1. Introduction

Spatial visualization of the historic landscape change is possible thanks to reconstructing the landscape in at least two time points in the past according to topographical maps content (Bielecka & Medyńska-Gulij, 2015; Halik, 2018). For this purpose, it is justified to use old maps presenting the state of the environment. To understand changes in the historical landscape, there is a need not only for qualitative modeling but also for the analysis of quantitative changes (Lorek, 2016; Medyńska-Gulij et al., 2019).

The Upper Silesian Industrial District, with its biggest municipality Katowice, is the largest industrial region in Poland. Despite the fact that many research studies were dedicated to this region, extensive quantitative research is still missing. Some studies have presented quantitative approach, however, in a general frame (e.g. Baranyai & Lux, 2014; Lorek et al., 2018; Stankiewicz, 2014) or only in a thematic approach (Absalon & Jankowski, 2002; Chmielewska, 2010). Therefore, we see a need to carry out more detailed studies concerning the spectrum of geographic features for smaller administrative units. Significant research is also conducted to analyze the functional and spatial transformations of the Upper Silesian Industrial District, whose authors refer to the pre-industrial period, noting the relationships and changes occurring in the functioning of Upper Silesian Industrial District cities along with the transformation of the economy and the development of the industry. In their research, they use the former (pre-industrial) status as a reference point in time to show the diametrical changes that have occurred since the nineteenth century in Upper Silesia (Krzysztofik & Runge, 2010 Runge, 2018). In their research, they refer to the changing directions of settlement and development of areas and also indicate the growing share and significant importance of Katowice in the functioning of the Upper Silesian Industrial District (Gwosdz, 2004).

For this reason, we have focused on producing series of thematic spatial visualizations presenting quantitative landscape changes in the Katowice municipality which are the Main Map. According to cartographic materials from the beginning of the nineteenth century, the landscape was slightly transformed by human activity. The development of the industry and railways, initiated by the Prussian government (in the nineteenth century, Katowice was part of Prussia), started huge landscape changes (Henderson, 1975). The nineteenth-century landscape changes depiction in a quantitative context, which affected today’s landscape, was the main motivation for conducting this study.

2. Methodology

2.1. Study area

The Katowice municipality, the central part of the Upper Silesian Industrial District, constitutes the
study area. It is situated in the Silesian Voivodship in southern Poland. Katowice has 16,400 ha of area in its today’s administrative borders. It is part of the Katowice urban area. The idea of this article was to trace the thematic changes taking place in Katowice and show the possibilities of presenting them in a cartographic and quantitative context. The presented example of Katowice, as one of the industrial cities of the region, allowed to show the direction of the transformation of spatial structures created between two periods of the nineteenth century in the Upper Silesian Industrial District. At the turn of the eighteenth and nineteenth centuries, Katowice was not the largest unit in the industrial region, and the direction of development of the surrounding areas progressed gradually from Gliwice, Bytom to the east. During the nineteenth century, the development of the region in raw material extraction and processing for industry resulted in the increment of the Katowice importance. In the last decade of the nineteenth century, Upper Silesian Industrial District name described most industrialized areas located mainly between Gliwice, Tarnowskie Góry, and Mysłowice (Gładysz, 1983) (see Figure 1).

The expansion of Katowice was related to the industrialization of Upper Silesia which started at the beginning of the eighteenth century, when the region was incorporated into Prussia (Hartshorne, 1934). At that point coal mining entered the stage of rapid development. Many of today’s mines were established between 1807 and 1850 and there was a demand for new workers, who needed housing estates (Grzegorek et al., 2017; Stankiewicz, 2014). The years 1850–1900 were the second time period during which revolutionary changes related to the construction of railroads advanced mining and metallurgy industry along with the expansion of settlements. Significant changes visible in topography over the past 60 years motivated us to choose Katowice for the study area. Unique, manuscript maps from the first half of the nineteenth century (Urmestischblätter) and a newer series of maps from the end of the second half-century (Messtischblätter) recorded these changes. These two time periods were the basis for the series of spatial

![Figure 1. Location of Katowice in the current voivodship division of Poland and cities marking (red dot) the Upper Silesian Industrial District in the nineteenth century (following Gładysz, 1983).](image-url)
visualizations of landscape changes in the nineteenth century – the Main Map.

2.2. Source materials

The Prussian topographic map, *Urmesstischblätter*, was the basic cartographic material for the reconstruction of the historical landscape. It was drawn in the scale of 1:25,000 by the army by means of plane table surveying methods in the years 1822–1865 (Lorek & Medyńska-Gulić, 2019). The municipality of Katowice in its today’s administrative borders is covered by 4 sheets of Urmesstischblätter named: Schwientochlowitz, Kattowitz, Nikolai, and Lendzin all of them from 1827. All maps were drawn in the same year, hence, they constitute appropriate source material from 1827. All maps were drawn in the same year, pointing to the coherence of the *Urmesstischblätter* series of maps, took into account, among others, a unified scale, sheet division, mathematical guidelines, or a system of conventional symbols to record the state of the former space. The evolving space recorded on sheets in subsequent years presents the changes in the information resource of editions of the later legend and maps.

*Messtischblätter*, the Prussian topographic map drawn in the 1880s, was another cartographic material used in the research (Kraus, 1969). The scale of the map is 1:25,000, based on precise measurements and the sheet division, and the names were the same as for *Urmesstischblätter*. For the Katowice municipality, *Messtischblätter* maps were made in 1883. We combined legends by selecting and classifying objects that appear on both maps to one of seven themes. Figure 2 presents the framework of combining legends of both maps.

Both *Urmesstischblätter* and *Messtischblätter* were obtained in digital form from the Staatsbibliothek zu Berlin – Preußischer Kulturbesitz (the Berlin State Library) in 400 dpi resolution. Figure 3 presents the sheet division of *Urmesstischblätter* and *Messtischblätter* with current borders of Katowice and Figure 4 shows some fragments of these maps.

A comparison of sheets from two series of maps was possible thanks to maintaining uniform guidelines related to scale and division into sheets, as well as the accompanying idea of developing this map. Some publications from the eighteenth and nineteenth centuries, treat as one series of maps using table measurements, both *Urmesstischblätter* and *Messtischblätter* maps. Adding the letter prefix Ur for sheets made up to 1865, delimited two series. The characteristic feature of *Messtischblätter* map is full cartometry or usage of contour lines method for relief presentation (Kraus, 1969). Both map legends (Urmesstischblätter and Messtischblätter) use the same symbols, coding method. However, differences between legends are related to the increased scope of the content in further editions. An example is a symbol for the railway, which did not appear on maps from the first half of the nineteenth century.

2.3. Georeference

The georeference in GIS software was the first step in processing the obtained cartographic material. In order to reconstruct landscape changes and design spatial visualization, old maps were adjusted to the current coordinate system. The georeference process started from fitting *Messtischblätter* into the Universal Transverse Mercator (UTM) WGS-84, zone 34N based on modern topographic map. UTM was chosen because it is a standard for modern Polish topographic maps. *Messtischblätter* does not have the cartographic grid and because of that we have used four common control points with the modern topographic map and 1st order polynomial transformation. Control points on the *Messtischblätter* were assigned according to the same points which did not change their location on a topographic map (e.g. characteristic road or railway intersections visible on both maps). After that, we georeferenced *Urmesstischblätter* based on unchanged common control points on *Messtischblätter* and the modern topographic map. Because of the need to be highly precise in the adjustment of *Urmesstischblätter* into the coordinate system, 30 control points and 3rd order polynomial transformation were used. The average RMSE (Root Mean Square Error) for all *Urmesstischblätter* maps was approximately 36–42 m, which is comparable to other georeference studies based on this source material (Deng et al., 2017).

2.3. Digitalization

After fitting old maps in current coordinate system, the content of both maps had to be digitalized. Digitalization included only selected types of land use depicted in cartographic materials. It was caused by the fact that the comparison of landscapes of two time periods requires the same type of land use on both maps (e.g. roads, settlements). We have chosen seven of them: water bodies, forests, rivers – representing a natural landscape, and roads, settlements, raw materials extraction places, churches – representing the anthropogenic landscape. These geographical features were divided into three types of geometry – polygon (settlements, forests, water bodies), polyline (roads, rivers), and point (raw material extraction places, churches).

The proposed research approach includes obtaining data from source materials (old topographic raster maps), their processing, and cartographic visualization. The use of raster source materials and their subsequent
digitization is aimed at presenting the method of obtaining data starting from unprocessed materials. This approach is in line with the geomatic method proposed by some authors (Dermanis et al., 2000; Halik & Smaczyński, 2018). The process of digitizing source material is long. Where vector versions of old topographic maps exist, spatial overlay in a GIS environment can be considered. It allows to can link vector data from both topographical sources (Zhang et al., 2002).

Despite the fact that the Urmesstischblätter was drawn in the same scale as the Messtischblätter (1:25,000), the content was more generalized. It is caused by the fact that the Urmesstischblätter was less

|               | Urmesstischblätter | Messtischblätter |
|---------------|--------------------|------------------|
| Forests       | ![Forest Image]    | ![Forest Image]  |
| Settlements   | ![Settlement Image] | ![Settlement Image] |
| Water bodies  | ![Water Body Image] | ![Water Body Image] |
| Roads         | ![Road Image]      | ![Road Image]    |
| Rivers        | ![River Image]     | ![River Image]   |
| Raw material extraction points | ![Raw Material Image] | ![Raw Material Image] |
| Churches      | ![Church Image]    | ![Church Image]  |

**Figure 2.** Types of land use and objects that were presented in both source materials. The figure shows our selection and classification concerning seven themes (forests, settlements, water bodies, roads, rivers, raw material extraction points, and churches).
detailed and not designed with mathematical basis unlike the Messtischblätter (Lorek & Medyńska-Gulij, 2019). For that reason, the content of the Messtischblätter had to be slightly generalized, especially the geometry of settlements (e.g. aggregation of single buildings into one area). Large distortions

![Figure 3](image_url)

**Figure 3.** The reach of the Urmesstischblätter and Messtischblätter sheets together with current borders of Katowice municipality.

![Figure 4](image_url)

**Figure 4.** Fragments of source cartographic material that was used in the study (A refers to Urmesstischblätter, B refers to Messtischblätter). Both maps show Katowice and its surroundings.
after the georeferencing process, characterize the *Urmesstischblätter* map. Therefore, there was a need for manual rubber sheeting (spatial adjustment) of vector data according to *Messtischblätter*. Our approach was similar to the methods presented by Medyńska-Gulij et al. (2019) and suggested by Kraak and Ormeling (2013, p. 95) for processing cartographic source materials from different time periods. This means snapping vectors from the *Urmesstischblätter* to the *Messtischblätter* vectors in places where there were distortions. However, in the case of *Urmesstischblätter*, the exact location and e.g. the flow of a river was not presented. Therefore, in cases where we were not sure whether the flow was the same, we left discrepancies in geometry. Figure 5 presents our approach to digitalization in five selected topics.

2.4. Visualization

Landscape changes in the nineteenth century were visualized through a series of regular grid choropleth maps (thematic visualizations). The size of the single grid cell was 0.5 km and the scale of the visualization was 1:100,000. We have generated seven maps of landscape changes between 1827 and 1883: forests, settlements, water bodies, roads, rivers, raw material extraction places, and churches in the administrative border of today’s Katowice municipality in southern Poland.

Differences in area, length and the absolute number of aforementioned features were the main factors defining quantitative landscape changes. All geometries were clipped according to today’s administrative

![Figure 5](image.png)

**Figure 5.** Selected digitized topics of the landscape from both maps sources in a grid cell on a topographic background. Black color presents the vectors from *Urmesstischblätter*, and red presents *Messtischblätter*. 
border of Katowice municipality. In each grid cell the area (for polygons), the length (for polylines) or the count (for points) of selected features were calculated both for 1827 and 1883. The area is a common index in landscape metrics (Esbah et al., 2010). After that in each grid cell the differences in geometry were calculated and for each feature different maximal and minimal values of the area, length or count were obtained. On the basis of maximum or minimum value of the feature seven quantitative color classes of changes were created (three classes of increase, three of decrease, and one for no change). We have used intuitive bipolar color scheme with differentiation of blue and red brightness (Medyńska-Gulij & Cybulski, 2016).

The class intervals show how much (in percentage ranges) a given topic in the primary field (single grid cell) increased or decreased in comparison to the previous years. For example, if the maximum difference in the forest area between 1827 and 1883 was −25.0 ha, then it was treated as 100%. The division of classes was based on percentage and there were no changes when the difference was between −10% to 10% for the maximal difference. We chose this range because of the sliver polygons that resulted from the fact that the objects on the Urmesstischblätter did not have a location presented with mathematical precision as in the case of the Messtischblätter. This allowed us to eliminate the presentation of changes, e.g. areas, in situations where the differences would result only from the uncertainty of the location of a given landscape element. Small changes were above 10% to 40% (the increase when it was plus and the decrease when minus), medium changes above 40% to 70%, and big changes were above 70%. Figure 6 presents example of visualization of changes based on differences in geometry of settlements.

3. Results and discussion

Quantitative landscape changes were calculated on the basis of the area or length parameters. In 1827 the analyzed area was mostly covered (based on map analysis) by forests which covered approximately 9728.4 ha. The second largest feature was settlements – 438.4 ha. Water bodies covered 160 ha. There were 253.7 km of roads and 190.8 km of rivers. At that time one church was found and five raw materials extraction places. In the 1887 landscape changed. The largest quantitative changes were related to forests which decreased by 604.4 ha (approximately 6% of the forest area in 1827). However, relatively largest changes were related to settlements which increased by 582.7 ha, nevertheless, it is about 133% the area of settlements in 1827. Also, relatively large changes affected lakes which decreased by 118.8 ha (74%). The length of the rivers decreased also by 70.6 km and at the same time, the length of roads increased by 84.3 ha. Moreover, the number of churches increased to 6 and the number of raw material extraction places increased to 50.

The decrease of forests was strictly connected with the increase of settlements area which took place mostly in the north part of the analyzed area. There were three places in which area of settlement slightly decreased. This could be linked with the increase of settlement area in surroundings which cause the migration of people and change of residence (Medyńska-Gulij et al., 2019). The growing area of settlements affected also water bodies which dried. Most water bodies are not impounded by dams.
(Machowski & Noculak, 2014). Road construction brought the decrease in forests area and river length, some rivers were regulated and canals were built (Absalon & Jankowski, 2002). Most raw materials places were established in the north-east part of Katowice, most of them being coal mines founded in the period from the 1830s to 1850s (Chmielewska, 2010).

4. Conclusions

The reconstructing landscape changes in the nineteenth century could be based on old cartographic materials, such as old maps. When they were created in the same century, however, in a different time period they could be a basis for comparison of the landscape. Obtained materials, such as the Prussian Urmesstischblätter and Messstischblätter, constitute the appropriate source for conducting the research aimed at presenting landscape changes. Thanks to professional GIS software it is possible to adjust those materials to the mathematical coordinate system at make digitalization, computation, and comparison of geometries of geographical features.

The methodology presented in the paper allowed one to estimate the quantitative landscape changes for the Katowice municipality with current administrative borders. It does not only provide overall statistics but also allows one to present landscape changes in the spatial manner by means of mapping methodology.

Naturally, the landscape is much more complex than geographic features selected for the study. Our limitations resulted from the information potential of cartographic materials used in the research. For that reason, we could not estimate, e.g. the area of farmlands or the area of industrial or residential buildings, because such information was not included in the map. Correct estimation of areas and lengths of geographical features, such as settlements or roads, is demanding without their actual measurement. Analyzing historical landscape changes is difficult because we do not have direct access to the past, so we use materials created in the past. Some of them were not designed with a mathematical precision, such as the Urmesstischblätter.

For future studies, the similar analysis could be enriched by other historical materials, such as photographs, plans, blueprints, or notes and written memories. The method of cartographic presentation adopted by us is not the only one possible. Alternatively, you can use cells that are not completely filled. Then the size of the filling (colored square) would give the impression of change. It would also interesting to compare two methods of the presentation by users to determine which one is more effective. The adopted research procedure presents selected elements of the landscape. Presenting landscape changes with just one indicator and visualizing these changes on one map is desirable. However, the use of a regular cell grid allows understanding the relationships between each topic.

Software

All spatial processing including setting the proper coordinate system, clipping geometry to the administrative borders, calculating geometry differences were done using Esri ArcGIS 10.6.1. The legend and the Main Map layout were created in graphic software – Corel Draw X7.

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