THE DYNAMICS OF LANDSCAPE PATTERN CHANGES IN MINING AREAS: THE CASE STUDY OF THE ADAMÓW-KOŹMIN LIGNITE BASIN

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Abstract: Mining belongs to the types of human activity that have a significant impact on the environment, and especially on the landscape. The main objective of this study is a quantitative diagnosis of the dynamics of land use changes and landscape pattern modification in areas shaped under the influence of processes related to the open pit exploitation of lignite. The study was carried out in the Adamów-Koźmin Lignite Basin, which is a model example of an area affected by strong anthropogenic pressure. An assessment of changes was carried out using a set of maps depicting land use in the period preceding the exploitation of lignite (the year 1940) and after over 60 years of the mining activity in this area (as of 2011). The source materials for mapping for the first period were archival maps and for the second period, an orthophotomap. The heads-up digitising method was used to determine 7 types of land-cover classes according to the definitions of Corine Land Cover. Ten landscape metrics for five categories of landscape features (surface, shape, neighbourhood, edge, spatial distribution and diversity) were used in the landscape pattern analysis. The results do not confirm the hypothesis of a significant landscape simplification after reclamation. The shape of patches in the landscape was more complex and the number of land-use types was higher, which combined with their spatial arrangement, caused the landscape pattern to be more diversified in the year 2011.

Key words: pre-mining and mining areas, land use changes, landscape pattern, landscape metrics, Adamów-Koźmin Lignite Basin mining

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Introduction

The landscape which changes over time and space is getting shaped as a result of complex physical, biological and anthropogenic impacts. As a result, it is created as a mosaic of natural and man-shaped units that vary in size, shape and distribution in space (Bowen, Burgess 1981; Burgess, Sharpe 1981; Forman, Godron 1981, 1986; Krümmel et al. 1987; Turner 1987, 1990). The study of landscape diversity therefore focuses on identifying the attributes of the patches which make up its structure, and the results of these studies form the basis for creating hypotheses with the strong influence of the composition and configuration on the processes taking place in the landscape (Cushman, McGarigal 2004; Levin 1992). Changes in the area, shape and ecosystems connectivity can influence the changes in species diversity, population dynamics

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and spread of species (Fahrig, Merriam 1985; Franklin, Forman 1987; Freemark, Merriam 1986; Van Dorp, Opdam 1987; Hanski 1999; Eriksson, Ehrlén 2001). Landscape, according to the definition of the European Landscape Convention, is understood in this work in a physiognomic sense. The authors assumed that a landscape understood in this way, especially in lowland conditions and at a supra-local scale, is Land Use/ Land Cover (LULC). The share of individual patches of land use, and their composition and configuration in space, indicate the dominant type of landscape and show the type of potential ecosystem services. At the same time LULC is the feature of landscape that is most completely represented on maps and it is also easy to characterise using quantitative indices. LULC is treated as a synthetic expression of the biotic and anthropogenic elements of the landscape (Solon 2008; Kondracki, Richling 1983). LULC changes are quite often discussed in Polish literature, especially in the scale of large cities and suburban areas. This applies to different dimensions of landscape; natural (Matuszyńska 2001), economic (e.g. Luchter 1997; Małuszyńska 2000), and architectural (Przegon 2011). With an increase in the availability of data from the land registration (Łowicki 2008a; Łowicki 2008b), and especially Pan-European data on LULC such as Corine Land Cover or Urban Atlas, the number of publications covering the whole country is growing (Łowicki, Mizgajski 2013; Woch, Woch 2014; Nalej 2016; Borowska-Stefańska et al. 2018). It is also worth emphasising the role of research using both archival maps and contemporary vector data bases, which allows the analysis of very long time series for large areas (Bielecka, Ciołkosz 2002; Ciołkosz, Poławski 2006). Unfortunately, the problem of spatial pattern of LULC and its impact on ecosystem functions and services is relatively rare (Łowicki 2012, 2019).

The functioning of post-mining landscapes in the Polish Lowlands, whose structure is the result of exploitation and multi-mode reclamation processes, which is dependent upon time, applied technological solutions (overburden removal, overburden dumping) as well as environmental, legal and political conditions, opens up a wide range of possibilities for the study of the transformation of landscapes, subjected to strong anthropogenic pressure. Therefore, the transformation of the structure of post-mining areas and reclamation are important research aspects. The most significant achievements in this field are presented in German literature. Studies on the reclamation of post-mining areas show the scope and spatial extent of reclamation in European mining areas (Drebenstedt 2003; Beerbalk et al. 2003; Fritz et al. 2001; Gerhardt, Slaby 2006). Reclamation methods, the potential of post-mining areas and processes that reflect the trends in the mining landscape changes in the Czech Republik are presented in the work of Popelková, Mulková (2018), Vacek et al. (2018), Moudrý et al. (2019). The reclamation of post-mining areas in Poland is also a field with significant cognitive and implementation achievements, which has developed both a theoretical framework and original methods of reclamation. They were described in the works of Bender (1983, 1995), Gilewska (1991), Bender, Gilewska (1989) in relation to agricultural reclamation and Strzyszcz (1982), Harabin, Strzyszcz (1977), Krzaklewski, Wójcik (2007) regarding afforestation. A comprehensive appraisal of the art of reclamation and revitalisation of post-mining areas in Poland was developed by Kasztelewicz (2010) together with the characteristics of the brown coal mining industry. The recognition of reclamation processes in Europe (Krüger 2003; Beutler 2003) and in Poland shows that after the stage of intensive exploitation and reclamation, which was limited to restoring the biological productivity of land for agricultural and forestry redevelopment (a technocratic approach), a new, landscape approach to the shaping of a post-mining area is preferred. It is based on a change in the perception of post-mining areas, not only as degraded ones but also as spaces with new features and a potential to perform new functions (Pietrzyk-Sokulska 2005; Paulo 2008; Nieć et al. 2008). The study assumes that in the areas of open-pit exploitation, which is related to the transformation of land relief, land use, a geological structure, and water resources, the upcoming changes will be reflected in the qualitative and quantitative description of the landscape structure. The feature of mining landscapes is high dynamics resulting from the sequence of changes during the mining process. In the first stage of exploitation the landscape is degraded and in the following phase it is adapted to new functions through the reclamation process.

The study was carried out in the Adamów-Koźmin Lignite Basin, which is a model example of an area affected by strong anthropogenic pressure associated with open-pit brown coal exploitation. Kozacki (1972) presents a comprehensive analysis of the first period of environmental changes in this area, together with elements of prediction. After another 20-year period of mining pressure in the area, its effects were assessed in a study of Stankowski (1991). The contemporary structure and functioning of post-mining landscape systems in this region are described in the works of Fagiewicz 2014; Fagiewicz, Szulc 2014; Fagiewicz, Brzęcka 2016. The specificity of the local brown coal deposits determined the multi-open pit system of exploitation. To date, five mining fields have been opened in this region (one remains open). This distinguishes the Adamów-Koźmin area from the Bełchatów and Turoszów mining areas, where the exploitation, carried out in one large-scale open pit in various stages of the mining process (mining, reclamation, redevelopment), occurs in the surrounding of non-transformed areas.

The main objective of this study is to determine the type, direction and intensity of changes as key issues of landscape pattern dynamics. Two hypotheses have been assumed: 1) anthropogenic pressure associated with opencast brown coal exploitation simplifies the shape of patches in the landscape structure (Turner 1990; O'Neill et al. 1988), 2) the structural diversity of mining landscapes concerning pre-mining landscapes is lower (Lausch et al. 1999; Bogaert 2014).

Study area

The research was conducted within the boundaries of the mining areas of open pits of Adamów and Koźmin, which is in the space covered by the anticipated influences of the mining activity of

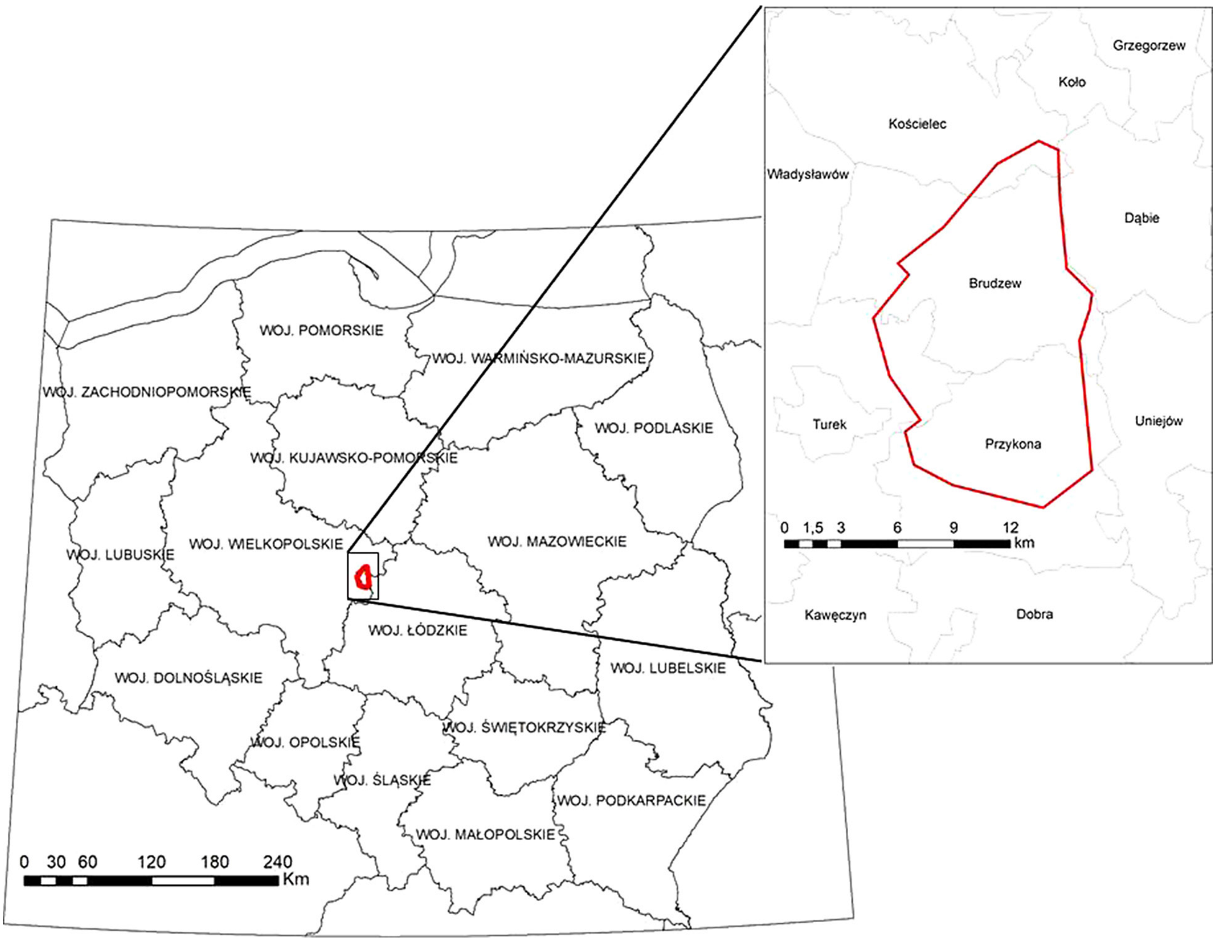

Fig. 1. Study area.
Source: own work.

PAK Kopalnia Węgla Brunatnego Adamów S.A., with a total area of 152.56 km^2. The area is located on the Polish Lowlands (Fig. 1) and its landscape was shaped in the periglacial zone during the Middle Polish Glaciations (Warta Stadium). The dominant landscape type is plains, mainly with fluvioglacial sands, loamy sands and clays, used as agriculture areas despite a poor quality of soils (Richling 1992). Another landscape characteristic of the study area is valleys with fluvioglacial sands used as farmland and meadows.

According to the typology of current landscapes (Chmielewski et al. 2015) including the 'natural' and 'cultural' landscapes present in Poland, areas of active and completed large-surface open-pit mining (type 13 – mining landscapes) belong to cultural landscapes in which the structure and function are fully shaped by human activity (group C).

The exploitation of deposits in the Adamów open pit started in 1959, in the Koźmin open pit – 1989, the completion of the exploitation is planned for 2023, which means that the transformation of the landscape resulting from mining activities has been ongoing in the area for over 60 years. In 2011, the share of post-mining land which got transformed into forms characteristic of open pit mining, such as overburden dumps, in-pit dumps as well as post-mining excavation covered the area of 31.89 km^2, which is 20.9%. The current landscape of Adamów-Koźmin creates a mosaic of semi-natural and post-mining ecosystems, whose structure results from multi-mode reclamation as well as various forms of redevelopment.

Research methods

The basic method of studying the transformations taking place in landscape systems is an analysis of structural changes in the areas within time sections. The assessment of changes was carried out using a set of vector maps depicting land use, developed for the study area, in the period preceding the exploitation of lignite (the year 1940) and after over 60 years of the mining activity in this area (as of 2011) (Fig. 2). The structure of the area in this study is understood as a mosaic of patches of different types of land use – arable land, meadows and pastures, forests, built-up areas, water bodies, and active open pits and

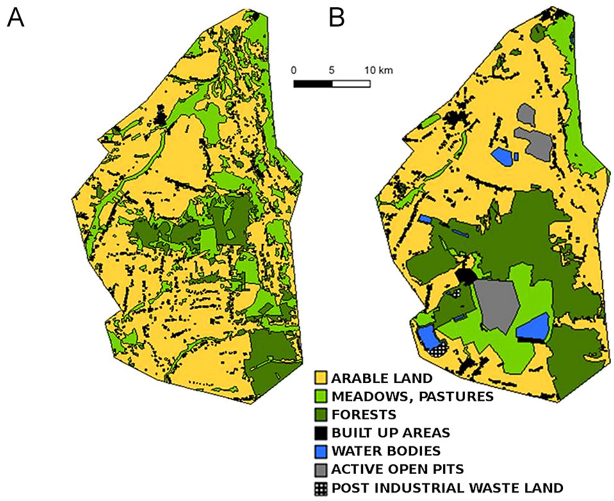

Fig. 2. Types of land use in the Adamów-Koźmin area. Explanation: A – pre-mining area (1940), B – mining area (2011).
Source: own work.

post-mining wastelands. The source material for mapping the land use of the pre-mining area was based on cartographic materials: Urmesstischblatt Topographische Karte 1:25 000 (3,877 sheet Koło, 3,977 sheet Turek). In the case of mining areas the main source of data was an orthophotomap of the Turek surroundings. The heads-up digitising method was used to determine 7 types of land cover classes according to the definitions of Corine Land Cover (Kosztra et al. 2017).

To assess the landscape pattern and its dynamics, class metrics and landscape metrics were applied, featuring the patches of land uses, their types and the mosaics which they make up. Ten landscape metrics for five categories of landscape features (surface, shape, neighbourhood, edge, spatial distribution and diversity) were used in the landscape pattern analysis (Fig. 3). They were selected on the basis of the recommendations presented in the studies on landscape changes (Ritters et al. 1995; Griffiths et al. 2000; Pietrzak 2010; McGarigal, McComb 1995; Solon 2002; Pietrzak 1989).

Due to methodological problems in the use of landscape metrics in comparative studies resulting from the sensitivity of metrics to resolution changes and the scale of source images, it is important to emphasise that, in this study, the data for analysis was obtained from numerical thematic maps developed with an accuracy of indications corresponding to the scale of 1:25 000. Digital images were converted to raster images

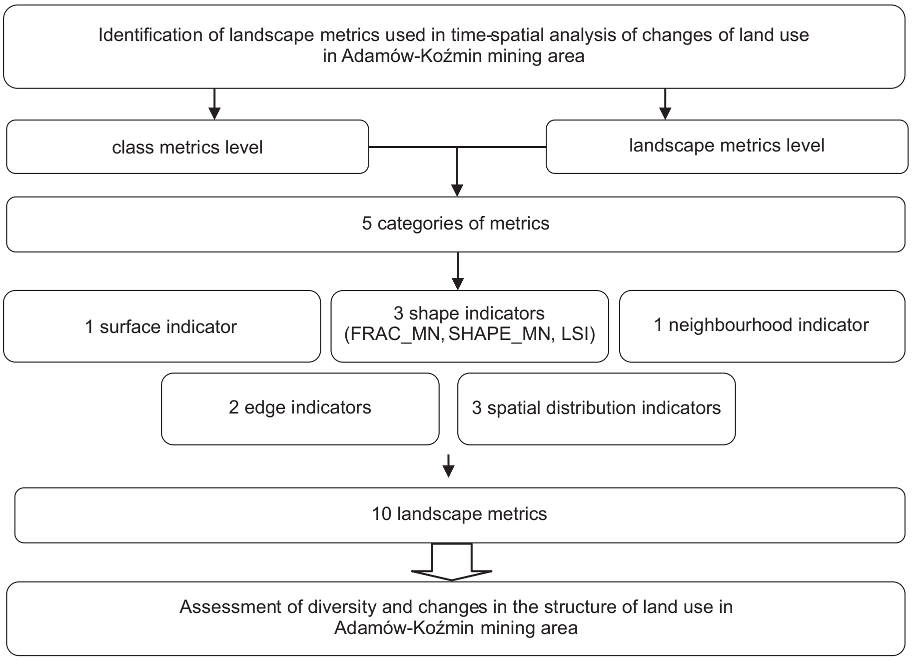

Fig. 3. Landscape metrics used in the analysis of land use changes in the Adamów-Koźmin mining area. Source: own work.

with a resolution of 25 m. The pixel size of 25 m was set based on the development of Zhu et al. (2006), according to which, this size, in the case of detailed studies, is optimal in order to capture more details of the landscape structure. Images forming the basis for the analysis of the landscape metrics were characterised by the same scale and resolution, which eliminated the emergence of errors related to metrics sensitivity to these factors. Therefore, the variability of the value of landscape metrics in time was analysed. To assess the significance of the variability of indicators, statistical methods were used. Shares of the area of various types of land use occurring in pre-mining and mining areas were compared with a ratio test (Agresti 2012), which assumes that each analysed patch of the particular type of land use is an element of the set. Then, the proportion of the surface of these patches before and after the exploitation was compared.

Results

Land-use changes

The changes of land use in the area of Adamów-Koźmin between the years 1940–2011 are clear and concentrate in the immediate vicinity of open-pit mines. Shares of the surface of particular types of land use compared with a ratio test are presented in diagrams (Fig. 4). The green colour shows the types of land use, whose share in the surface of mining area decreased in a statistically significant way. In the secondary structure, we can see a clear decline in the shares of meadows and pastures from 21.41% to 13.54% and arable land (from 62.84% to 51.46%). The most noticeable upward trend can be observed in the case of forests. Their share increased from 15.41% to 23.52%). An increase in the land share also applied to built-up areas and water bodies. The elements characteristic of the mining area (marked grey on the chart) constitute active open-pits Adamów and Koźmin which now covers an area of 6.82 km^2 (4.47%) and post-mining wasteland in the form of ash storages (0.63 km^2). Large water bodies formed within the in-pits dumps and post-mining excavation constitute new elements of land use structure associated with that approved in the Adamów-Koźmin post-mining area direction of water reclamation. In the pre-mining area, this land (2.26 km^2) was used as arable land. Currently, there are three reservoirs: Bogdałów (10.8 ha), Przykona (139.7 ha), Janiszew (59.6 ha); other two – Koźmin (108.5 ha) and Głowy (64.5 ha) are currently being filled with water. After the completion of

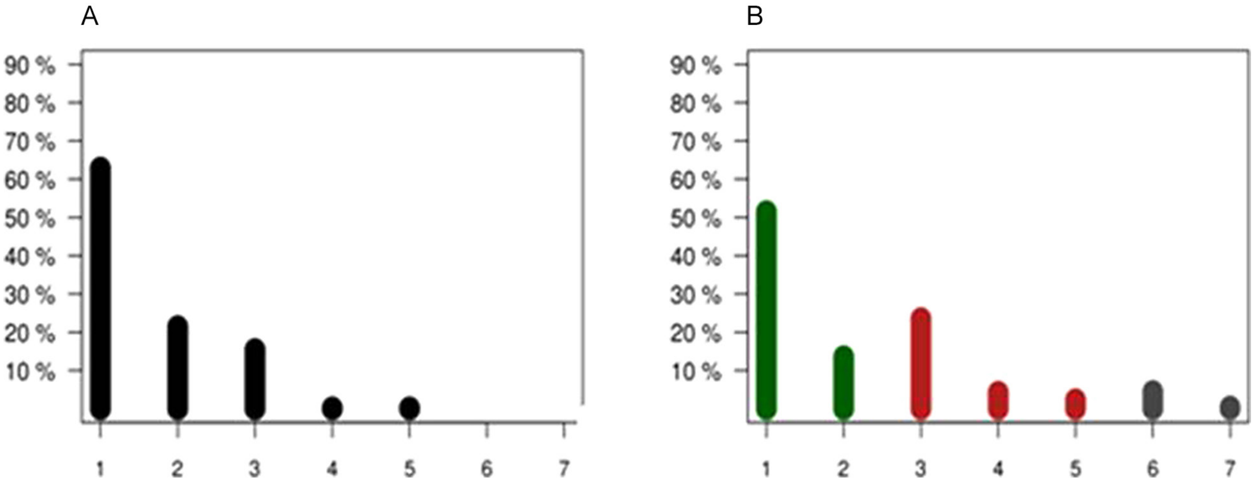

Fig. 4. The share of particular types of land use in the structure of the pre-mining (A) and mining (B) Adamów-Koźmin area.
Explanation: 1 – arable land, 2 – meadows and pastures, 3 – forests, 4 – built-up areas, 5 – bodies of water, 6 – active open pits, 7 – post-mining wasteland.
Source: study based on ratio test (Agresti 2012).

the exploitation of brown-coal deposits in the Adamów-Koźmin area, which is predicted for 2023, the water reclamation of post-mining excavation is planned (two reservoirs will be built, with 248 ha and 424 ha). The result of these actions is to increase the share of water in the landscape, which is currently occupied by the area of 3.53 km^2 (2.31%), eventually their acreage will increase to 11.97 km^2, and the share in the structure to almost 8%. In the absence of large bodies of water in the pre-mining, old-glacial landscape (0.17%), the emergence of multifunctional water reservoirs is a spectacular change both from the point of view of the structure of the area, in particular the ecological structure, the processes taking place within it, as well as the physiognomy of the landscape. Obtained as a result of a statistical test, a low value of test probability ($p < 0.001$) for each of the analysed types, confirms trends in changes in the use of post-mining areas and shows that the presented dependences are highly statistically significant. The details of the analysis are presented in Table 1.

To identify what processes had an impact on the changes in the share of surface patches for the particular type of use, and as a result influenced the decision on the arrangement of the types of land use in the post-mining structure, the transformation (transitions) of different types of land use into other types was analysed after exploitation. The directions and dynamics of these transitions were shown in the pie charts developed (Fig. 5) on the basis of the matrix of transitions (Table 2). The outer ring of the pie chart is divided into segments corresponding to the different types of land use. Corresponding widths of the segments of the inner part of the circle, visualise the dynamics of the transformation of the types of land use. The connecting bands within the segment show the surface of a given type of land use

Table 1. The share of particular types of land use in the structure of the pre-mining and mining Adamów-Koźmin area.

Type of land use	Share in pre-mining area (1940)	Share in mining area (2011)	Classification	Direction
Arable land	62.84%	51.46%	$p < 0.001$	decrease
Meadows, pastures	21.41%	13.54%	$p < 0.001$	decrease
Forest	15.41%	23.52%	$p < 0.001$	increase
Built-up area	0.17%	4.27%	$p < 0.001$	increase
Bodies of water	0.17%	2.31%	$p < 0.001$	increase
Active open-pits	0.00%	4.48%	$p < 0.001$	increase
Post-mining wasteland	0.00%	0.41%	$p < 0.001$	increase

Source: study based on ratio test (Agresti 2012).

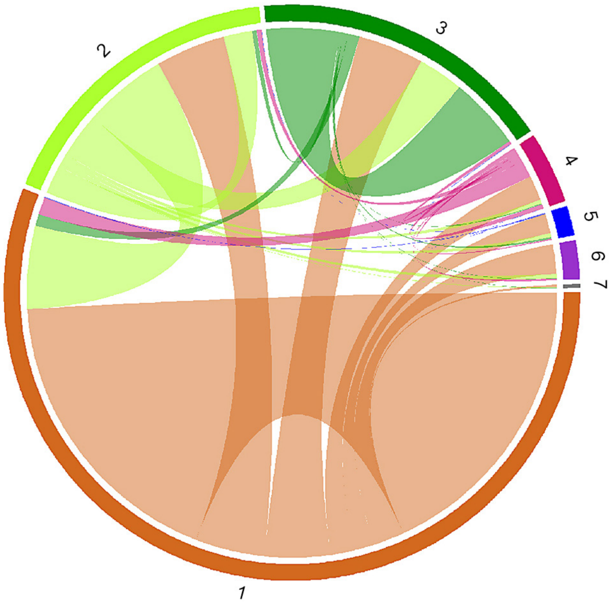

Fig. 5. Land use transitions in the Adamów-Koźmin area.
Explanation: 1 – arable land, 2 – meadows and pastures, 3 – forests, 4 – built-up areas, 5 – water bodies, 6 – active open pits, 7 – post-mining wasteland. Source: own work.

which has not been converted, while the bands passing from one segment to another illustrate the surface of a type converted into another one. The width of a band corresponds to a share of the transformed surface. The most characteristic transformations involved the prevailing structures in the pre-mining area of arable land. They accounted for the maintenance type of land use for all other types in the post-mining structure. The biggest part of them was transformed into grassy land and covered with structure-creating vegetation, used and classified as meadows and pastures, and created in the in-pit dumps of open pit Adamów (13.76 km^2). This transition is illustrated on the pie chart as a band extending from segment 1 (arable land) to 2 (meadows and pastures). At the same time we observe that the share of arable land in the mining structure increased at the expense of the original meadows and pastures (15.99 km^2), which evolved through natural (geological) and anthropogenic (melioration, the impact of a depression cone) processes (band passing from segment 2 – meadows to 1 – arable land). The transformation covered a substantial area (15.99 km^2) of natural meadows, which fill up the valley of the rivers Mała and Duża Kiełbaska, Struga Janiszewska and Teleszyna in the northern part of the area. The aforestation of 12.55 km^2 of arable land adjacent to the valley from the southeast and areas of overburden dumps and open pits of Adamów and Bogdałów on the west side of the depression, which originally was used as arable land, resulted in a clear increase in the share of forest areas. Forests also covered a large part of the area of meadow (8.67 km^2) in the depression of the river Kiełbaska Środkowa and Ciek Zachodni. The direction and intensity of these changes are illustrated on the pie chart by the bands passing from sector 2 (meadows) and 1 (arable area) to sector 3 (forests). Together with the forest coverage which were not converted into other types of land use (13.91 km^2), they show the post-mining structure of forests. As a result of the described transformation, a compact forest complex was created covering an area of 24.76 km^2, which together with the forest patch located in the south-east, preserved from the pre-mining period, dominated the structure of land use of the southern part of the Adamów-Koźmin area. The total forest area doubled from 17.52 km^2 to 35.80

Table 2. The land use transition matrix in 1940-2011, the Adamów-Koźmin mining area.

Type of land use (km^2)	Arable land	Meadows pastures	Forest	Built-up area	Bodies of water	Activ open pits	Post-mining wasteland	Structure of land use in pre-mining area (km^2)
Arable land	56.42	13.76	12.55	4.71	2.26	5.55	0.44	95.69
Meadows, pastures	15.99	5.67	8.67	0.79	0.76	0.87	0.14	32.89
Forest	2.22	0.79	13.91	0.17	0.30	0.09	0.04	17.52
Built-up area	3.35	0.91	0.60	0.81	0.21	0.31	0.01	6.20
Bodies of water	0.13	0.04	0.07	0.02	–	–	–	0.26
Structure of land use in mining area (km^2)	78.11	21.17	35.80	6.50	3.53	6.82	0.63	152.56*

Explanation : 1 – arable land, 2 – meadows and pastures, 3 – forests, 4 – built-up areas , 5 – bodies of water, 6 – active open-pits, 7 – post-mining wasteland, * – the area of the mining land; the area of particular type of land use, which did not undergo any transformation has been presented in a grey colour.
Source: own work.

km^2 including the share of post-mining land reclaimed in the direction of the forest covering an area of almost 46% (8.39 km^2).

The analysis of the transitions of the primary types of land use in the mining area showed that the greatest transformation involved arable areas, which accounted for the maintenance type of land use for all other types in the secondary structure.

Changes in landscape composition and configuration

The Adamów-Koźmin area retained its agricultural character between the years 1940–2011. In connection with the reclamation of a significant area of post-mining land (16.25 km^2) the agricultural proportion of arable land was reduced to a small extent (down by 11.52%), but a quarter of the surface area of transformation by direct mining activities significantly influence the changes in their structure. The characteristic system of the pre-mining area of arable land, split by ribbon-like (band) divided surfaces of meadows and pastures filling up the valleys, was replaced by the large patches of arable land and anthropogenic meadows. These changes are most clearly expressed by the variability of landscape metrics, in particular a decrease in the number of patches (NP) from 40 to 12 and a nearly threefold increase in their surface. It should be noted that even in the original arrangement, arable land formed large, dense patches. The share of the largest patch in the total area (LPI) was 61.53%, while the average area was 239.68 hectares. The degradation of meadows and pastures due to the transformation of large acreages (15.99 km^2) into farmland caused a disruption and loss of banded grassland structures separating arable land. As a result, patches have been consolidated, their average area increased to 654.25 ha, the amount was reduced, and so was density (PD) from 0.26 to 0.08, as well as the length (TE) and the density of boundaries (ED) by 47%. These changes testify to an increase in regularity of the arrangement of patches and their lower dispersal in the landscape, which is expressed by a decrease in the indicator of overall complexity of geometric landscape (LSI) from 20.85 to 7.12. A similar type of changes refers to the meadows, pastures and forest areas. Transformations of meadows are mainly associated with a reduction in the number of patches (from 165 to 24). Pre-mining landscape showed strong dispersion and fragmentation of meadows, especially in the northern part of the area, while presently we have large, compact patches. Moreover, the analysis of other indicators of shapes and surfaces confirms that the most significant changes included more than a fourfold increase in the average area of patches (from 19.70 to 86.07 ha), a fourfold reduction in length (TE) and density (ED) and a threefold reduction in the edge shape ratio (LSI), which shows a greater regularity in the distribution of patches and less dispersal. The overall balance of meadows in the pre-mining and mining area indicates a decrease in the share of the surface by 7.68%. In the case of forests, the direction of changes of the structure is analogous. Forest patches are less numerous (in the pre-mining one – 105, whereas in mining – 23), significantly

Table 3. Changes in the indicators of composition and configuration of patches of land use.

Selected landscape metrics	Patches of land use				Landscape mosaic
	arable land	meadows and pastures	forests	reservoirs	
Number of patches (NP)	−	−	−	−	−
Patch Density (PD)	−	−	−	−	−
Average size of a patch of a certain type (AREA_MN)	+	+	+	+	+
Total Edge (TE)	−	−	−	+	−
Edge Density (ED)	−	−	−	+	−
Landscape Shape Index (LSI)	−	−	−	−	−
Mean Fractal Dimension Index (FRAC_MN)	+	+	+	+	+
Mean Shape Index Distribution (SHAPE_MN)	+	+	+	+	+
Euclidean Nearest_Neighbor Distance (ENN_MN)	+	−	+	+	+
ContagionIndex (CONTAG)					−

Explanation: + increase, − decrease
Source: own work.

larger (respectively 16.69 hectares and 156.03 ha), but their total area was not reduced but increased twofold (from 17.52 to 35.80 km^2), just like in the case of other types of land use, the arrangement of the patches become more regular and less dispersed (a decrease in the indicator of shape LSI from 25.11 to 6.76). Transformations specific to particular types of land use affected the structure of the site as a whole, where the number of patches was reduced by over 72% (from 1,072 to 297), their density from 7.03 to 1.95, the mean area has almost quadrupled (from 14.23 to 51.37 ha). Trends in changes in the selected landscape metrics have been shown in Table 3.

The processes following changes in the landscape pattern

The types of recognised transformations of the landscape pattern point to diverse processes taking place in the landscape of mining areas. In the Adamów-Koźmin mining area we observe the process of the attrition of the patches. Merging ecosystems is the second process of landscape transformation recognised in the analysed area. Primary, a highly fragmented structure of this area, underwent strong merging (a decline in the number of patches by 72%). This resulted in a clear isolation of patches, which is reflected in the increased rates of distance to the nearest patch of the same type (ENN_MN). The most direct effect of patches isolation is the disturbance of the migration pattern and the subsequent isolation of selected local populations. Transitions of land use structure are associated with a clearly marked increase in the mean area of patches and an increase in the share of large patches in the structure while reducing their number. The observed decrease in the total edge length (TE) should also be associated with the processes of patches attrition and merging. Changes in the main configuration indicators show that the distance between the patches of the same type increased.

Discussion

In the research on the dynamics of landscape changes in the Adamów-Koźmin area, traditional methods of surface balancing of land use types and quantitative methods (landscape metrics) were used. The applied landscape metrics showed a variety of features of mining land use changes, as well as spatial pattern resulting from these changes. The first hypothesis assumed that anthropogenic pressure associated with open-pit brown-coal exploitation increases the share of regularly shaped patches of landscape. However, the shape of patches in the mining structure of the Adamów-Kożmin area indicates a greater irregularity in relation to the primary patches. This result does not confirm the hypothesis of the significant simplification of the shape of the patches (Turner 1990; O'Neill et al. 1988). Note, however, that the original structure was dominated by arable land, and this type of land use, to the greatest extent, is characterised by regular patches referring to squares and rectangles forming a checkerboard of fields. With regard to such shapes of landscape, the patches created as the result of reclamation processes can be more diversified in their form.

The second hypothesis was that the structural diversity of mining landscapes in relation to pre-mining landscapes is lower. The results obtained in the study show that structural diversity of landscape has grown in the mining area studied. An increasing diversity results from an increase in the number of types of land use, mainly post-mining ones, in a landscape pattern. Within the structure, new types of land use appeared. They are typical of the mining areas, e.g. in the form of post-mining wasteland and active open-pits. Enriching the structure with anthropogenic types of land use as well as changes in the composition of the patches contributed to a slight increase in the mosaic types of land use, which shows an increase in Shannon Diversity Index (SHDI) from 0.93 to 1.34. The share of the area of individual patches is more proportionate, as confirmed by an increase in the value of Shannon's Evenness Index from 0.58 to 0.69. However, landscape remains still with a predominance of natural elements, but with a large and clearly marked share of anthropogenic elements. The increase of diversity in mining areas was also confirmed by Popelková's study (2010) conducted in the Karviná-Doly mining area (Czech Republic). SHDI was the highest in the period of intensive exploitation and simultaneous reclamation of post-mining areas when mining and post-mining ecosystems appeared in the landscape. A decrease in mining activity and an increase in the share of reclaimed post-mining areas resulted in a reduction in SHDI in the Karviná-Doly region. It proves that a greater diversity in the mining structure of land use resulted from anthropogenic pressure. However, higher SHDI values are often caused by new or expanding mining-related categories of land use, therefore, increasing diversity in landscape affected by mining does not always mean a distinctive increase in species diversity (Popelková 2010). The landscape metrics can be used to identify and then monitor changes in landscapes subjected to strong anthropogenic pressure (state, dynamics, predicting changes). The use of Shannon Diversity Index confirmed that it as a simple tool for monitoring landscape diversity.

In practice, a quantitative recognition of the structure and spatial relationships in the landscape is crucial in shaping post-mining areas. It allows determining the changes caused by mining activity in the landscape pattern and assessing the landscape ecological connectivity between the geosystems. Identifying the areas which require to be re-shaped and reclaimed in order to maintain spatial connectivity between the post-mining areas and their vicinity not affected by mining is vital for defining modes of reclamation and assessing the effectiveness of the conducted reclamation works. The lessons learned may be used to correct the reclamation activities in progress, as well as to plan future actions.

Conclusions

The open-pit lignite mine opened in Adamów-Koźmin region in the ‘50s was located mainly in rural areas of a typical agricultural character. Their landscape structure was characterised by a very low share of forests and a lack of lakes in the old-glacial part of the area. The research carried out in those areas helped to determine the sequences of changes taking place in the structure of rural landscapes affected by the exploitation of lignite. In the initial phase of mining, structure is characterised by a large share of active open-pits and post-mining areas in the first phase of reclamation. This stage involves the elimination of patches, which results from mechanical degradation, as well as changes in land use following the drainage of surface and underground water-bearing horizons (the transformation of grassland into arable land). The increase in the isolation of habitats can be a result of a decrease in the number of patches. The further the exploited area is moved, the greater the share of reclaimed land in different directions (agriculture, forestry, water) in the landscape, which effectively compensates for the lost space. The increase in the share of forest, both as a result of reclamation and afforestation of post-agricultural land, as well as the increase in water surfaces, is essential for the structure of the post-mining landscape. These changes contributed to a significant increase in the share of semi-natural elements, which was previously very low.

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