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Digital adaptation of the Geomorphological Map of Upper Silesian Industrial Region, Poland (1:50,000) – old map new possibilities

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ABSTRACT
The paper is a brief description which discusses the stages of the digital adaptation of the printed version of old geomorphological map. It was paid attention to difficulties and errors that arose during work (incompatibility adjacent sheets, problems with distinguishing of the particular landforms, lack of some landforms). As a result, a geodatabase with 30 vector layers was obtained depicting all relief forms on the original map. The uniqueness of this map arise due to anthropogenic relief forms placed on it. It was extremely important because the mapped area was very strongly transformed by economic human activity. It was decided to compare recorded anthropogenic landforms with maps from other periods (1890, 1993 and 2014). As a result, it was possible to trace spatial and quantitative changes of selected anthropogenic forms on this. In general, between 1890 and 2014, all anthropogenic forms increased with the largest share of the anthropogenic flats.

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1. Introduction

Current development of digital technology for obtaining and processing spatial data allows to conduct effective operations also with historical maps. It is so-called HGIS (Historical Geographic Information Systems), which is interdisciplinary research direction on the borderline between historical geography, geoinformation and geoecology (Affek, 2013; Gregory & Ell, 2007). Although historical maps are often of poor quality, at a small scale and difficult to verify, they are still an invaluable source of information about the geographical environment condition of a given area at a certain point in the past (Affek, 2013; Prokop, 2017). They represent primary research material for the analysis of changes in spatial characteristics of the environment. Some authors have encouraged the use of old maps with due diligence and awareness of their limitations (Bosy, 2015; Mikulski & Raszeja, 2017; Sobala, 2012). Historical maps are used in earth sciences and serve as a powerful tool for geomorphological analysis and reconstruction, in particular in areas affected by rapid morphologic change and modified by human activity, e.g. reconstructing salt marsh losses (Bromberg & Bertness, 2005), long term analysis of land cover change (Pătru-Stupariu et al., 2011), rapid mapping of urban development from scanned historical maps (Visser, 2014), reconstructing historic European land cover/use change (Fuchs et al., 2015), reconstructing the hydrographical network and geomorphological setting (Furlanetto & Bondesan, 2015), reconstructing historic forest area and historic forest types (Munteanu et al., 2015), reconstructing water areas (Pavelková et al., 2016), historic analyses of land use of the Carpathian area (Lieskovský et al., 2018), studies of forest cover changes (Godziek & Szypuła, 2018, 2020; López-García, 2019) or research on historical land-use and land-cover of urban areas (Drummond et al., 2019).

The Silesian Upland is a particularly interesting area for studying relief transformation, especially its southern part (formerly called Uppersilesian Industrial Region), where there are many anthropogenic landforms that resulted from human economic activity (Pełka-Gościniak, 2006). Generally, the impact of human activity on relief is both direct and indirect. As far as the direct influence is concerned, man creates anthropogenic landforms, such as sand pits, spoil tips, railway embankments, agricultural terraces or pond dikes, intentionally. Regarding the indirect human impact on nature, the course, and the intensity of relief forming processes occur primarily through the impact on vegetation cover. Grubbing and burning of forests, ploughing steppes and overgrazing farm animals lead to changes to the original land cover and the method of its use (Dulias, 2016). In this area, direct human

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impact manifests itself in such forms as: road and railway embankments and incisions, artificial river channels and canals, excavations, dumps, subsidence basins, anthropogenic flats and anthropogenic water reservoirs (Jania et al., 2014). Generally, it should be stated that all human activities responsible for the biggest changes in the environment and topography are related to urbanization.

The archival geomorphological map discussed here (Klimaszewski, 1959) is very important for recognizing the relief of the studied area, because it is the only map from that period which also contained anthropogenic forms. Due to the fact that this area was one of the fastest economically growing areas in Poland at that time (1950s) – anthropoforms are an important indicator (benchmark) of a very strong human impact on the environment. Currently, it is a unique map, which is a testimony to the surface relief condition with man-made changes. The multitude of anthropogenic forms at this area has already been noticed by Klimaszewski (1947) on the occasion of the geomorphological division of Poland. Hornig (1955) made the first attempt to classify anthropogenic forms. He distinguished forms created by destructive and building human activities, and then he divided them into genetic types. He noticed that human influence changed land surface so much that it is difficult to determine the ratio between natural and artificial morphology. The most comprehensive studies of anthropogenic forms for the Silesian Upland are the works of Żmuda (1973) and recently Dulias (2013, 2016).

The aim of the work was to convert and adapt an old paper geomorphological map into a fully digital version. Owing to the vectorization of all landforms and water courses, a vector database was created in the GIS environment, a total of 30 layers in shapefile format. This study reflects a current in research of digitization of old geomorphological maps in Poland in the last several years (Dmowska et al., 2010; Geomorfologia Pojezierza Myśliborskiego i Niziny Szczecińskiej, 2008; Kijowski et al., 2012; Mania, 2005; Mapa Geomorfologiczna Niziny Wielkopolsko-Kujawskiej, 2007; Mapa Geomorfologiczna Wzgórz Ostrzeszowskich i doliny środkowej Prosny, 2011). Owing to this, we gain access to archival materials in digital form, which allows to conduct comparative studies, as well as to develop modern geomorphological maps.

On the basis of the juxtaposition of the digital version of the geomorphological map (Szypuła, 2017) with the current map (Jania et al., 2014), it became possible to compare the changes that took place in the surface relief of the southern part of the Silesian Upland in the period 1956-2014. Particular attention was paid to anthropogenic forms, which are evidence of a strong human impact on the topography of this area. Quantitative summary of individual types of anthropogenic forms was made and the spatial changes to which they were subject were traced.

2. Study area

The study area, which covers circa 2000 km^2, is situated in southern Poland. In the light of the latest physico-geographical divisions of Poland (Solon et al., 2018) this area belongs to the province: Polish Uplands, subprovince: Silesia-Kraków Upland, macroregion: Silesian Upland and mesoregions: Katowice Upland (1), Tarnowskie Góry Hummock (2), and partly Bojszów Depression (3), Upper Mała Panew Depression (4), Jaworzno Knolls (5), Pszczyna Plain (6) and Rybnik Plateau (7) (Figure 1). Local relief exceeds over 200 m. The highest parts are located in the NE part of the area (Siewierz Hill, 401 m a.s.l.), while the lowest places occupy W part (Dzierżno Duże Lake, 195 m a.s.l.). The average elevation of this territory is 271 m a.s.l. Regarding the relief of the area, the central and eastern part of the highest elevations include horst surfaces, and the elevations in the north of the area are cuestas. The western depressed part of the area belongs to the high plains and plateuax with Pleistocene deposits. There are erosional-denudation depressions with Pleistocene deposits in the east, while outwash plains constitute the lowest places in the southern part (Dulias, 2016). In addition, the entire area is cut by floors of larger flat-bottomed valleys. Geologically, the study area is divided into three zones which refer to the presence of older bedrock rocks. These zones differ in their style of geological structure, the lithology of bedrock, hydrogeological conditions and mineral resources. These zones are: Triassic in the north, Carboniferous in the centre and east, and Miocene zone in the west and partially in the south (Kaziuk & Lewandowski, 1980; Kotlicka & Kotlicki, 1979). Regarding present-day land development, it is a highly human-transformed area. Based on the CORINE Land Cover database (2018) it can be observed (Figure 2) that agricultural areas – 38% (arable land, pastures and erogeneous agricultural areas) and artificial surfaces – 36% (urban fabric, industrial units, mine, dump and construction sites, and artificial, non-agricultural vegetated areas) prevail. One quarter of the area is occupied by forest and semi natural areas – 25% (forests and transitional woodland-shrub), and water bodies (only 1%).

3. Source data and methods

The source data for this study was an archival geomorphological map (Klimaszewski, 1959). The original geomorphological map is the result of field works, the purpose of which was to accurately learn and describe the surface relief of the southern part of the Silesian Upland. On the one hand, the creators' intention was to recognize the character and development of the

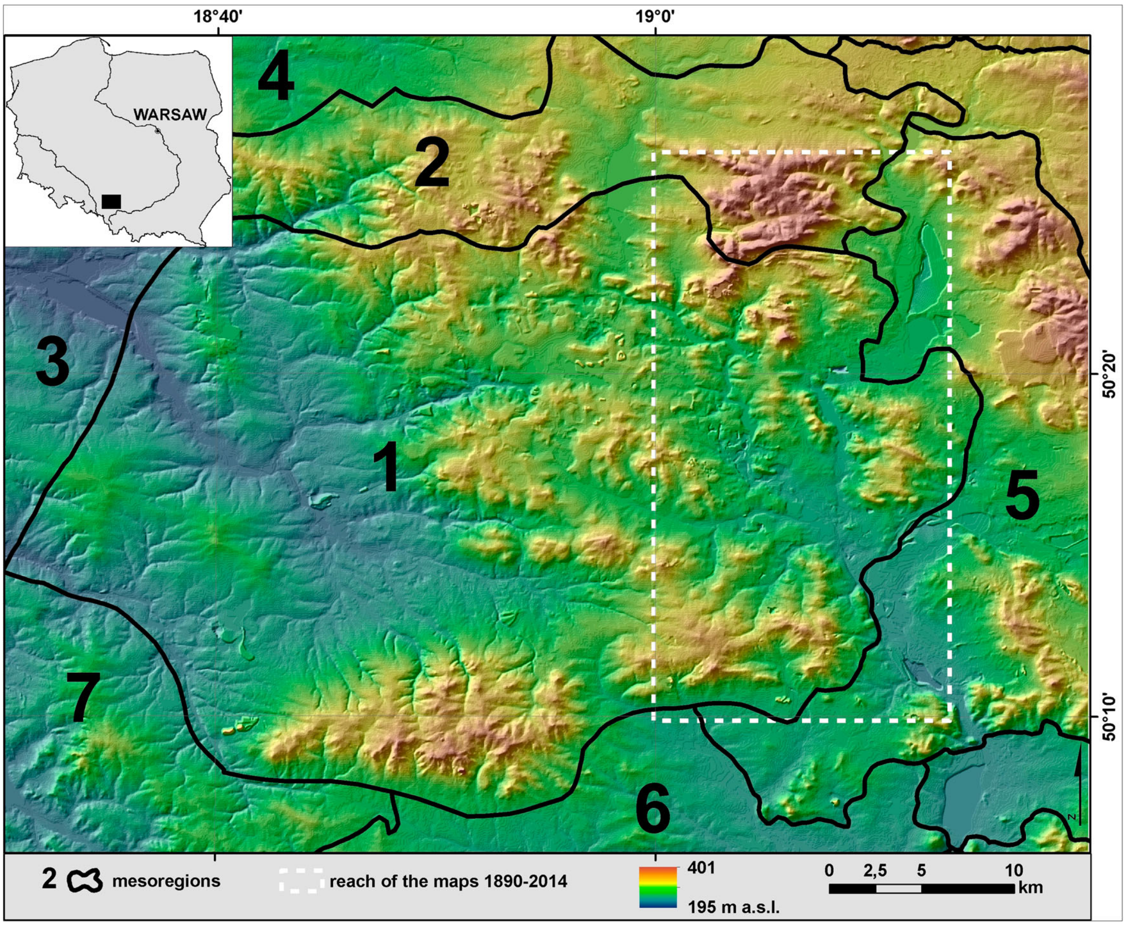

Figure 1. Study area location, hypsometry and geomorphological units (mesoregions): 1 – Katowice Upland, 2 – Tarnowskie Góry Hummock, 3 – Bojszów Depression, 4 – Upper Mała Panew Depression, 5 – Jaworzno Knolls, 6 – Pszczyna Plain, 7 – Rybnik Plateau.

relief, and, on the other one, to identify the usefulness and possibilities of planned exploitation of this region from an economic perspective (Karaś-Brzozowska, 1960). Geomorphological mapping covered an area of 2020 km^2. The works were carried out in 1955–1956 by a team of over twenty people, researchers and students of the Laboratory of Geomorphology and Hydrography of the Polish Academy of Sciences in Cracow. The works were managed by M. Klimaszewski. Originally, the map was developed in a colored form, according to the instructions for the geomorphological map (Klimaszewski, 1956) at the scale 1: 25,000. However, owing to technical and publishing difficulties, it was printed in one color. Colors were changed into signatures of different thicknesses: the thickest ones were used for the oldest landforms. Slope heights denotations were given using different densities and lengths of lines (Figure 3). Anthropogenic forms, which are shown as overlapping contour signatures (point, line and polygonal), were presented as a separate group. The map was finally published as an atlas with 20 sheets (25 × 32 cm) at a scale of 1: 50,000.

Usually the process of digital adaptation of a paper map should consist of several basic stages (Dmowska et al., 2010). In this study, the following steps were performed:

(1) preparation of source materials, which consisted in creating a raster image of an archival map (scanning). Then, geometric and graphic correction (sharpening, contrast change, etc.) of the obtained scans was made;
(2) georeferencing of the obtained rasters by affine transformation method. ArcGIS 10.6 software (ESRI, 2018) was used to georeference all sheets of the developed map into flat rectangular Polish coordinate system PUWG-1992 (EPSG: 2180, Gauss-Krüger Transverse Mercator grid projection). Unfortunately, it turned out that the adjacent sheets do not match the content. To deal with this problem, a shapefile layer representing the kilometer grid lines was created and the edges of the sheets with corresponding kilometer markings were attached to them. It also did not give satisfactory results. Finally, it was decided to improve the georeference of the map sheets by snapping the content to the latest orthophotomap, which is the official reference material of Head Office of Geodesy and Cartography (GUGiK) in Poland. Owing to these operations, an average accuracy of +/−50÷60 m was achieved, which corresponds to 1.0–1.2 mm for a map at a scale of 1: 50,000 (see Timár & Biszak, 2010);

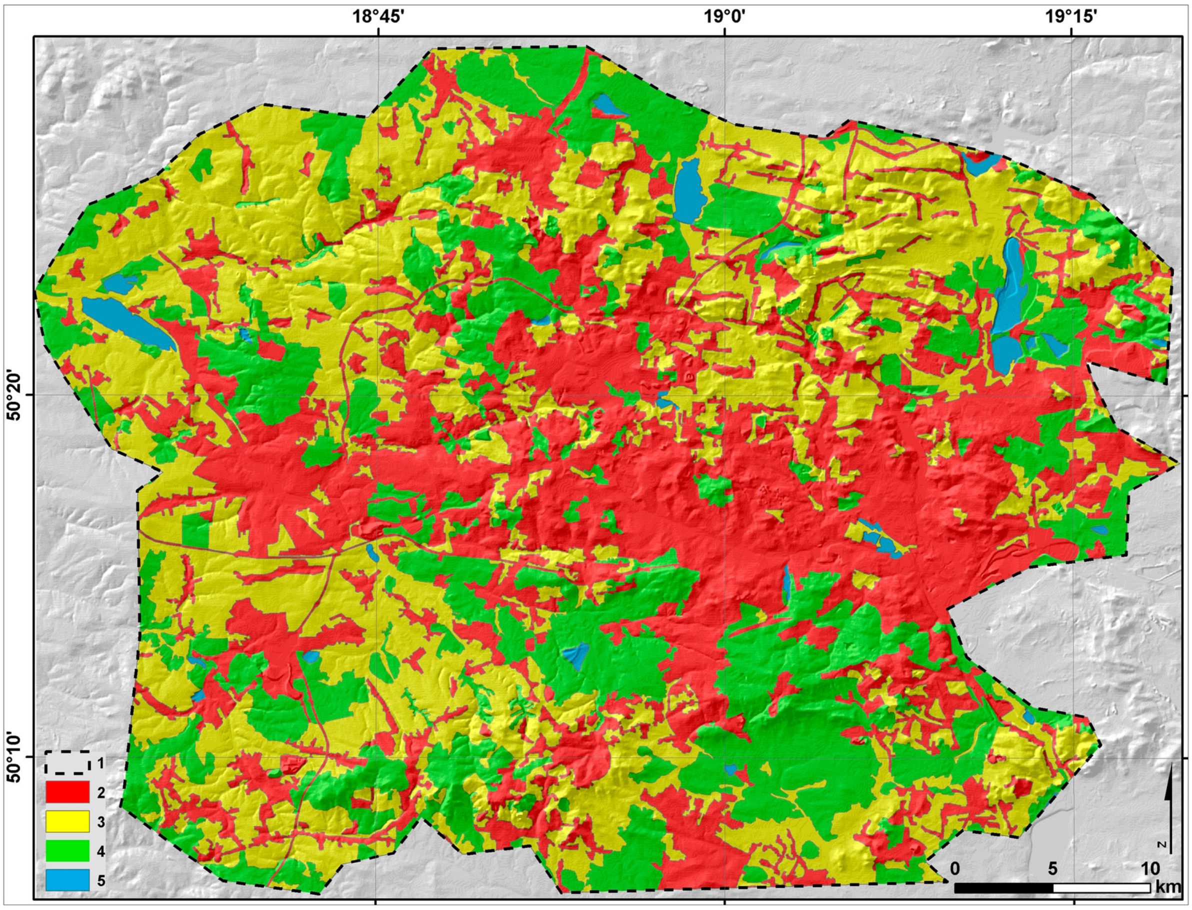

Figure 2. Land cover classes (on the base CLC, 2018): 1 – study range, 2 – artificial surfaces, 3 – agricultural areas, 4 – forest and semi natural areas, 5 – water bodies.

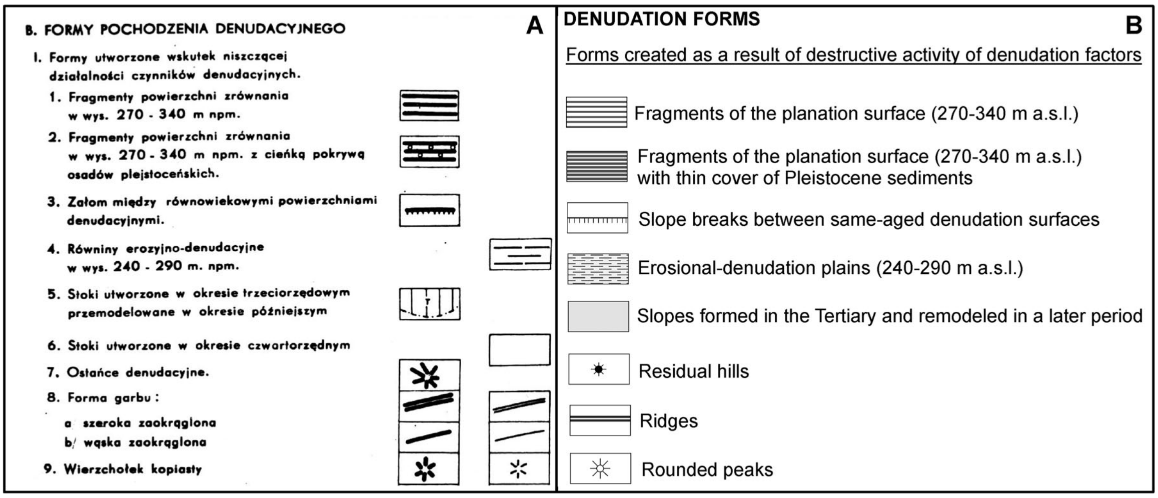

Figure 3. Comparison of the fragment of the legend from the old map (A) and a new one (B).

(3) detailed analysis of materials and creation of the concept of result layers. Due to the inability to draw the boundaries of some relief elements and to distinguish between different types of forms (e.g. terraces by height) or lack of some relief forms, quantitative and qualitative generalization was made by reducing the number of form classes. Next, the number of layers and the type of vector data structure (points, lines, polygons) were determined;

(4) digitization of all relief forms according to pre-established criteria;

(5) symbolization of layers – appropriate adaptation of the signatures of individual geomorphological map objects;

(6) final stage – editing of the geomorphological map. New elements were added to the digital version of the map, which significantly enriched its content and updated its appearance: (i) names of cities

and rivers were added; (ii) shaded relief map (at 20 × 20 m resolution) as a background, which was derived from DEM from the ISOK project (2014) was used; (iii) geographical coordinates grid was created on every 15-arc minutes according to the Gauss-Krüger single-zone projection on the WGS-84 ellipsoid and a kilometer grid on every 10 km in accordance with the PUWG-1992 system (EPSG: 2180); (iv) the map was made as one large sheet with a full, bilingual legend (Polish and English). English translations of the names of the forms were combined with the Digital Geomorphological Map of Poland (Jania et al., 2014), which is the latest geomorphological map in Poland.

4. Results and discussion

Owing to the vectorization of all landforms and water courses from an old paper geomorphological map (Klimaszewski, 1959), a vector geodatabase (a total of 30 shapefile layers: 5 point layers, 10 line layers and 15 polygon layers) was created in the GIS environment. Table 1 shows statement of all vectorized landforms and their total quantity.

In order to verify the overall picture of the geomorphological setting of this area, the digital version of the old map (Szypuła, 2017) was confronted with the latest geomorphological map (Jania et al., 2014). Both maps overlap in the eastern part of the area (see Figure 1), circa 490 km^2 (24% of the digital version of the map). The course of terrain landforms is more precise on the map from 2014 than on the map from the 1950s (despite the scale being twice smaller) due to differences which occurred during the mapping itself. The map from 2014 was made using modern GIS techniques and modern, high-resolution background data sources (DEM and orthophotomaps) were applied.

A detailed comparative analysis of both maps showed that natural forms did not change over the past 60 years. It applies to denudation forms (cuesta backslopes, plateaus, residual hills) and fluvial forms (river terraces and floodplains) that dominate in this area. It is obvious that apart from extreme catastrophic phenomena man exerts the strongest impact on changing the earth's surface and the created anthropoforms reflect the pace and direction of these changes. As mentioned in the Introduction section, the terrain of the analyzed area has been considerably transformed by human activities. Due to the presence of anthropogenic forms on both maps, it was decided to compare their quantitative and spatial distribution. Moreover, referring to previous research (Szypuła, 2011, 2014), additional data sources were taken into account: German

Table 1. Quantitative statement of the all landforms on the digital version of map.

Landforms	Quantity
DENUDATION FORMS	
Forms created as a result of destructive activity of denudation factors	
Fragments of the planation surface (270-340 m a.s.l.)	17 km^2
Fragments of the planation surface (270-340 m a.s.l.) with thin cover of Pleistocene sediments	3 km^2
Slope breaks between same-aged denudation surfaces	10 km
Erosional-denudation plains (240-290 m a.s.l.)	156 km^2
Slopes formed in the Tertiary and remodeled in a later period	409 km^2
Residual hills	12
Ridges	237 km
Rounded peaks	224
Passess	31
Forms created as a result of construction activity of denudation factors	
Diluvial accumulation plains	25 km^2
EOLIAN FORMS	
Dune ridges and dune areas	24 km^2
FLUVIAL FORMS	
Forms created as a result of destructive activity of flowing water with the participation of denudation processes	
Accumulative terrace escarpments	1262 km
Erosional cuts	276 km
River channels	156 km
Trough valley	3603 km
Forms created as a result of accumulative activity of flowing water	
Accumulative terrace plains	270 km^2
Alluvial fan plains	0,1 km^2
FLUVIOGLACIAL FORMS	
Forms created as a result of construction activity of glacial water	
Outwash plains	43 km^2
Forms created as a result of construction activity of ice sheet	
Bottom moraine plains	8 km^2
Denudationed embankments of bottom moraine	-
ANTHROPOGENIC FORMS	
Forms created as a result of destructive human activity	
Excavations (quarries, clay-pits, sand-pits, open coal mines)	31 km^2
Areas post opencast mining	12 km^2
Opencast mining (pits and heaps)	–
Road – and railway-incisons	173 km
Artificial river channels and canals	162 km
Subsidence basins	15 km^2
Forms created as a result of construction human activity	
Dumps	22 km^2
Anthropogenic flats	5 km^2
Anthropogenic mounds	85
Road – and railway-embankments	550 km

(Topographische Karte 1:25,000, 1883-1890) and Polish (Topographic map 1:50,000, 1993) topographic maps, which allowed to trace changes in anthropogenic relief since 1883. The following landforms were analyzed: embankments, incisions, artificial regulated river channels, dumps, excavations, subsidence basins, anthropogenic flats and artificial water reservoirs. Table 2 shows quantity statement of all the analyzed anthropogenic landforms.

When it comes to linear forms, between 1883 and 2014 there was generally an increase in their total amount from about 30% (embankments and incisions) to over 400% (river channels). The slightly lower values in 1955 (compared to 1883) may be the result of the scale of the study (1:50,000 vs 1:25,000), not the actual situation. However, it does affect the idea of a steady increase in the number of linear forms, which also applies to the mean length of individual forms – the number of longer forms went up (Table 2). In consequence, the

Table 2. Quantitative comparison of the anthropogenic forms in the period 1890–2014.

	1883–1890		1955		1993		2014	
	Length							
Line landforms	sum [km]	mean [m]	sum [km]	mean [m]	sum [km]	mean [m]	sum [km]	mean [m]
road and railway embankments	132.0	337	127.8	639	176.8	807	170.5	1168
road and railway incisons	37.2	265	32.6	398	58.5	914	49.2	984
artificial river channels and canals	–	–	58.7	–	–	–	236.5	–
Polygon landforms	**Area [ha]**							
	sum	**mean**	**sum**	**mean**	**sum**	**mean**	**sum**	**mean**
excavations	429.2	2.5	1597.3	7.8	2044	53.8	2258.5	77.9
dumps	59.7	1.1	570.8	3.9	508	18.8	433.9	18.1
subsidence basins	–	–	214.6	4.6	–	–	1793.3	39.0
anthropogenic flats	–	–	45.8	2.9	–	–	6168.6	561.0
`anthropogenic water reservoirs	59.7	3.0	–	–	947	3.1	1036.6	41.5

Table 3. Density of the line anthropogenic forms in the period 1883–2014.

	1890	1955	1993	2014
Landforms	Density [km/km^2]			
Road and railway embankments	0.27	0.26	0.36	0.35
Road and railway incisons	0.08	0.07	0.12	0.10
Artificial river channels and canals	–	0.12	–	0.48

average density of these forms in the analyzed area also grew (Table 3). The largest increase (more than fourfold) occurred for artificial river channels and canals, which indicates strong human interference in the surface hydrographic network in this area over the last 60 years (geometry and character of the rivers changed mainly due to regulation), as already pointed out Bukowska (1982), Bukowska-Jania (1986) and Czaja (1997, 1999, 2005).

As for the spatial distribution of embankments (Figure 4(a)), it can be seen that from 1883 the largest accumulation of these forms occurred in SW part; theses were many short sections. In subsequent periods, longer sections and many new objects can be seen,

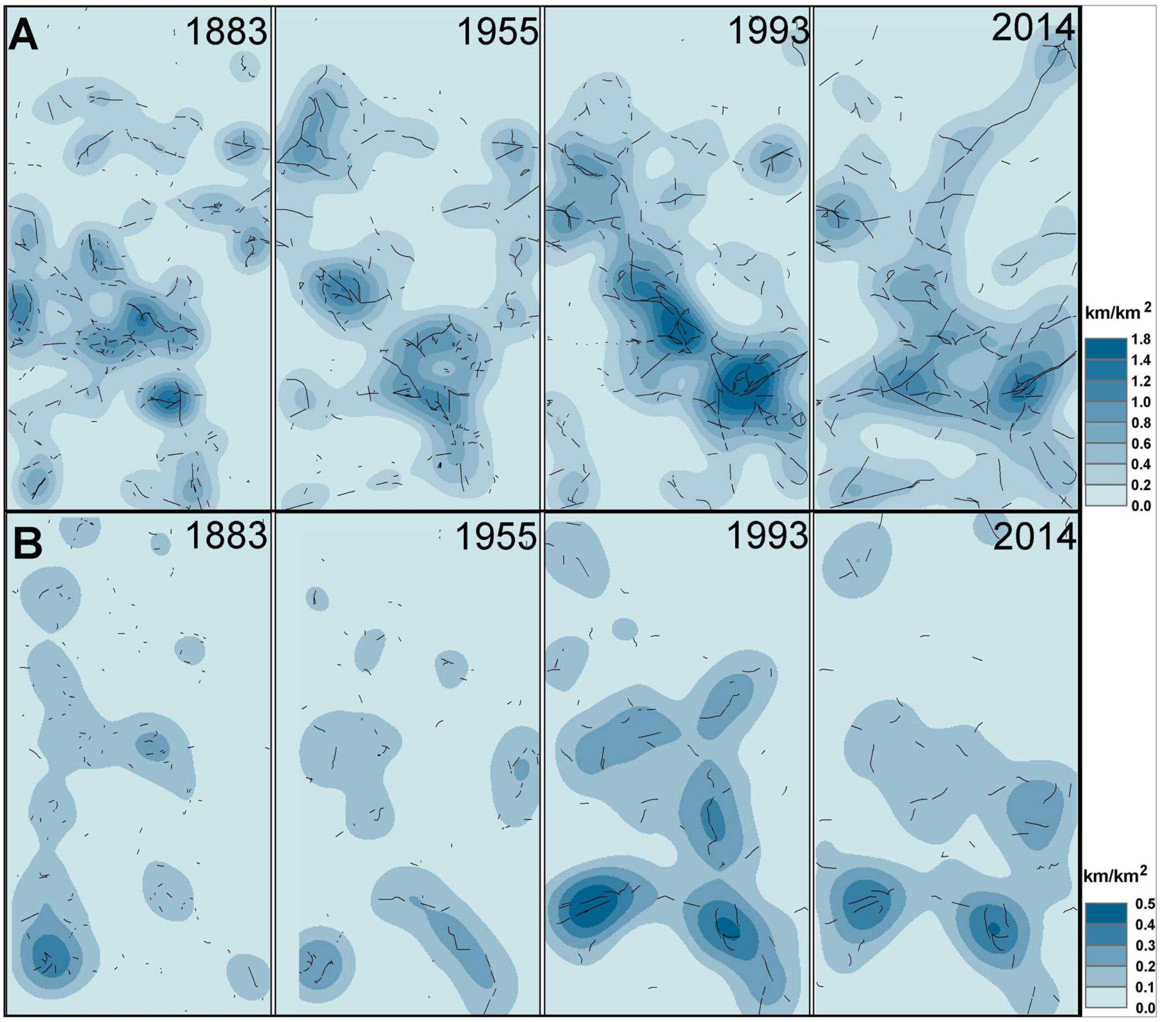

Figure 4. Density of the road and railway embankments (A) and incisions (B).

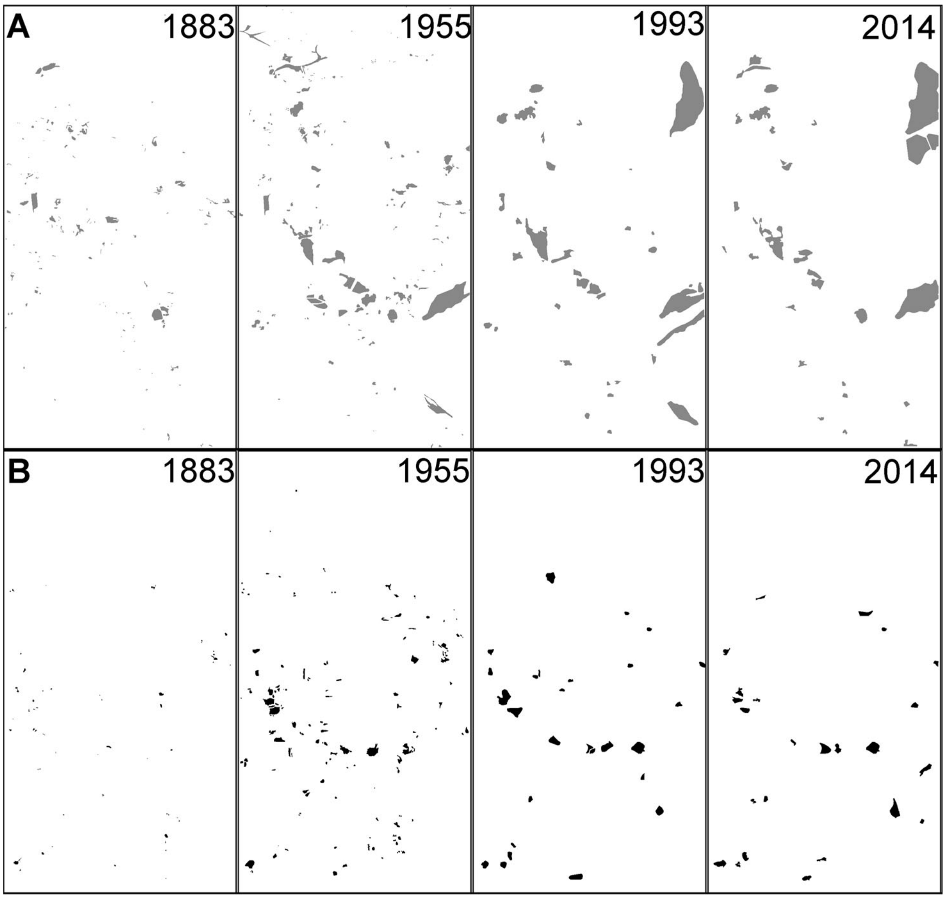

Figure 5. Spatial distribution of excavations (A) and dumps (B).

mainly in parts N and NE and SE. This is undoubtedly related to the development of the railway network and the creation of new roads. The situation is similar with regard to incisions (Figure 4(b)). We can observe an increased number of forms in 1993, but again this may be the effect of the map scale (1:50,000 compared to the latest map 1:100,000). The same trend occurs here – mainly longer forms in the south and in the central part of the area.

The analysis of surface landforms also showed a significant increase in the total amount (occupied area) of all forms. The smallest increase was recorded for excavations (only 309%), but in their case the largest increase in average size of forms was recorded (over 31 times!). In 1883 there were many scattered, barely visible forms, while in subsequent periods large-surface forms were observed, mainly in the eastern part of the area (Figure 5(a)). Dump forms (Figure 5(b)) were the only ones to record their maximum in 1955 and since then their surface has been shrinking and disappearing gradually from the landscape (Table 2). This is the result of the closure of many coal mines operating in this area (Dulias, 2007) and continuous dismantling of post-mining dumps mainly for building roads (Solarski, 2013).

The largest increase was recorded for water reservoirs (over 1700%), many of which were not included on the map from 2014 due to the scale of the map (sic!). The largest reservoirs were created in the NE part of the area (see Dulias, 2010), where a large field after an opencast sand pit mine was flooded (Figure 6 (a)). In turn, a lot of small forms were created mainly as the effect of filling subsidence basins with water (see Solarski et al., 2012; Solarski & Pradela, 2010). Despite lack of data from 1883 and 1993, we can see how dynamically the areas of subsidence basins (Figure 6(b)), which are a by-effect of mining activities, are growing (see Dulias, 2011).

The last analyzed landforms were anthropogenic flats. Their growth is enormous (over 134 times – see Table 2), but here we need to consider probable differences in defining these types of forms. On the latest geomorphological map (Jania et al., 2014), human leveled terrain surfaces (e.g. for airports, car parks, residential buildings, etc.) were considered anthropogenic flats, while on the map from the 1950s (Klimaszewski ed., 1959) only small and sparse forms were included, where the ground surface was purposefully leveled. Certainly, over the past twenty years, the number of anthropogenic flats has actually risen through the construction of large-area stores (hypermarkets) along with large parking lots, huge warehouses of forwarding companies, and rapidly developing housing construction in this area.

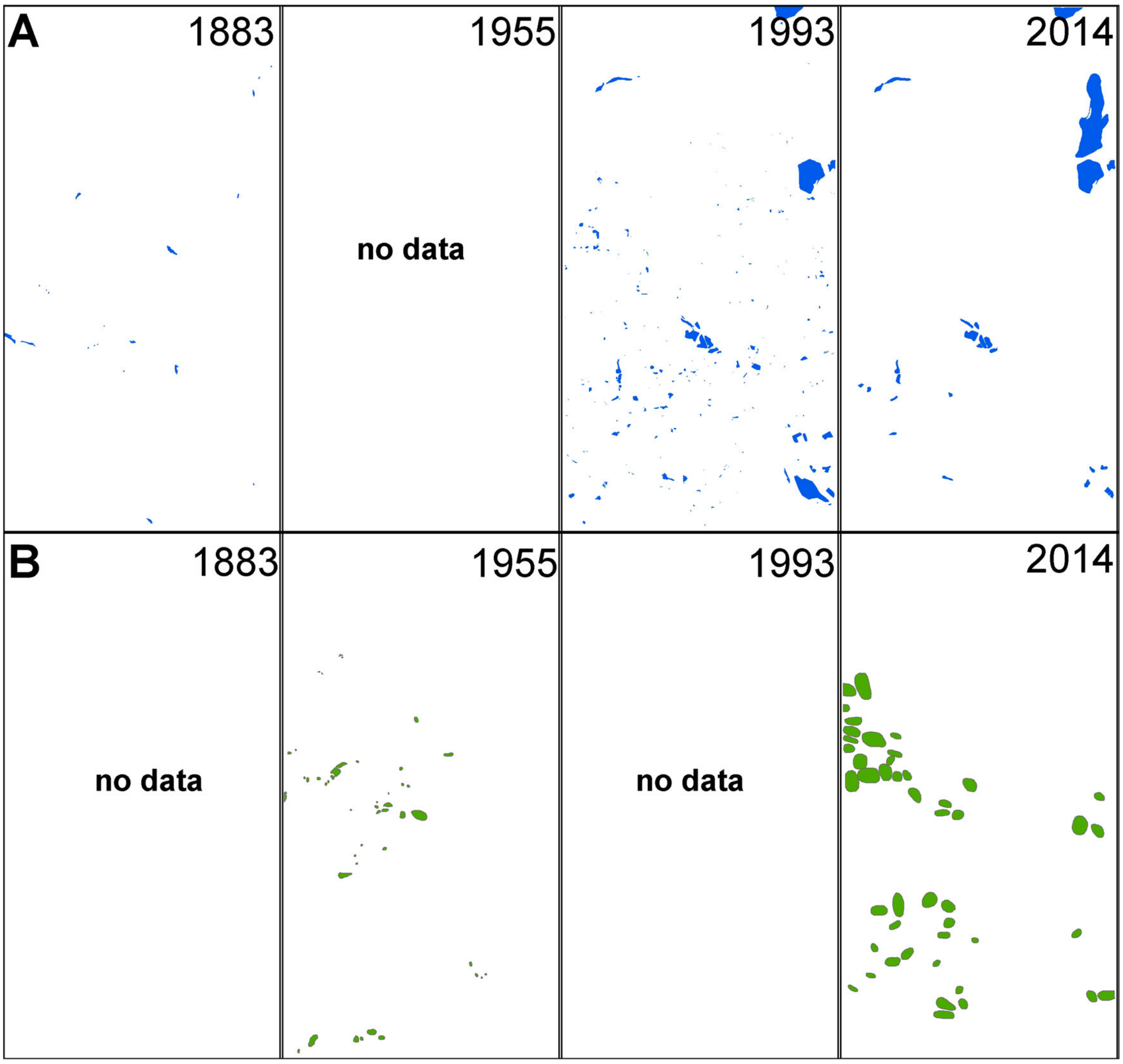

Figure 6. Spatial distribution of anthropogenic water reservoirs (A) and subsidence basins (B).

5. Conclusions

The key conclusions arising from this paper are as follows:

During adapting old paper maps to the digital version (Figure 7), one has to take into account errors and limitations (e.g. lack of information about the coordinate system, inconsistent content of adjacent map sheets, inability to determine the boundaries of polygonal forms with open signatures, errors on maps, etc.). Nevertheless, these old maps are an extremely valuable source of information about the state of the environment at a given moment in the past. Digitizing a paper map into a digital version and creating a geodatabase in the shapefile format enables comparative studies with the contemporary state and character of relief. Owing to this, it has become possible to trace how the quantitative character and spatial distribution of individual elements of anthropogenic relief have changed.

Generally, it should be noted that the number of anthropogenic landforms in the study area increased significantly over the past 120 years. Linear forms rose by 30–400%, while polygonal forms grew by several to over a hundred times. Moreover, together with the increase in the total number of anthropogenic forms, their structure also changed – many large forms appeared, i.e. the average length/area of individual forms went up. This is direct evidence of a constant, strong and increasingly growing human impact on changing the appearance of the landscape. It seems that currently the most common anthropogenic forms are anthropogenic flats, due to their basic character of application (e.g. built-up urban areas, large parking lots next to hypermarkets, new highways, etc.). It should also be noted that on numerous occasions a change in relief also entails a change in the quality of the surface nature (e.g. small water reservoirs in subsidence basins).

And one last thing, when comparing old historical maps with modern ones, one should always be aware that even despite the same scale of scientific description, they were made with different technologies that will never guarantee absolute comparability of

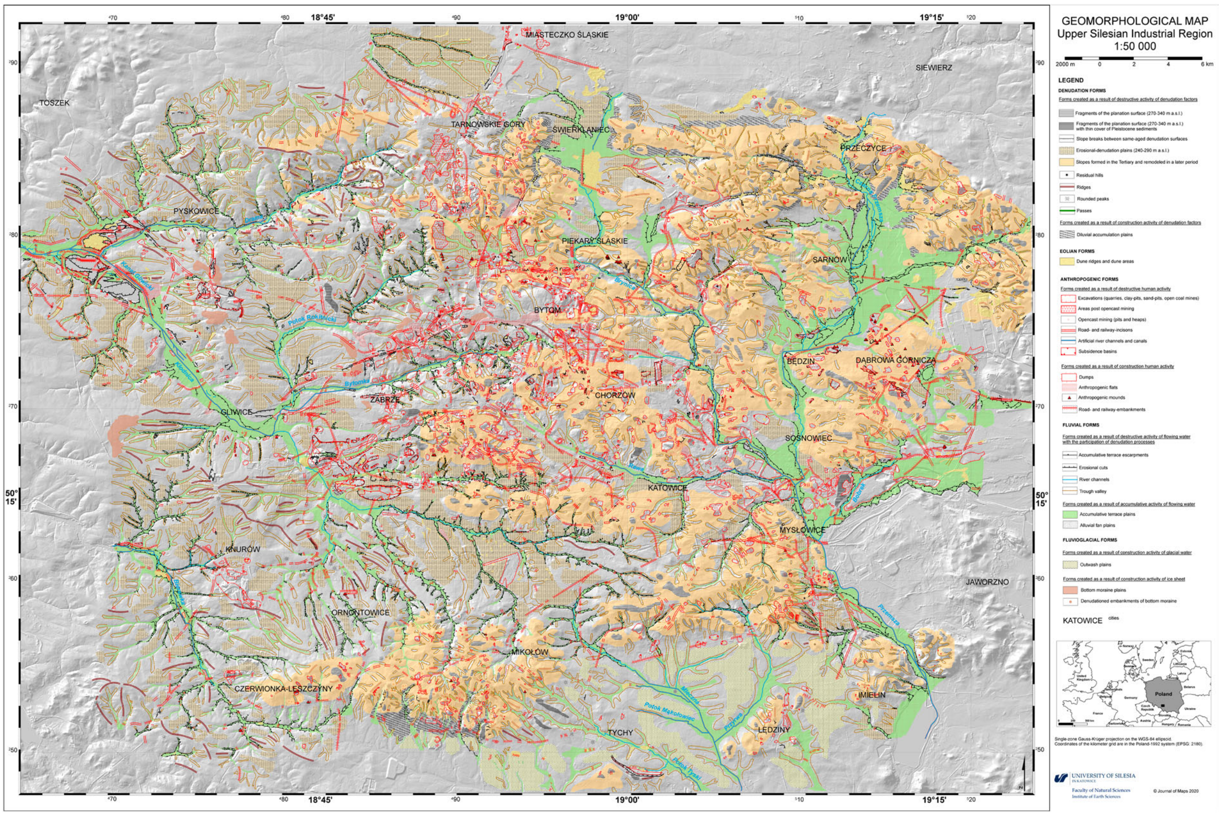

Figure 7. Geomorphological map of the Upper Silesian Industrial Region 1:50,000 – digital version.

accuracy. Therefore, the quantitative data described above should be treated with caution, rather as an indication of the trend and nature of changes, and not as precise values with decimal precision.

Software

ESRI ArcMap 10.6 was used to all cartographic works: georeferencing of the scanned historic maps, on-screen digitizing of all the landforms with attributes, spatial and time comparisons of the landforms, and edition, visualize and export of the final map.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon request. Map in pdf format is available from: http://hdl.handle.net/20.500.12128/6338 or doi:10.6084/m9.figshare.9904679.v1

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