Original Research

Spatial Processes of Landscape Transformation in Mining Areas (Case Study of Opencast Lignite Mines in Morzysław, Niesłusz, Gosławice)

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Received: 25 February 2013
Accepted: 2 April 2014

Abstract

This paper is a landscape study conducted in the post-mining area of Niesłusz-Gosławice. The diagnostic research included qualitative-quantitative features of the landscape (types of patches of land cover, their number, participation in the area) as well as spatial characteristics resulting from the relative positions and deployment of patches. The research was conducted using a set of environmental indicators – landscape metrics that provide a simple tool used in the study of landscape structure. The trends in changes of the analyzed landscape indicators, both for the individual patches of land cover (class metrics) as well as in relation to the landscape as a mosaic of patches of all types of land cover (landscape metrics), show that fragmentation and atrophy of patches, which manifests itself in the form of reduction of area of patches and the increase of their number, is the main processes of spatial transformation of the landscape in post-mining areas. Diagnosis of the structure of post-mining areas and the conclusions arrived at should be taken into account in determining the directions of reclamation and assessment of the effectiveness of the reclamation works carried out.

Keywords: post-mining areas, changes of landscape structure, landscape metrics

Introduction

The landscape is a dynamic system: it changes its structure and function in different directions and with varying intensities depending on location, time, and mode of action of the forces of nature and the character of human activity [1]. Opencast mining is a form of human activity that causes a spectacular transformation of the landscape. This is because of its specificity: in the first stage it contributes to the degradation of the landscape, and in subsequent stages, through a process of reclamation and development, it shapes the new (secondary) post-mining landscapes.

The spatial changes are the effect of reclamation limited to technical and biological retrieval of the areas for the natural environment. They are, from the point of view of landscape ecology, the most important [2]; as their nature and dynamics determine the functioning of landscape systems. Among major processes that transform the landscape in areas of strong anthropogenic pressure, is the increase in the level of fragmentation [3, 4]. According to [3-7] fragmentation is a combination of such processes as: perforation, dissection, dissipation, shrinkage, and attrition and proceeds in phases. It is a process whereby a compact patch disintegrates into smaller pieces (fragments), thus the surface area of patches decreases; the number of patches as well as the length of landscape edges increases; and the compactness of the landscape decreases [3, 8-10]. In subse-

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quent phases of the transformation, this can lead toward atrophy (reduction) of various types of patches. Each of these processes is specific and has a different impact on the structural and functional characteristics of the landscape [4]. The changes of the structure consisting of a reduction of the surface of the patches as well as the disintegration of natural and semi-natural patches with a larger area into smaller ones, plays an important role in the ecological process. The functioning of biocenosis and the number of specimens that may survive in them depends on the area of the patch [11]; smaller patches have a smaller habitat capacity and are more isolated [9]; large ecosystems are more stable ecologically as they are created by a higher number of species' populations and they are more resistant to anthropopressure [12]. The fragmentation of the landscape and its environmental effects are, at present, a strategic problem in wildlife conservation and management of the environment [9].

Capabilities offered by the geographic information system (GIS) and tools for quantitative assessment of landscape structure in the form of landscape metrics [13-15] found its application, in landscape ecology, in the study of the structure of ecosystems [16], the study of population processes and metapopulation [17] as well as in the assessment of landscape fragmentation [18-22]. Important current research relates to the relationship between spatial patterns and ecological processes [14, 23-25]. However, interpretation of these relationships with the use of landscape metrics is not easy [26, 27]. This involves the consideration of two issues in research – sensitivity of landscape metrics to changes in spatial resolution and scale of images as well as the sensitivity of metrics on classification accuracy.

Li and Wu [28] pointed out that research with the use of metrics can be related to three different scales: the scale of observation (video recording); the scale of analysis (where the original data underwent e.g. filtration or aggregation); and the scale on which particular ecological processes are being examined. In each of these scales, metrics exhibit different behaviors. With regard to this relationship, an attempt has been made to answer the question of whether the landscape metrics calculated at multiple scale can be used to determine the hierarchical structure of landscape [28]. Comprehensive assessment of the sensitivity of metrics to change the scale are presented in the work of Zhang and Li [29]. Metrics relating to spatial texture and fragmentation (NP, ED, AREA_MN, LSI, GYRATE_MN) and measure the complexity of shape (patch shape complexity) (FRAC_MN, SHAPE_MN) are closely related to the scale pattern and are highly sensitive to change at the lower levels of the structure. Measurements of spatial aggregation and cohesion (CONTAG_MN, COHESION) are the most sensitive at the average level of the structure. Measurements independent of the scale are the measures relating to the landscape as a whole (CA, ENN). This characteristic of the sensitivity of metrics is also confirmed by Hargis et al. [30]. Reactions of landscape metrics to diverse grain size and scale also are described in [31-33]. It is assumed that this problem is well recognized. However, the sensitivity of landscape metrics to classification accuracy is less known. The existence of this relationship is confirmed by the researches of Hess, Bay [34], Wickham et al. [35], and Shao et al. [36] .They showed that some landscape metrics, such as mean patch size and patch density, are more sensitive to classification accuracy than others. Landscape metrics respond to changes in two aspects of landscape structure: class area and aggregation. Comprehensive study on behavior of class-level landscape metrics across gradients of class aggregation and area is the work of Neel and McGarigal [37]. Mass [38] analyzed the sensitivity of the 85 landscape metrics in relation to the different methods of classification of digital images (pixel based and objects based). Almost all metrics showed variability associated with the methods of classification, in particular core area metrics and some proximity and contagiom indices. These examples show that one needs to be careful while comparing the index values obtained from different images [38], and comparable results are limited to one scale of observation (grain and extent) [39].

The purpose of this study is identification as well as qualitative and quantitative assessment of the processes of spatial changes of post-mining landscape structure related to the successive stages of opencast lignite mining and reclamation phases, carried out with the use of tools in the form of landscape metrics.

Study Area

The areas near Konin are a model example of an area with landscape changes due to the influence of opencast mining. In this paper, I have analyzed the mining-agricultural microregion Niesłusz-Gosławice, a natural unit separated in the process of a detailed physico-geographical regionalization of the northern part of the district of Konin by Kozacki [40]. Within the borders of this microregion are the oldest opencast mining pits Morzysław, Niesłusz, and Gosławice along with representative forms in the form of external and internal dumps and the end cavities. Exploitation of mineral deposits in these areas was carried out in 1934-74 (the beginning of the opencast mining Morzysław – the end of the opencast mining Gosławice). Transformation of the landscape, resulting from both natural processes and reclamation and various economic forms of its usage, has been progressing in this area for more than 40 years.

Research Methods

One of the primary methods of studying the transformations taking place in landscape systems is the analysis of structural changes in land cover in particular time sections. In this paper we analyzed the structure of land cover, which is characteristic for the study area before the exploitation of lignite – pre-mining area (Fig. 1) and the structure formed as a result of natural processes, reclamation and development – post-mining area (Fig. 2).

The relief of land, surface geological structure, and land cover were analyzed. The time horizon of the study includ-

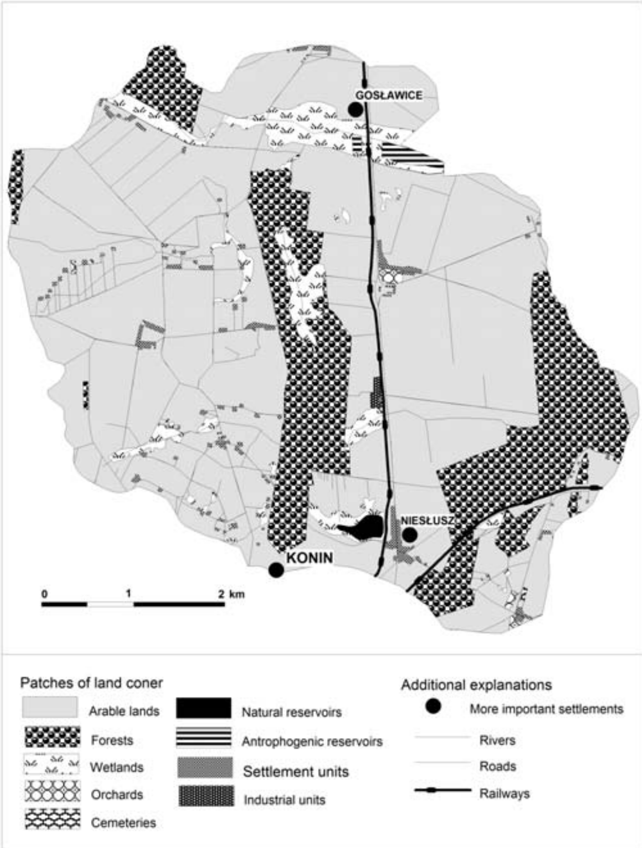


Fig. 1. Landscape structure in the Niesłusz-Gosławice pre-mining area.
Developed by: Fagiewicz K., Grządzielski M.

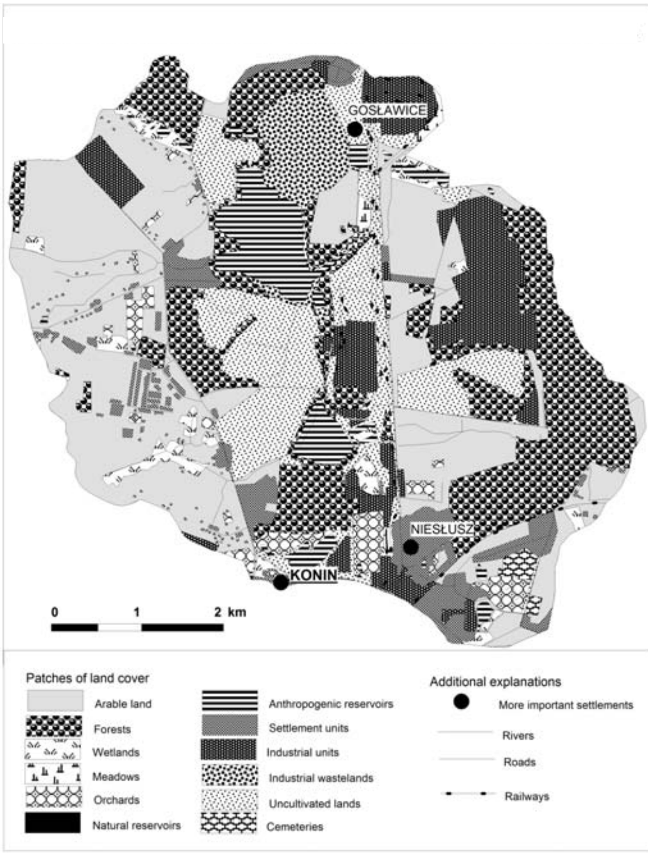


Fig. 2. Landscape structure in the Niesłusz-Gosławice post-mining area.
Developed by: Fagiewicz K., Grządzielski M.

Table 1. Types of lowland relief and their features.

Types of land relief	Morphometric features of relief	
	Hight difference (m)	Drops (º)
Plains	up to 2m	up to 3º
Undulating and hummocks	up to 20 m	up to 15º
hilly (with separate slopes)	above 20m	above 15º

Source: own work

ed two periods: the years 1940 and 2009. The basis for the assessment of changes in topography were maps of types of lowland landform developed in the scale 1:25,000, which highlighted the areas of eminence (plains, undulating and hilly, thalamic areas) as well as concave landforms (valleys, troughs, depressions filled with water), presented in Table 1 criteria.

Transformations of surface geological structure were analyzed based on the developed lithological maps, using soil-agricultural maps (scale 1:25,000).

The structure of land cover is a quantitative presentation of structure of forms that make up the land cover in a particular area [1]. The introduction to the analysis of changes in land cover was the separation of the land cover patches that occur in the study area: arable land, forests, meadows, wetlands, orchards and allotment gardens, natural water reservoirs, anthropogenic water reservoirs settlement units, industrial and commercial units, cemeteries and wasteland, and uncultivated land, which are characteristic and occur in the post-mining landscape. Cartographic and teledetective materials were the data sources for development of the maps of land cover. For the pre-mining areas – Urmesstischblatt Topographische Karte 1:25,000 (sheet 3775 Konin), orthophotomap in the scale of 1:25,000 Konin (sheet 3775 Konin) showing the structure of the landscape in 1940, while for the post-mining areas – topographic maps in the scale of 1:10,000 (sheets N-34-133-A-b-4 Posada, N-34-133B-a-3 Konin-Gosławice, N-34-133-B-c-1 Konin-East) were used to analyze the relief; archival materials of Lignite Mine “Konin” and orthophotomap of Konin area, which shows the land cover in 2009 (www.maps.geoportal.gov.pl).

In the analysis of the sources of materials used in spatial analysis, capabilities offered by GIS and the methods of quantitative geostatistical description of spatial structures (using the program FRAGSTATS 3.30) [13], which consists of a system of indicators of landscape composition and configuration (so-called landscape metrics) includes more than 100 indicators. Studies show that the landscape metrics are often highly correlated, describe similar aspects of landscape structure, and their use is not justified [23, 30, 41, 42]. Ritters et al. [43], on the basis of multivariate analysis taking into account the 55 metrics, recommends indicators that best describe the variability of the landscape (which are the least correlated): perimeter-area ratio, landscapes shape index, fractal dimension index, number of patches (of the corresponding patch type, class), the total number of patches in the landscape, largest patch index. The metrics used in this work were, therefore, selected because this set was supplemented with metrics that best describe the spatial changes of the landscape (fragmentation phases), and has been tested on a large scale [44]. Data for the analysis were obtained from the maps of land cover developed for the two research periods (1940 and 2009). The accuracy of the classification corresponds to a scale of 1:25,000. Digital images were converted to raster with a resolution of 25 m. The images, which were the basis for the analysis of landscape metrics, were characterized by the same scale and resolution, which eliminated the errors associated with the sensitivity of the metrics to these factors. The value analyzed in this study was the variation of landscape metrics over time.

Analysis of the structure of the pre- and post-mining landscape included the following:

- qualitative aspect – the identification of land cover types
- quantitative aspect – determining the number and share in the area of different types of land cover, as the basis for assessment of landscape geo-diversity
- spatial aspect – the identification of the spatial arrangement of different types of patches; the relationship between different types of patches due to their relative positions and deployment (landscape configuration).

Results

Visualization of processes and phenomena occurring in the environment under the influence of lignite mining, reclamation works, and land development are changes in the structure of the landscape. They are manifested most strongly in the surface geological relief and land cover, consequently leading to changes in land use. The study provides a quantitative and qualitative transformation of landscape structure within the mining area Morzysław, Niesłusz, Gosławice.

Relief and Lithology Changes

The landscape of the mining area before the exploitation was characterized by an average, diversified, flat, and undulating relief. The predominant type of land was undulating and hilly with height differences of up to 10-15 meters and the downslopes not exceeding 10^0, related to the terminal moraine zone between Morzysław and Międzylesie and eskers stretching around Wola Łaszczowa. They covered 51.3% of the area and were surrounding the ground-moraine plains, the surface of which consisted of 42.43% of the mining area. The landscape was complemented by depression (6.26%) in the form of Wieruszew-Niesłusz gutters, dissecting the plain longitudinally (Fig. 3). This is beneficial, from the viewpoint of hypsometry, since the conditions of retention of lignite deposits did not cause radical changes in land relief. The exploitation area covered almost 96% of the area of plains with the gutters dissecting it, as well as 3.61% of the area of undulating and hilly relief. Currently, this area constitutes the internal dump, which is evenly leveled and heaped up to the ordinate height.

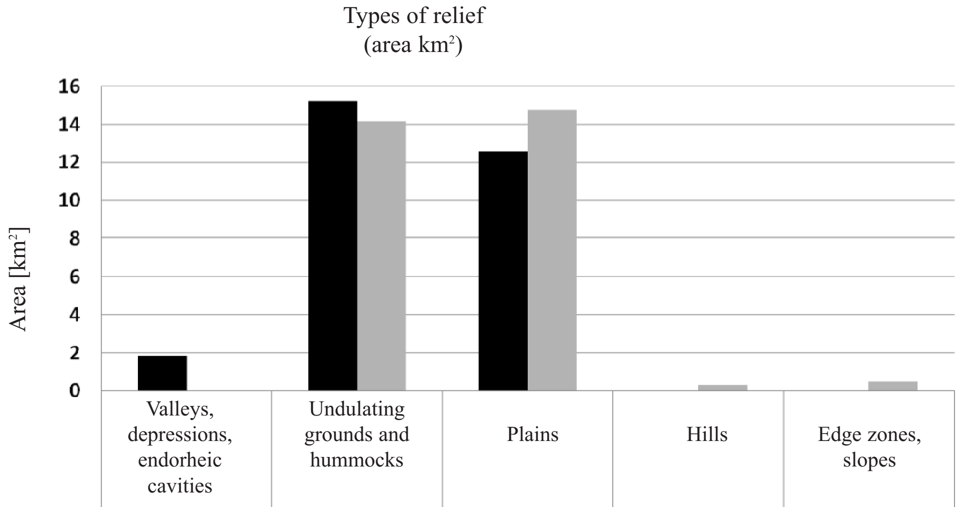
Physiognomy of the landscape dotted with external dumping ground pits Morzysław, Niesłusz, Gosławice, in the form of single, isolated hills, which represent a relief type not occurring previously in the area (with the share of 2.51%). According to the classification of anthropogenic geocomplexes [40], the spoil tips are included in unfamiliar forms in this environment, separating it from the surroundings.

Surface geology structure of the study area is characteristic of glacial landscapes, with a predominance of clayey sands and clays (59.08%) and sandy forms (36.4%). Land altered by humans (anthropogenic) occurred mainly in the residential and industrial development areas, and had a small share (1.38%) in the lithology of the study area (Fig. 4). The mixture of different formations occurring in the overburden of deposits in the process of mining, transportation, and tipping caused permanent and irreversible changes in the surface geological structure of the area. The share of land converted as a result of mining activities and the development of building has increased from 1.38% to 41.42%.

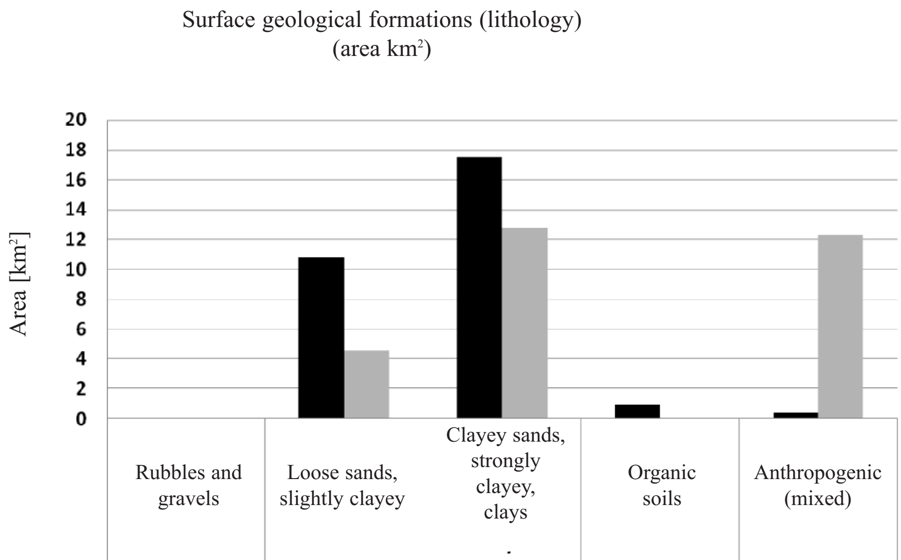
The qualitative characteristics of the changes are shown in Table 2, in order to allow a comparison of environmental conditions prior to the mining activities and after its completion.

Landscape Structural Changes

The landscape before the exploitation of lignite was formed under the dominant influence of the processes in the system of natural environment and was changed slightly by



	Valleys, depressions, endorheic cavities	Undulating grounds and hummocks	Plains	Hills	Edge zones, slopes
■ Before explotation	1,86	15,22	12,59	0	0
■ After explotation	0	14,15	14,78	0,28	0,46



	Rubbles and gravels	Loose sands, slightly clayey	Clayey sands, strongly clayey, clays	Organic soils	Anthropogenic (mixed)
■ Before explotation	0	10,8	17,53	0,93	0,41
■ After explotation	0	4,58	12,8	0	12,29

Fig. 3. Relief and lithology changes within the mining area Morzysław, Niesłusz, Gosławice (1940-2009).
Source: own work

Table 2. Environmental changes due to exploitation of lignite mining (1940-2009) – a case study of the Niesłusz-Gosławice mining area.

Mining-agricultural microregion of Niesłusz-Gosławice	
Pre-mining area (1940)	Post-mining area (2009)
Topography	
Gutters cut undulating terrain with channels on the meridian course; elevations ranging from 85 meters above sea level to the south of Gosławice to 115 m asl within the end moraine near Niesłusz. Declines from 0^{o}-0^{o}.	Terrain with a very diverse relief and numerous denivellation. New, in the form of dominant forms of topographical external dump.
	Gosławice opencast mine – dump height 38 m, surface area 63 ha; 39 ha of the plateau surface, the surface of the slopes – 24 ha, slope gradient 15%
	Niesłusz opencast mine – the dump height 26 m, surface area 42 ha; 30 ha of the plateau surface, the surface of the slopes – 12 ha, slope gradient 20%
	Internal dumps of equal level used as arable land, allotment gardens and shopping center. The final pit in the form of a lake with a meridian morphological axis used as a landfill for ashes is also a new form of topography.
Geological structure	
The geological structure of the surface layers of the rocks are Tertiary and Quaternary rocks in the form of fluvio-glacial sands, gravels, boulder, and moraine clays and loams. In the depressions there are peats and other organic formations.	The primitive geological structure is destroyed in post-mining areas. As a result of non-selective dumping of overburdened dumps, external and internal dumps create mixed forms. Gray boulder clays of the mid-Poland glaciation dominate in the area. The surface layer of Quaternary sands are placed in the form of streaks. In the entire profile of a dump, there is an admixture of Poznań varicolored clays in the form of lumps of various sizes.
Surface waters	
The area is situated in the catchment of Morzysłwski Canal; a small number of streams and drainage ditches; hydrographic network is replenished by Lake Niesłusz (area of 8 ha.)	Drying of Lake Niesłusz elimination of the network of small rivers. New elements of hydrographic network constitute the drainage channels and sumps. Within the post-exploitation excavations, new lakes were created – Morzysław, Zatorze and Czarna Woda. In the areas where exploitation and dehydration were terminated – small streams and wetlands, often episodic in nature. A change of the course of watersheds.
Soils	
Soil medium, the quality depends on the formations on which they were developed; podzolic soils formed from sands and clays dominate	Soils created during the process of reclamation, mainly on gray boulder clay, with a high retention capacity and wetness; soil fertility allows them to be used in agriculture
Land use	
Mostly farmlands, small areas occupied by forest areas, residential development in the eastern part of the micro-region, industrial buildings in the central part	Internal and external dumps reclaimed toward agriculture and forestry in the southern part of the microregion – multi-storey residential housing development of the town of Konin, as well as commercial center and allotment gardens in the western part – rural settlements (Posada, Wola Łaszczowa).
	The central part of the micro-region is occupied by a final pit of Gosławice opencast mine, which serves as a wet repository of the ashes of "Pątnów" Power Station; in the northwestern part of the micro-region there is a concentration of industrial and service buildings; a larger, compact forest complex is situated in the eastern part of the area.

Source: own scientific description on the basis of [6, 17, 18].

agricultural use. Patches of arable land (2,144 ha) occupied 72.25% of the studied area, the elements of ecological structure in the form of forests, wetlands, reservoirs (natural reservoirs and breeding ponds) accounted for 25.53%, while the remaining 1.67% of the area was used mainly as residential areas. The landscape was typically agricultural in its character; 98.33% of its structure was constituted by natural and semi-natural elements. Another distinctive element in the pre-mining landscape structure is the forest, which occupies an area of 565.4 ha. The average size of separated forest patches was 47.1 ha, allowing for a consideration of each of the separate forest habitats for very stable ones [47]. A relatively large proportion of the landscape were wetlands (5.78%) occurring in greater fragmentation. Their total area covered 171.7 ha.

Transformations in the structure of the changes in land cover mainly concern the participation of different types of patches in the landscape. The area of arable land decreased from 2144 ha to 950.7 ha (about 56%), and their percentage share in the landscape to 32.04%. The forest area has increased by almost 10% (from 565.4 to 611.7 ha), but at the same time their structure has undergone a large transformation. Although the number of forest complexes increased, the area they cover is smaller. The areas of wetlands (reduced from 171.7 ha to 77.0 ha) with a network of small watercourses and the only natural water reservoir (drainage of Lake Niesłusz) underwent large reductions. The area of anthropogenic water reservoirs increased significantly from 12.2 ha to 164.8 ha. A water reservoir was created in the hollow final pit Gosławice, acting as a wet storage of ashes. The reservoir is an unstable element of the post-mining landscape. Its surface is changing dynamically while the reservoir is being filled with ashes.

The balance of the area of patches forming the ecological structure (forests, wetlands, meadows, and bodies of water) shows that their participation in the landscape increased to 29.05% (from 25.53%). However, a reduction of arable land results in a reduction of over 37% (from 98.33% to 61.09%) in the share of natural elements in the post-mining landscape, and an increase in the participation of the area of anthropogenic patches is clearly indicated. The residential area increased from 37.3 ha to 295.8 ha and industrial buildings area from 3.8 ha to 295.8 ha. The areas of unused land, overgrown with synanthropic vegetation, which in this study was defined as fallow, is a new element characteristic of post-mining landscapes. Their total area is over 442 ha, which is 14.92% of the study area total. Another type of patch not occurring earlier in the pre-mining landscape are industrial wastelands (3.6%), formed as a result of lignite processing and storage of industrial waste (ash). The overall share of anthropogenic patches in the post-mining landscape increased from 1.67% to over 37% (Fig. 4)

Landscape Metrics Analysis

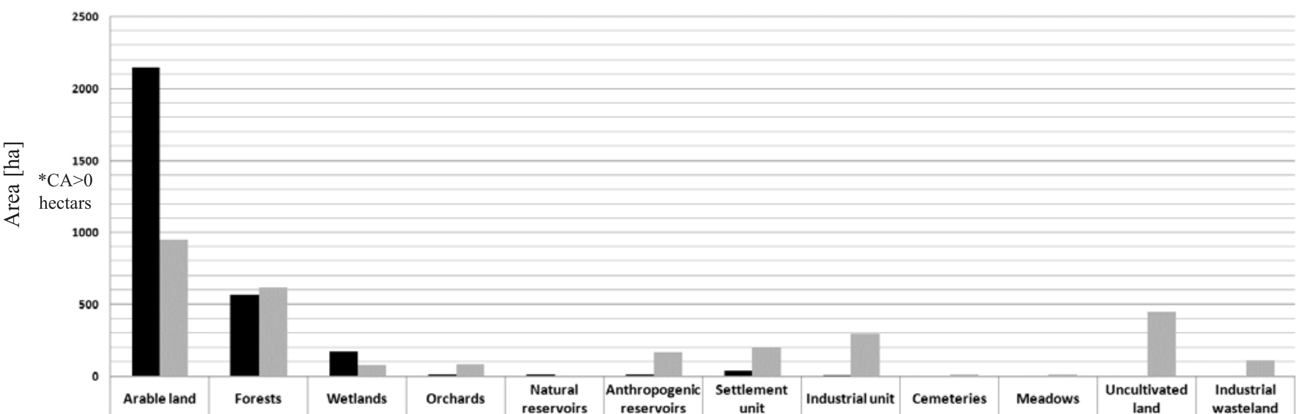
The structure of the pre- and post-mining landscape was characterized with the use of landscape metrics (Fig. 5). The landscape before exploitation was typically agricultural in its nature (the share of arable land amounted to 72.25%). The large, dense surface patches of land cover and the resulting small density (PD = 0.37) were characteristic for this landscape. The average size of 11 separate patches of arable land (AREA_MN) was 194 ha, while the share of the largest patch of the total arable land (LPI) was 44.68%. The value of the LPI index assessed for arable land is the highest among all the existing types of patches (compare the value of LPI for the landscape) and it clearly shows their dominance in the landscape. The forest areas consisted of 12 patches of the average area of 47.1 hectares, and their density in the landscape was quite small (0.40). Wetlands, occurring in greater fragmentation, shared a relatively large proportion of the landscape (5.78%) – out of 28 separated patches, each one covering an average area of 6.1 ha (total area of 171.7 ha), and the patch density index PD was 0.94 – higher than in the case of arable lands and forests.

The analysis of similar landscape metrics calculated for the post-mining area can indicate directions and trends of the changes that occurred in the landscape as a result of lignite exploitation and development of the area. Along with a reduction of 56% of the arable land, the number of patches increased from 11 to 48, their density increased from 0.37 to 1.62, and the average area of the patch decreased tenfold from 194.9 ha. to 19.0 ha. The increase in forest area of nearly 10% was associated with the transformation of the structure of forests. Forest patches are overrepresented in space, their number rose from 12 to 28, the density from 0.40 to 0.94, but the average size of a single forest patch decreased by almost 50%. (AREA_MN).

The reduction in the number of patches from 28 to 16 and decrease in their density from 0.94 to 0.54 results from the reduction of wetlands by 3.19%. What is characteristic here is the increase of the share in the landscape of industrial and service development patches. The average size of the patch increased from 3.8 ha to 112, 5 hectares, the number of patches increased from 1 to 24, and their density increased from 0.03 to 0.81. The analysis of the structure in relation to particular patches enables the diagnosis of the condition of the structure of the landscape as the structure of patches, which determines the specificity (properties, characteristics) of the study area.

The analysis of the diversity of the pre-mining and post-mining landscape (carried out using the Shannon diversity index) indicates a greater diversity of the post-mining area. The SHDI index value increased from 0.865 for the pre-mining area to 1.924 for the post-mining area. This reflects the increase in the landscape mosaic and landscape multifunctionality. New forms of anthropogenic type of land

Land Cover

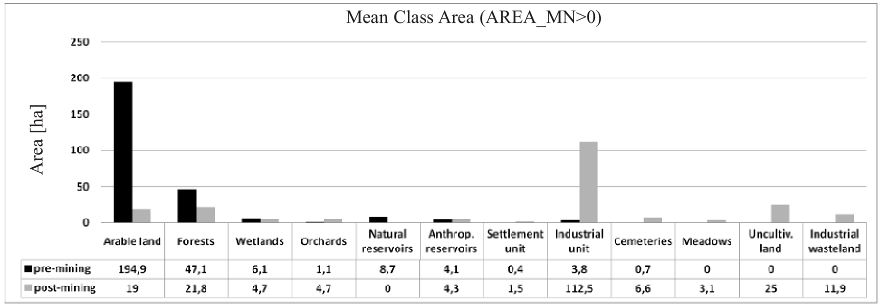


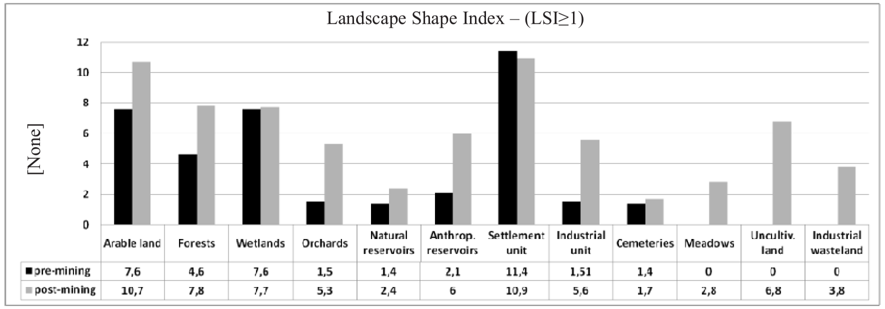
	Arable land	Forests	Wetlands	Orchards	Natural reservoirs	Anthropogenic reservoirs	Settlement unit	Industrial unit	Cemeteries	Meadows	Uncultivated land	Industrial wasteland
■ pre-mining	2144,00	565,40	171,70	9,30	8,70	12,20	37,30	3,80	0,70	0,00	0,00	0,00
■ post-mining	950,70	611,70	77,00	82,20	0,37	164,80	203,60	295,80	13,10	9,30	442,60	106,90

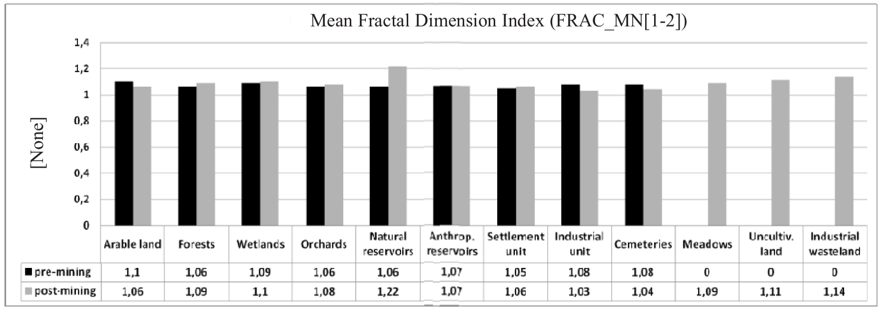
Fig. 4. Land cover changes within the mining area Morzysław, Niesłusz, Gosławice.
Source: own work.

1. CLASS METRICS

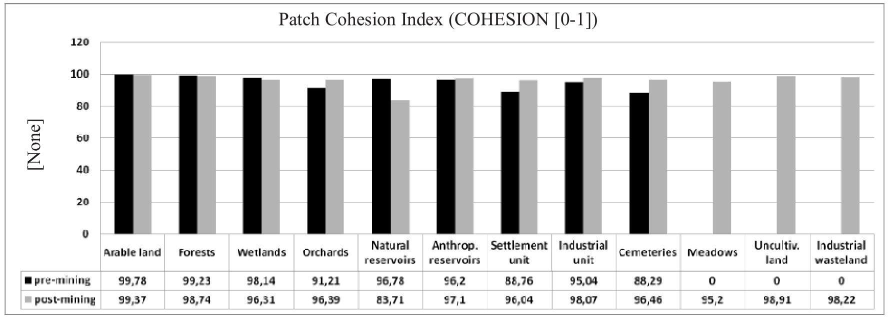
1.1 Qualitative







1.2 Spatial



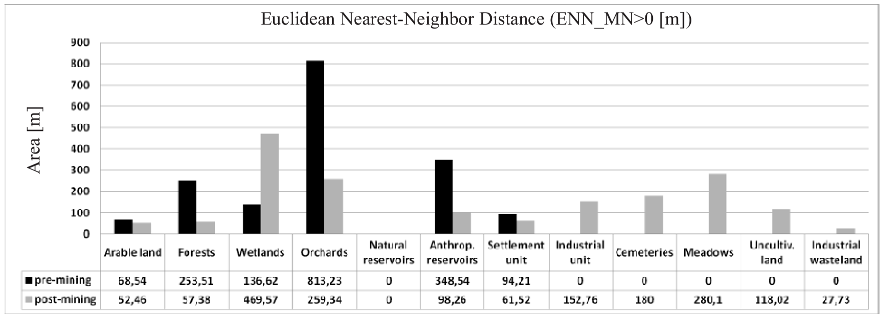
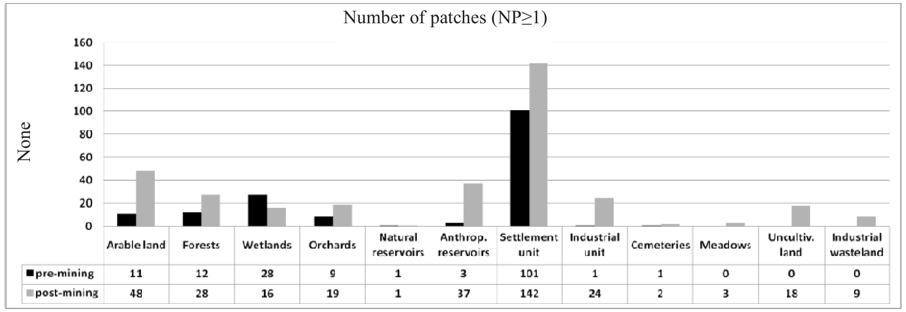
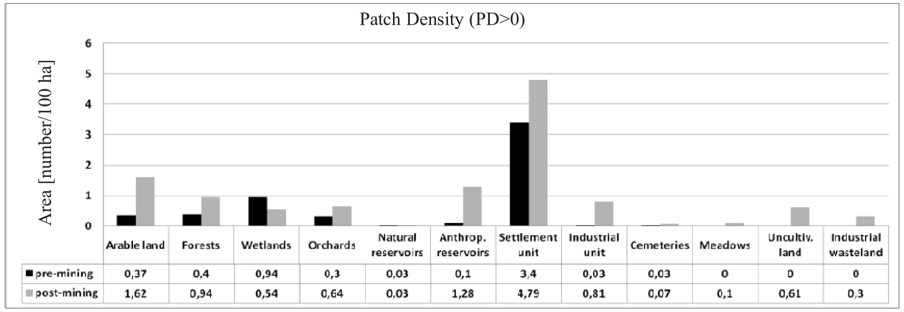


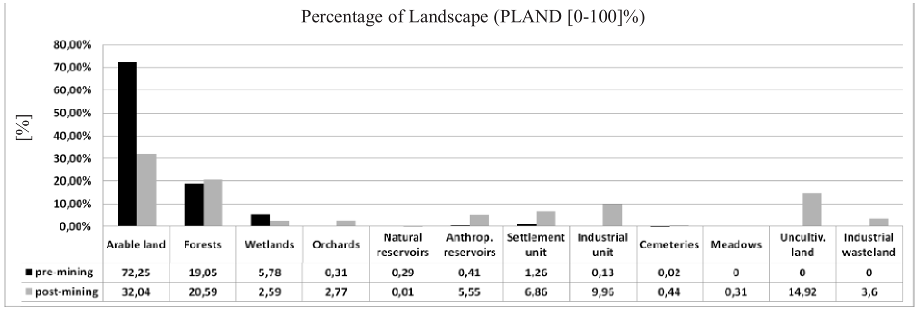
Fig. 5. The quantitative characteristics of environmental changes in Niesłusz-Gosławice mining area (1940-2009).

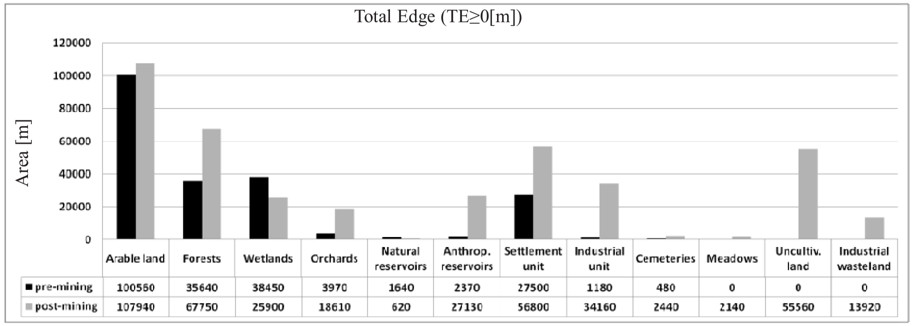
1. CLASS METRICS

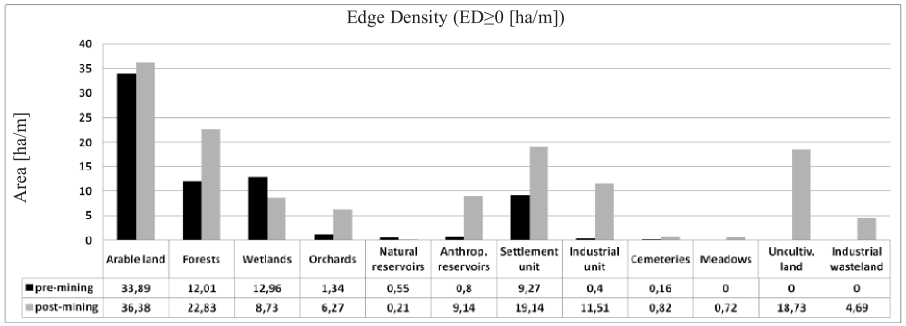
1.3 Quantitative











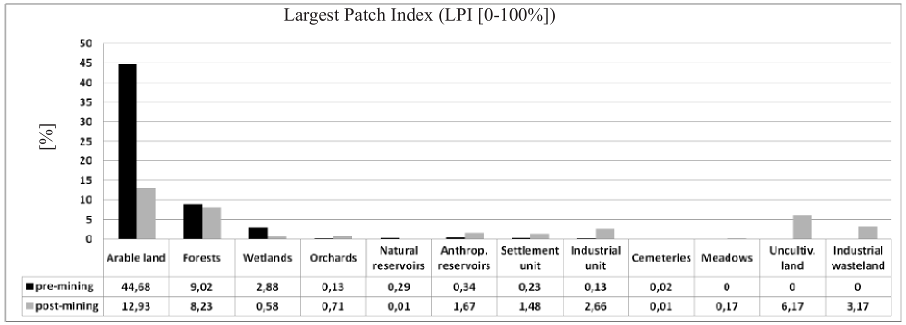
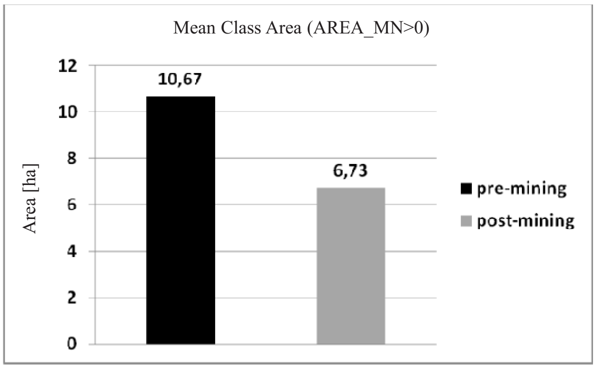
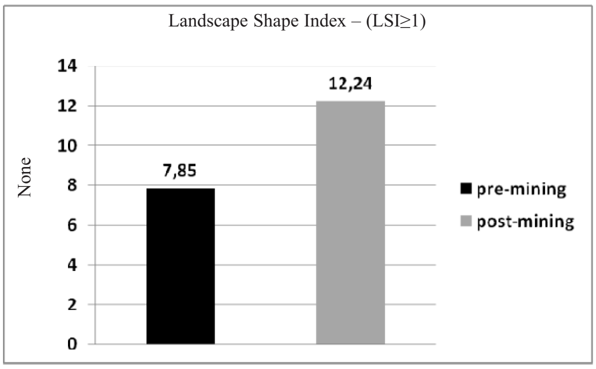


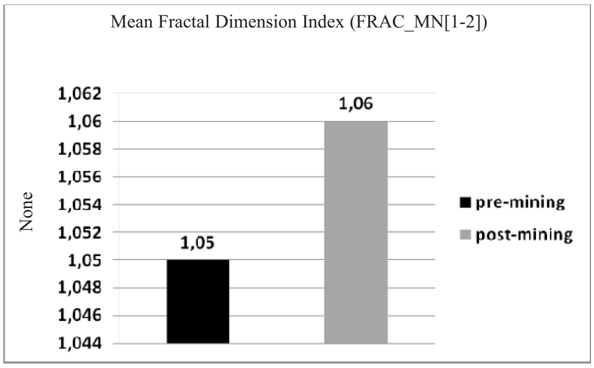
Fig. 5. Continued.

2. LANDSCAPE METRICS

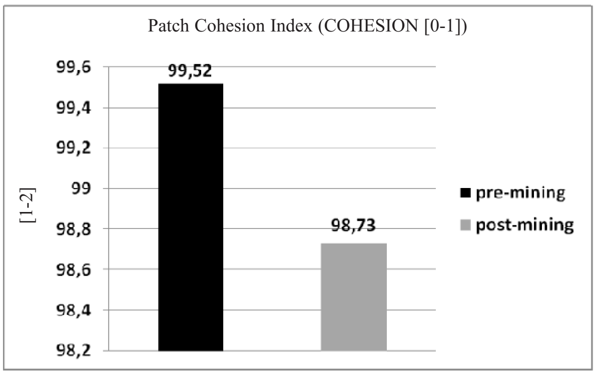
2.1 Qualitative

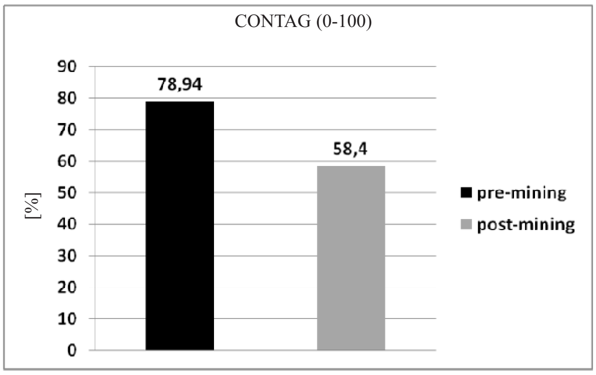




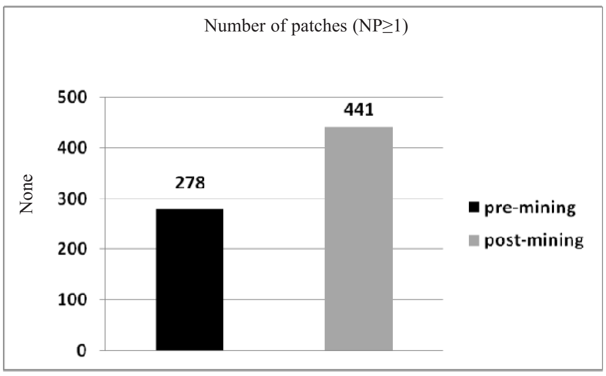


2.2 Spatial





2.3 Quantitative



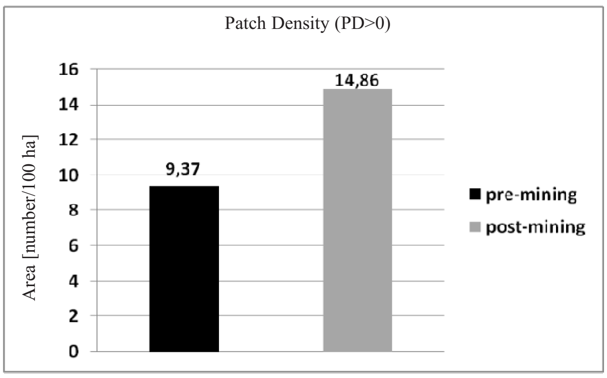
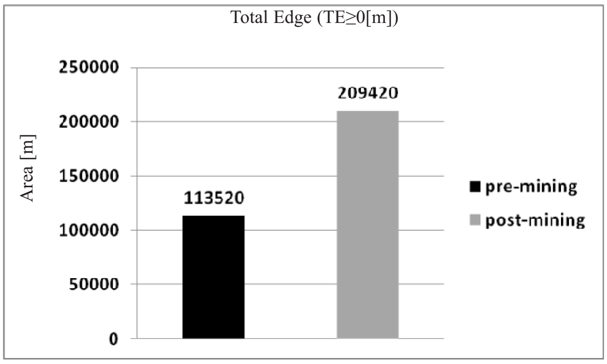
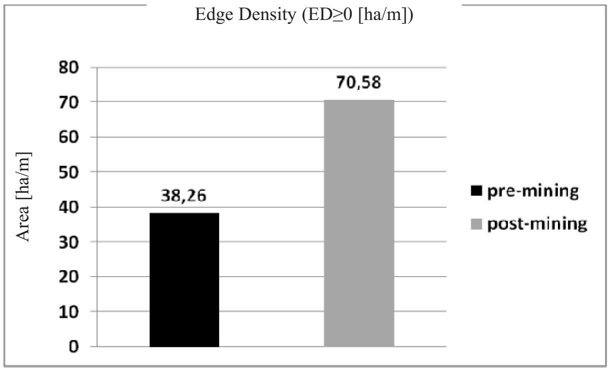


Fig. 5. Continued.





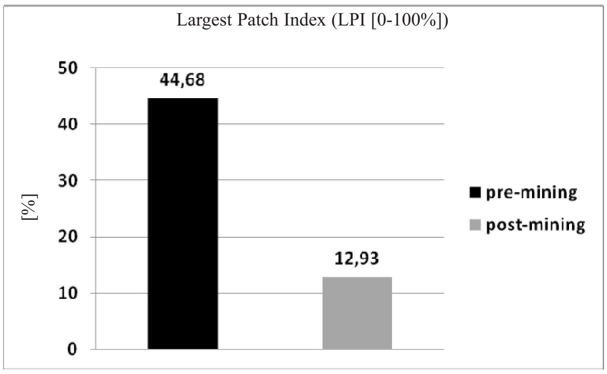


Fig. 5. Continued.

cover (PR) were identified in the structure of post-mining landscape; the surface and the number of other patches as well as their distribution in space also changed. The pre-mining landscape of low complexity, with the domination of patches of arable land, was characterized by moderate diversity, shaped mainly by natural elements. The post-mining landscape is characterized by a greater variety of landscape resulting from anthropogenic pressure, without clear predominance of natural elements, but still with their advantage, with a large share of anthropogenic elements.

The participation and number of individual patches is more proportional, which confirms the increase in the value of Shannon's Evenness Index from 0.38 to 0.75.

However, in relation to all types of patches (except for the dried ones due to dehydration of wetlands) one can observe the reduction in their area and increase in their number. The total number of patches in the landscape increased to more than double from 161 to 347 and the average area of the patch decreased from 10.67 ha to 6.73 ha. The density of the patches increased from 9.37 to 14.86.

In proportion to the number and density of patches, the total length of the edges of patches (TE) and their density (ED) increased.

In relation to the landscape as a whole, the length of the edges has nearly doubled from 113.52 km to 209.42 km, as well as the density (from 38.26 to 70.58), and this is not due to a variation in the shape of the patches, as the slight change in the fractal dimension (1.05 to 1.06) of the patches (FRAC_MN) shows that the patches remained simple in their shape, similar to the shape of a circle or square. The reduction of the compactness index value (CONTAG) and the reduction of the distance between similar patch types (ENN_MN), confirms a fragmentation of the patches and their greater dispersal in the landscape.

Spatial Processes of Landscape Transformations

Landscape metrics analysis allows diagnosing the main directions and intensity of changes in landscape structure, which testifies to the spatial processes of landscape transformation that took place in the study area. Table 3 shows the analyzed tendencies in the changes of values of the metrics used in this study, which best described the changes in the landscape. It concerns the size, shape, and density of the patches as well as the length of their borders. They were referred to the main natural structures that form the landscape.

The increase in the number of patches (NP), while their average area is being reduced (AREA_MN), is characteristic for agricultural areas and forests. This trend shows that the most important feature of the newly formed post-mining landscape is its dissection (trenching). A significant increase in the density of patches (PD) as well as an increase in the length (TE) and density (ED) of their boundaries indicates that trenching of the landscape is an advanced process that led to the fragmentation (disintegration) of large and dense patches dominating the structure of the pre-mining area. Fragmentation of the landscape is confirmed by the decline in the value of the EE_MN index, which indicates the reduction in the distance between the patches of the same type and, characteristic of anthro-

Table 3. Spatial processes of landscape transformations in the Niesłusz-Gosławice mining area.

Select indicators characterizing spatial processes of landscape transformation	Spatial processes of landscape transformations					
	Patches of land cover					Landscape mosaic
	Arable lands	Forests	Settlement unit	Natural reservoirs	Wetlands	
Number of patches (NP)	+	+	+	0	-	+
Patch density (PD)	+	+	+	0	-	+
Average size of a patch of a certain type (AREA_MN)	-	-	+	-	-	-
Total length of edge in landscape involving patch type (TE)	+	+	+	-	-	+
Edge density (ED)	+	+	+	-	-	+
Landscape shape index (LSI)	+	+	_	+	+	+
Mean fractal dimension index (FRAC_MN)	-	+	+	+	+	+
Euclidean nearest-neighbor distance (ENN_MN)	-	-	-	N/A	+	N/A
Compactness of the landscape (CONTAG)						-
	Fragmentation			Shrinkage	Attrition	Fragmentation of the landscape

Explanation: + increase, - decrease, 0 lack of changes, N/A – the value impossible to determine.
Source: own scientific development.

pogenic pressure, simplification of the shape of the patches (expressed by increase of LSI index).

Another process observed in the post-mining area is reduction in the size of the existing patches and the length of the boundaries with the unchanging number of them (natural water reservoirs), which is called the consumption of landscape. Consumption in subsequent stages of landscape evolution leads to the disappearance of the patches. This process has been observed in relation to wetlands, which are most vulnerable to the impact of opencast mining. The disappearance of the patches is confirmed by the downturn tendency of the analyzed class metrics (NP, PD, AREA_MN, TE, ED). The analysis of the values of landscape metrics in relation to the landscape mosaic shows the same tendencies as the class metrics characterized above. This indicates that the dominant process of landscape transformation in the mining areas is their fragmentation. This is also confirmed by the decline in value (by 26%) of the index of compactness (CONTAG), which indicates the fragmentation of the landscape and increase in its mosaicism.

Discussion

The analysis showed the impact of opencast mining on the changes in the structure of the landscape. Changes in topography and lithology are permanent and irreversible. They are associated with the appearance, in the landscape, of new, characteristic for opencast mining forms, such as: external and internal spoil tips and end hollows as well as the movement of earth masses, which lead to the transformation of surface geology structure. Analysis of changes in the composition and configuration indicates a progressive process of fragmentation in the post-mining landscape. This results from the nature of mining activities, which leads to the loss and degradation of habitat, interruption of continuity, and compactness of ecological structures. At the same time, the transformed landscape has enormous potential and opportunities that can be used in the reclamation process.

Huttl and Weber [48] present the post-mining areas as the ideal case study for the development of ecosystems starting from point zero – "terra nova." Skalenicka and Lhota [49] define post-mining areas as "landscape without memory." The authors, heretofore cited, make us realize that the post-mining areas are a spectacular example of geographical space whose development is all about appropriate shaping and creation of new landscapes in the process of reclamation and management. In Poland, this process focuses mainly on technical and biological aspects of reclamation of degraded areas, and the result of this approach is indicated by the outlined problems of fragmentation.

The implementation of reclamation and management process, taking into account natural conditions and laws of ecology, is a prerequisite and a chance for the development of integral and coherent post-mining landscapes.

Conclusion

The diagnosis of the structure of post-mining areas, including analysis of existing habitat types and their spatial distribution as well as evaluation of the composition and configuration of the landscape with the use of a simple tool in the form of landscape metrics, should be the initial step in the development of the concept of reclamation and management of these areas. Such an approach would allow the determination of changes in the habitat (size and type of the lost area) resulting from mining activities, and assess the nature of the ecological relationships between them (spatial coherence).

The results obtained from the diagnosis should constitute the basis for indicating the areas that require re-shaping or reconstruction, along with the determination of the types and kinds of habitat necessary to fill up or strengthen the natural structure. At the same time, they determine the directions of reclamation and management of the areas, which in effect will allow the restoration or creation of the appropriate structure of post-mining landscape, which will facilitate both a maximization of benefits for people and the achievement of a new equilibrium in the natural system.

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