig. 3, 5). The Triassic zone (284 km^2) encompasses an area where the Carboniferous overburden consists of the Triassic carbonic rocks, which collect rich groundwater resources and are susceptible to karst processes. It is an area with either intense or moderate relief, characterised by escarpments and horsts (Fig. 5). Mining pression affected not only the Carboniferous substratum but also the Triassic overburden containing zinc and lead ores (Fig. 9). In the Miocene zone (nearly 860 km^2), the Carboniferous substratum lies beneath an impermeable overburden of the Miocene clayey rocks, and groundwaters occur in the Quaternary deposits. In the landscape with predominant low-relief clayey plateaux and outwash surfaces (Fig. 4, 6), the Rybnik Plateau, intensely dissected and quite strongly urbanised, is a distinguishable part.

A cartometric analysis of relief was carried out using archival topographic maps from the late 19th century (Fig. 8) and contemporary ones from the late 20th century. The maps were adjusted by *ArcMap 9.3* to the coordinate system 1992, and then vectorised and analysed by *MapInfoProfessional 7.0*. Consequently, 2 numerical models of the area were constructed – for the years 1883 and 1993. Each model encompasses an area of over 2,800 km^2. By subtracting the contemporary model from the late 19th century model, a raster map of changes in altitude from 1883 to 1993 was obtained. Also, maps of gradients and relative heights were constructed on the basis of digital elevation models. A database was created for geological zones, geomorphological units, catchments (I-VI order, Fig. 18) and hard coal mines. Hypsographic curves were drawn for selected geomorphological units and catchments for the years 1883 and 1993 (Fig. 39, 40), and indices of rock mass volume were calculated (STRAHLER 1952, Fig. 27, 28).

Mining production was calculated using numerous sources. Data on hard coal mining in all the mines of the Upper Silesian Coal Basin from 1769, that is when the records were started, to 2009 (Fig. 1, 2), and on the extraction of stowing sands (Fig. 4) and other mineral resources were collected. The data on extraction of twelve main resources in Poland mostly come from the last 50 years (Fig. 37). Total hard coal extraction by main European and world producers since the year 1800 is shown in figures 47 and 48.

Calculations of anthropogenic denudation rate in coal mine areas were made from hard coal production, following the procedures described by ŻMUDA (1973) and DULIAS (2011). Calculations of anthropogenic denudation rate on the basis of a morphometric analysis consisted in dividing the volume of resultant depressions by the surface area of the studied region (geological zone, geomorphological unit, catchment and coal mine) and the years of mining activity. Calculations of anthropogenic denudation from the analyses investigation, of sediments in closed basins were made using the method described by BORÓWKA (1992); the age reference level was obtained on the basis of ^{137}Cs dating. Research results were compared with data from other mining areas in Poland, as well as in the Ruhr Coal Basin (Ruhr District) and the Ostrava-Karvina Coal Basin.

During the thousand years of mining in the Upper Silesian Coal Basin, more than 13 billion tons of mineral resources and approximately 2-4 billion tons of waste rock (Fig. 29) were removed. The removal of rock mass was in nearly 94% connected with the extraction of hard coal and stowing sands; 98% of loss occurred during the last 100 years. The forms created as a result of direct mining activity (Tab. 3, 5, 6, Fig. 10) cover the area of less than 150 km²; half of this area falls on stowing sandpits (Fig. 14) and 1/3 on mining waste heaps (Fig. 15, 16, 28, 29, photo 5). The location of concave forms (Photo 4) is related to the lithological features of the substratum, that is to particular forms of relief of higher order, including quarries of solid rocks on cuestas and horsts, clay pits on high plains built from cohesive deposits, sandpits in basins and depressions overlaid with fluvoglacial deposits. The majority of directly anthropogenic forms preserved, to a considerable degree, the morphologic distinctiveness from the mining period. This pertains to numerous minor landforms from several hundred years ago (Fig. 11) and some opencast coal mines (Fig. 13).

From a geomorphological point of view, the most significant effect of mining is the emergence of indirectly anthropogenic forms - subsidence basins (Fig. 23-25, photo 10). Sinkholes, which are characteristic landforms in the process of shallow exploitation, were of marginal importance both in terms of morphology and the volume of the rock material moved as a result of their emergence (approximately 1 mln m³ - 0.007%) (Fig. 17-22, photos 6-8). Subsidence basins cover an area of 1,125 km² and have a volume of 3.3 billion m³ (Tab. 7-11). The largest volume of subsidence was observed in the Carboniferous zone (40% of total volume) – the area was lowered by 3.4 m on average. The biggest average subsidence of 4.4 m was recorded at the Triassic zone; here, also maximum subsidence of approximately 35 m was observed (Fig. 26, photo 9). A series of subsidence basins which are the deepest in the entire Upper Silesian Coal Basin corresponds in shape to the course of Saddle Beds (Fig. 27). In the Miocene zone, depressions below 2 m predominate, although in many places, they exceed 20 m.

The emergence of anthropogenic forms of relief, especially subsidence basins, caused significant changes in morphometric features of former relief. Absolute heights in vast areas of dozens and hundreds of square kilometers altered (Tab. 12), and new height-intervals appeared in many areas (Fig. 30). The surface area of the high-lying (above 280 m asl) mining areas decreased by over 42 km², whereas the surface area of those low-lying, (below 250 asl) increased by approximately 34 km². In the overwhelming majority of geomorphological units, an average height of the area decreased from 0.2 m to 4.5 m (Tab. 13); the least - on plainland, and the most - in areas with slope angle of 1-5. In more than ¾ of the area, relative heights increased (Fig. 31, tab. 14), mostly by less than 5 m. Generally, the relief of plains was diversified, whereas higher relief was moderated. Changes in slope angles (Tab. 15-17) are the same in all geological zones: they consist in a decrease in plainland and an increased share of slopes representing each class of slope angle, mostly those ranging between 1 and 3°.

Along with the transformation of morphometric features of relief, the conditions for matter movement altered (Photo 12, 16). The increase or decrease in absolute and relative heights changed the "distance" to local erosional bases, which, together with the changes of slope angles, modified the character and intensity of geomorphological processes. In the circulating matter, there are deposits with different physical and chemical qualities because new lithological deposits (waste rock, processed wastes) appeared on the surface (Fig. 32, photo 13), and in some areas, the natural surface sediments were dessicated, dampened, polluted, deprived of a vegetation cover and mixed with waste material.

The existence of anthropogenic landforms impacts currently occurring fluvial and slope processes (Fig. 28, 29, photo 11), including sheet wash, aeolian and lithoral processes, regardless of the fact that the relief is being modelled by these very processes (Photo 2). One of the most significant changes relevant to the circulation of matter in the Upper Silesian Coal Basin is the emergence of numerous closed basins (Fig. 37, tab. 19, 26, photo 19, 22), mostly in subsidence basins. This area, excluded from the fluvial system, encompasses more than122 km², that is almost 8% of the entire mining area, mainly in the Triassic zone - within the Vistula-Odra watershed. The reversal of natural fall of the land directed the surface wash toward the centre of basins and considerably shortened its way to the base-level of erosion (Fig. 38). As regards the closed basins, their emergence in relief is in 84% attributed to the increase in average slope angles. The deposition in these new sedimentation basins goes at a rate of approximately 0.6-0.9 mm/year (Fig. 43, tab. 35, photos 20, 21).

The conditions for the circulation of matter are also affected by discontinued circulation between the two systems: slope and fluvial ones with the construction of embankments, high railway embankments and waste heaps. Disturbances in the circulation of matter in fluvial systems are, first and foremost, a consequence of changes in: the location of erosional base, geometry of river beds, fall of valley bottoms and slopes, course of watersheds (Fig. 33) and resultant changes in the surface area of catchments, flows and load of transported material. In the 90% of the investigated catchments, slope angles increased (Tab. 20), and in the 80% of them, relief energy increased (Tab. 21). Over 80% of the rivers have a lowered erosional base (Tab. 23), which is on average, 3.4 m lower in the river basin of the Vistula, and 4.8 m lower in that of the Odra, while ¾ of the rivers have increased longitudinal falls (Tab. 22, fig. 36). To the highest extent, the lowering of erosional base pertains to rivers dewatering the Miocene zone. The subsidence caused the increase in the rate of their incision – starting from several centimetres per year to a dozen or so per year. Some river beds were deepened by several metres (Tab. 36, photo 15, 23).

The majority of rivers, especially the big ones, have increased flows also due to the share of alien waters (Tabs. 24, 25). Simultaneously, the river beds of almost all rivers and watercourses underwent at least one kind of transformation of their geometry (straightening, relocation, embankment, paving of the bottom, bank reinforcement, construction of steps, etc.) (Fig. 35, photo 14). In many catchments, land use radically changed and there appeared anthropogenic deposits (Fig. 34). The majority of big rivers were shortened in contrast to medium and small watercourses which were lengthened, mainly in the headstreams, especially in the Miocene zone in the Odra river basin. Mining activity increased the erosional potential of the rivers in the Odra catchment, and decreased it in the Vistula catchment. Intensified removal of matter from slopes is "effected" mainly in small and medium catchments which are scarcely built-up and woodless. Main rivers are polluted above-average with suspension, predominantly coal slimes, which is common in the young alluvia building up the fluvial terraces (Photo 17). Some large and medium rivers transport matter along short sections, „leaving" it in the water reservoirs with flow (Photo 18).

The movement of such large amounts of matter in mining areas may rejuvenate or age the relief, or, it may not cause any changes in this respect. However, the changes in the development stage of relief do not depend on the scale of mining waste disposal or rock material dumping, but on the location of mining areas within catchments. Very intense exploitation of resources, distributed evenly may not reflect itself at all in hypsographic curves and the value of the rate of rock mass volume. On the contrary, incomparably lower intensity of mining activity, but carried out only in selected parts of a catchment may result in distinctive rejuvenating or ageing of relief (Fig. 39, 40).

The lowering of surface caused by underground extraction of hard coal, that is as a result of rock matter movement with predominant vertical component of movement and unrelated to surface erosional base, was diversified in terms of space and time (Fig. 41, 42). In the initial period of mining, the subsidence rate calculated from the volume of extraction was several, or seldom a dozen or so mm/year, and in the 20th century, it reached several dozen mm/year (Tab. 30-32). During the last ten to twenty years, the intensity of denudation in the Silesian Upland diminished from 28 mm/year to 26 mm/year, whereas in the Racibórz-Oświęcim Basin, it increased from 21 to 30 mm/year. This reflects the direction of mining activity moving from the upland to the basin (Tab. 34), which is forecasted to continue in the following years (Fig. 44). The concentration of extraction in a smaller area, high rate of longwall exploitation conducted nearly always by means of a roof-fall method, is reflected in higher values of anthropogenic denudation ratios for the last ten to twenty years; in the case of 1/3 of mines, these values exceed 100 mm/year. The rate of surface lowering as a result of opencast exploitation of stowing sands was a few hundred mm/year (Tab. 32).

The ratios of anthropogenic denudation calculated using a morphometric method range from 2 to 43 mm/year, while the rate of anthropogenic agraddation is considerably lower – on average, it is 4 mm/year. Denudational balance of geomorphological mezoregions is negative, and the highest value of 17 mm/year (Fig. 42) pertains to the southern Silesian Upland. Particular geomorphological units and catchments are extremely diversified in terms of denudational intensity. The highest negative value of denudational balance was obtained for the Biały Orzeł Ditch, and it was 80 mm/year. Denudation ratios calculated using the morphometric method do not diverge from those calculated from precise geodetic measurements.

In Poland, no other mining area (Fig. 45, tab. 39) underwent such intense mining activity as the Upper Silesian Coal Basin during the last half a century. Its share in the total extraction of mineral resources was as high as 32% (Fig. 46). The total extraction of hard coal since the mid-18th century until the year 2009, situates the Upper Silesian Coal Basin in the sixth place in the world (Fig. 48). Thus, the effects of mining anthropopressure on the relief are among the most severe in Poland, Europe and the world. These changes have regional and permanent character. The anthropogenic denudation rate in the Upper Silesian Coal Basin, as well as the Ruhr Coal Basin (Ruhr District) and the Ostrava-Karvina Coal Basin, is from several dozen up to several hundred times higher than the rate of natural denudation, no matter what calculation method is used. It would take the natural denudational processes tens of thousands of years to remove the same amount of material from the substratum as man removed through his mining activity.