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Research Paper

Urban green resilience: Experience from post-industrial cities in Poland

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ABSTRACT

De-industrialisation triggered economic, spatial and environmental changes in cities. Therefore, this study identifies whether there has been a reorientation of spatial development in post-industrial cities towards the creation of green spaces. The aim of the study is to analyse and evaluate the transformation of green spaces in 32 major cities in Poland, including 12 post-industrial cities. Data sources were vector land cover data models from the Urban Atlas for 2006 and 2018, administrative boundaries from the National Boundary Register and building layers from the Topographic Objects Database. The research procedure was carried out using the GIS environment, through spatial analysis, geoprocessing algorithms, and spatial statistics. The results have shown that post-industrial cities do not develop their urban resilience based on the expansion of green spaces and, consequently, do not build green urban resilience. In addition, the research has proven that the greatest loss of green spaces is noticeable in parts of post-industrial cities with medium and high development intensity, where there is an intensification of construction activity. The dominant direction of the transformation of green spaces has been the conversion of agricultural areas into green spaces (87.79%). In contrast, the main direction of loss in green space has been the creation of new industrial units (24.80%) and the expansion of the urban fabric (23.53%). The article is original due to the fact that there is a gap in the literature regarding the study of green spaces in post-industrial cities with regard to the concept of green urban resilience.

1. Introduction

1.1. The developmental and devastating role of industry

Industrialisation was an impetus for the spatial development of cities. Its origins in Europe date back to the 18th century, when the Industrial Revolution began in England and Scotland (Loures, 2015). This process had a huge impact on the formation of cities. Above all, it contributed to a more dynamic urbanisation process, due to increased rural–urban migration, resulting in a transformation from an agrarian society, where farming was the dominant means of livelihood, to an industrial society, living in the city and making a living from factory work (Gospodini, 2006). The expanding population drove increased investment in infrastructure or public facilities, at the expense of green spaces. Industrialisation forced the spatial development of cities and, consequently, affected environmental degradation (Urbinato, 1994). In addition to social and spatial changes, it brought about numerous economic and technical changes, such as the establishment and development of railways, mechanisation, and the creation of industrial districts (Chodkowska-Miszczuk et al., 2021). All these measures had a positive impact on the economic dimension of the cities, but a negative one on the environmental aspect. Intensive industrial activity put pressure on many components of the natural environment (water, soil, air). Industrial cities created jobs but also contributed to environmental degradation.

The growing importance of industry has resulted in irreversible environmental impacts, the reduction of which is a long-term process (Douet, 2016; Dutheil et al., 2021). Man is the final recipient of the polluted environment (Barca, 2011). Researchers distinguish a number of negative impacts of industrial activities on the environment (among others emissions and deposition of gaseous, particulate, and aerosol pollutants) (Lorber, 2011).

The period of intensive urban industrialisation ended in the second half of the 20th century, when the dominance of services

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began to spread globally. In cities, there was a shift towards servitisation and the development of a knowledge economy. When, as a result of socio-economic and political changes, industry began to lose its importance and mines and steelworks ceased to be priority investments, cities were confronted with the problem of managing post-industrial land and reorienting urban policy (mainly spatial, but also environmental and economic) (Gasidło, 1998; Carter, 2016). The process of de-industrialisation has brought about a change in economic paradigms, but also a change in the management of urban spaces. There has been a reorientation towards 'green cities', i.e., centres that can be resilient to, for example, pollution and climate change, thanks to their large green spaces. This reorientation has been mainly theoretical, although we do see some implementation and attempts to create 'green cities', e.g., in Sunderland, UK (Pike, 2022).

1.2. Urban resilience – Towards the green component of the concept

In recent years, as a result of industrial anthropopressure, we have also seen increased research on urban development concepts and ideas that have an ecological, pro-environmental component at their core (Szymańska et al., 2015; Chang, 2018; Wang, 2019). One of such concepts is urban resilience, which is a response to the progressive degradation of the natural environment, climate change, and negative urban processes, such as urban sprawl or the presence brownfields in the spatial and functional structure of cities (Sharifi, 2020). According to the concept of urban resilience, a city should be planned in such a way that it can respond to threats and crises in real time. Urban resilience is considered as the measurable capacity of any urban system to maintain continuity in the face of all shocks and stresses, while positively adapting and transforming towards sustainability (Coaffee, 2008; Rogatka, et al., 2021). Industrialisation has also contributed to globe's climate warming (Przybylak et al., 2022) and one of the remedies could be the implementation of the principles of urban resilience, one dimension of which is the design, construction, modernisation of the 'green potential' of cities (Vavrus et al., 2008). Urban greenery, in its broadest sense, should be seen as an integral part of the urban resilience concept, crucial in its construction (Roundy et al., 2018).

The concept of urban resilience has been introduced in the research on the urban environment together with the systems theory, which means that city consist of the anthropogenic and the ecological subsystems (Coetzee et al., 2016; De Montis et al., 2019). In the urban resilience concept, the urban environment is characterised by stability, a specific homeostasis of all elements (social, spatial, infrastructural, environmental, cultural, etc.) which is defined through the sustainability of the system and its ability to return to the baseline state after the impact of disruptive external factors has ceased (Holling, 1973; Richling and Solon, 2011; Davidson et al., 2019). In other words, it is the ability of the urban system to return to a state of equilibrium when the disruption is over. This concept, therefore, primarily means resistance to destructive events, the ability to regenerate and reassume sustainable development (Newman et al., 2017). Preparing a city for potential changes or threats is about achieving a state of resilience which will allow it to return to the state from before the negative phenomenon. In conclusion, the concept of resilience responds to a number of current social, economic and environmental challenges and problems faced by modern cities (Drobniak, 2015; Fastiggi et al., 2021). For a city to obtain resilience means to diagnose and minimise its crucial vulnerabilities (e.g., brownfields) through, among other things, the establishment of new green spaces (Collier et al., 2013; Adger et al., 2020).

Two basic methodological approaches can be applied to the concept of urban resilience, one highlighting engineering resilience and the other ecological resilience (Holling, 1996). Engineering resilience takes for its basis the operation of a system with a stable structure. This type of resilience focuses on the speed of recovery from a negative factor. In this approach, the urban system does not change its structure. Ecological resilience by Holling (1973) is understood as the magnitude of a negative factor that can be absorbed before the system changes its structure. A change in the structure of the system can occur as a result of changing the processes, structures, and components that control the system and are integral parts of it (Hodgson et al., 2015). By definition, in ecological resilience it is more important to adapt the urban system to the current conditions than to maintain the equilibrium itself (Melkunaite and Guay, 2016). The ecological resilience of the urban system is closely linked to the ecosystem services provided by the urban natural environment, which, based on natural capital, generate a flow of benefits to the centre of the urban system, protecting it from negative factors, i.e., crises (Costanza et al., 1997). From the point of view of urban resilience, the most important services are regulatory ecosystem services, such as air quality regulation, cushioning of extreme weather events, or regulation of hydrological cycles, which are catalysts for green resilience (Rogall, 2010). The literature indicates that urban systems with extensive green infrastructure become more resilient to crises and are more human-friendly (Davoudi et al., 2013; Caprotti et al., 2015).

In the context of the above considerations, it is important to recognise that urban planning in line with the concept of urban resilience adapts urban spaces to contemporary challenges, and one of the key elements in the implementation of urban resilience is the development of green spaces (Douglas et al., 2002; Wolch et al., 2014). Green spaces in the city serve a number of positive functions (Virtudes, 2016). Polish legislation (Nature Conservation Act of 16 April 2004) sees green spaces in the city as all arranged areas that are covered with vegetation and perform public functions, together with technical infrastructure and buildings functionally connected with them, located within the administrative borders of cities, performing aesthetic, recreational, health, or shelter functions (Wang et al., 2019; Stąpór and Beck, 2017). The function of green spaces is so important that one can speak of creating green urban resilience as an integral part of urban resilience. In this context, industrial or post-industrial sites have had a negative impact on urban resilience over the years (Schippa et al., 2017).

1.3. Aim of the study and novelty of the research

The aim of this article is to analyse and evaluate the transformation of green spaces in post-industrial cities in Poland. The authors wanted to verify whether there has been a reorientation of spatial development through increasing green spaces in the total urban area in post-industrial cities, which would testify to the implementation of the urban resilience concept and, above all, its green component. To this end, we carried out an analysis of the directions in which green spaces change in the cities under study. We also spatially identified locations where there has been a loss or gain of green spaces.

To the authors' knowledge, the literature does not currently contain any extensive spatial analyses of land use change in post-industrial cities with a particular focus on changes towards the creation of green spaces that are an element of urban resilience. The authors searched two scientific databases, i.e., Web of Science and Scopus, covering scientific resources published between 1899 and 2022 (June 30, 2022). The aim of the review of databases was to find scientific articles that simultaneously contained the following search phrases in their title, keywords or abstract: 'resilience'; 'industrial', and 'green spaces'. In the Web of Science database, the authors found five articles that included the above keywords. There are only four articles in the Scopus database, three of which are also included in Web of Science. The analysis confirms that there is a research niche in the study of green spaces in post-industrial cities in the context of the urban resilience concept with a particular focus on the green component.

Therefore, the innovation of the conducted research lies in taking up an original topic and filling the scientific gap concerning a narrow component of the urban resilience concept, which can be called green urban resilience. As such, the issues addressed in the work complement and extend the existing state of knowledge. The study also provides new knowledge in the context of analyses of spatial change in post-industrial cities. These cities, due to their industrial past, should seek to develop their land in such a way as to mitigate the negative effects of their past activities (Loures and Panagopoulos, 2007).

2. Materials and methods

2.1. Study area

The spatial scope of the study consisted of two groups of cities – those constituting the analytical background and post-industrial ones. The cities included in the background were 32 of the largest Polish cities selected on the basis of criteria proposed by Szymańska (2007), i.e., population over 100,000 inhabitants. According to data from the Local Data Bank of Statistics Poland, there are 37 cities in Poland that meet this criterion. The analysis was carried out for 32 cities (Fig. 1), because 5 cities (Bielsko-Biała, Elbląg, Tarnów, Wałbrzych and Włocławek) did not have data in the Urban Atlas in 2006.

The spatial scope of detailed research included the analysis of 12 cities in Poland which in their history were centres with a dominant role of industry (Fig. 2), hence they have been branded post-industrial cities (Kaliński, 1999; Paradysz, 2015; Fierla, 1973).

The analysis of Fig. 2 yields that the main type of industry that dominated in the cities analysed (Bydgoszcz, Olsztyn, Poznań, Wrocław) was the engineering industry, which generated pollution largely in the form of heavy metals, such as nickel and iron. The mining industry (Gliwice, Katowice, Zabrze) located in southern Poland and the shipbuilding industry (Gdańsk, Szczecin) in northern Poland also played an important role. The types of industry listed are among those with the heaviest impact on the environment (Fierla, 1973). The three other cities were dominated by the steel (Kraków), metallurgical (Warsaw), and textile (Łódź) industries.

2.2. Data

The source materials used in the study were spatial data in the form of vector thematic layers:

- Urban Atlas 2006 and Urban Atlas 2018 – the data concerned land cover in 2006 and 2018;
- buildings extracted from the Database of Topographic Objects (BDOT10k);
- administrative boundaries extracted from the National Boundary Register (NBR).

In the case of land cover data, particular attention was paid to green spaces, which comprised three categories listed in the Urban Atlas – green urban areas, sports and leisure facilities, and forests, which is in line with the definition of green spaces well-established in Polish legislation (Nature Conservation Act of 16 April 2004).

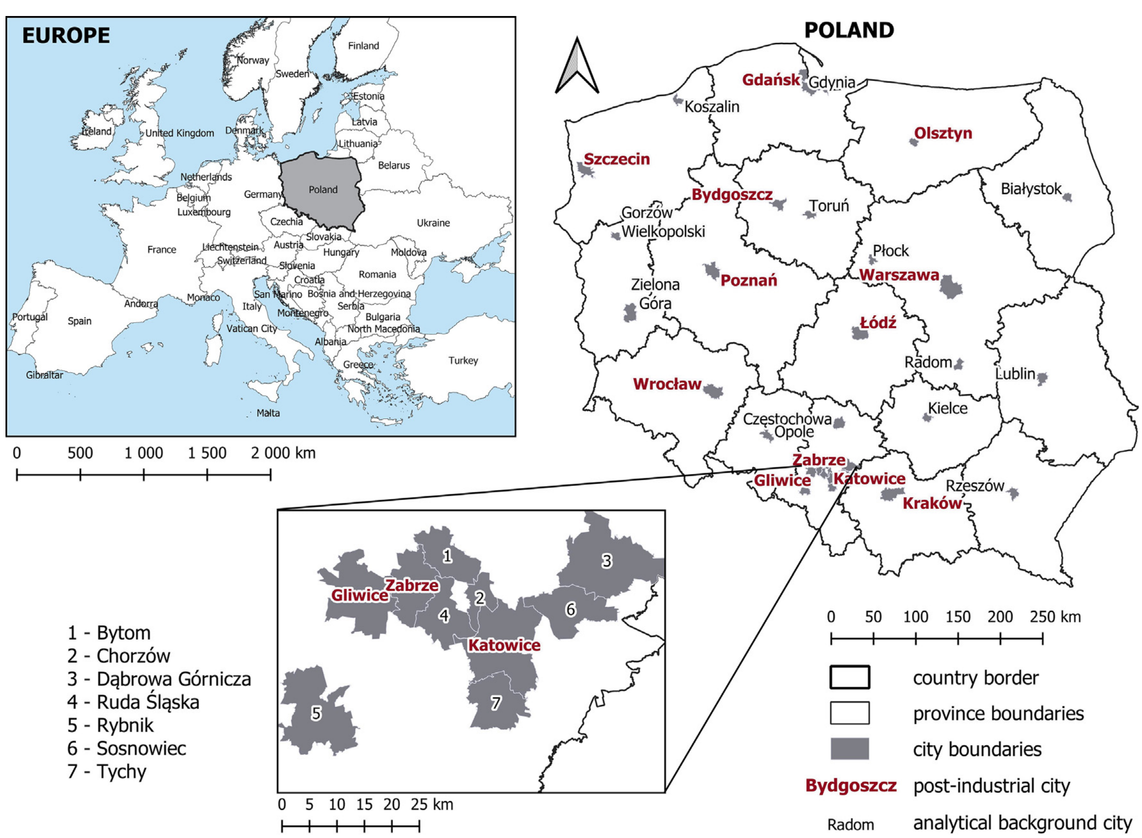


Fig. 1. Cities constituting the analytical background and the post-industrial cities constituting the detailed spatial scope of the study.

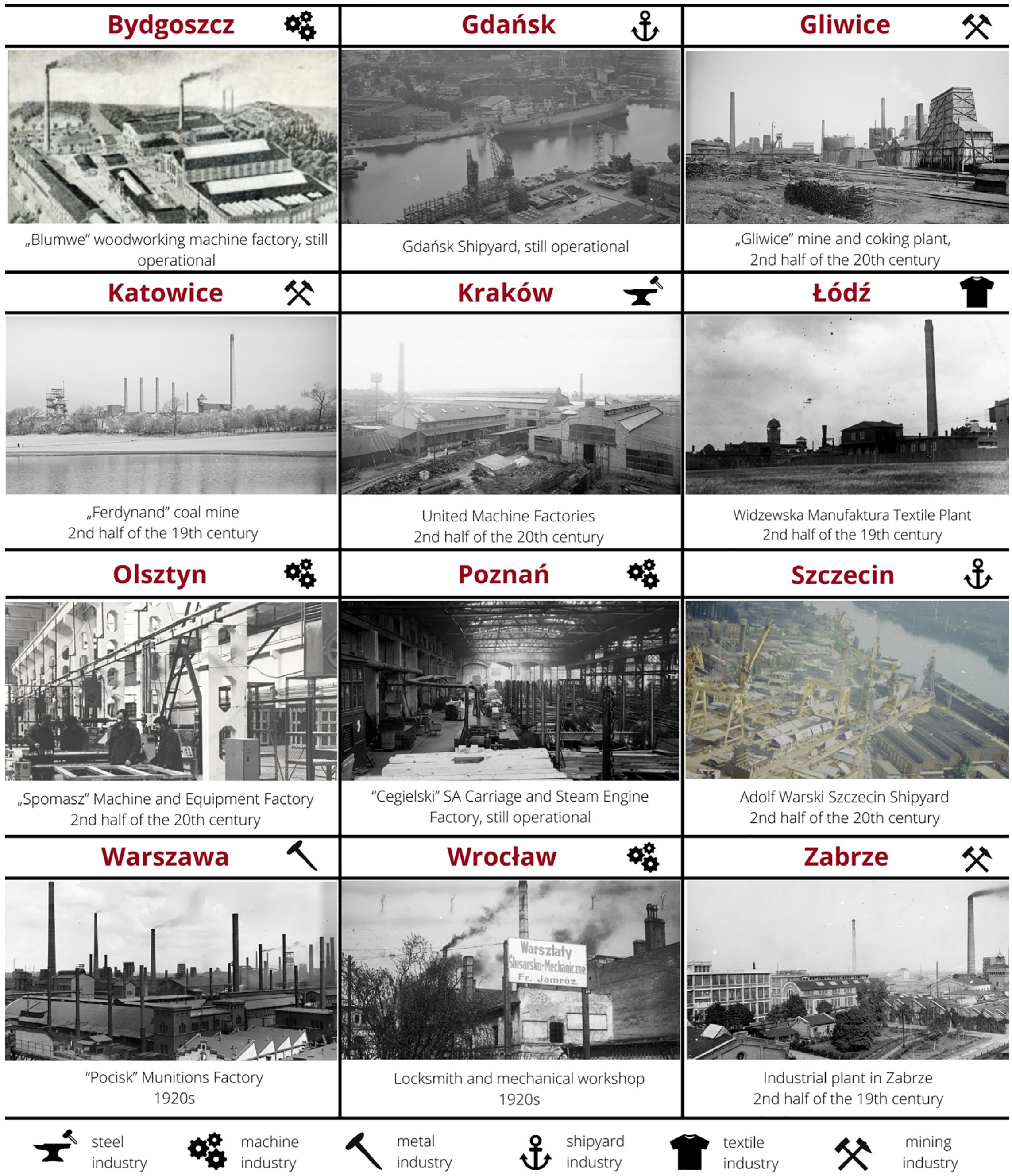


Fig. 2. Examples of industrial plants in the analysed post-industrial cities.
Source: own compilation based on photos from the National Digital Archive of Poland.

The authors analysed the directions of transformation of green spaces by means of a Sankey diagram based on their original reclassification of the Urban Atlas nomenclature (Urban Atlas Mapping Guide, 2018). The following seven categories were identified within this reclassification: (1) green spaces; (2) urban fabric; (3) industrial units; (4) transport units; (5) mine, dump, and construction sites; (6) agricultural areas; (7) water and other natural areas.

2.3. Research procedure and methods

In order to accomplish the aim of the study, the authors distinguished three basic stages of the research procedure. Three research tasks were planned in each stage (cf. Fig. 3).

The research stages presented in Fig. 3 were each completed using two main research methods. The conceptual stage was developed based on desk research. This included an analysis of the literature on the concept of urban resilience, its green component and how the subject is embedded in the context of the transformation of post-industrial cities (Kiecolt et al., 1985; Makowska, 2013). The second research method used concerned the operational stage, in which a series of spatial analyses were carried out using GIS methods and techniques (software QGIS 3.22.0). Detailed spatial analyses included a research background analysis (section 2.3.1), a hexagonal analysis in post-industrial cities (section 2.3.2), and an analysis of the directions of transformation of green spaces in post-industrial cities (section 2.3.3). During data processing, analysis, and visualisation, the authors used advanced combinations

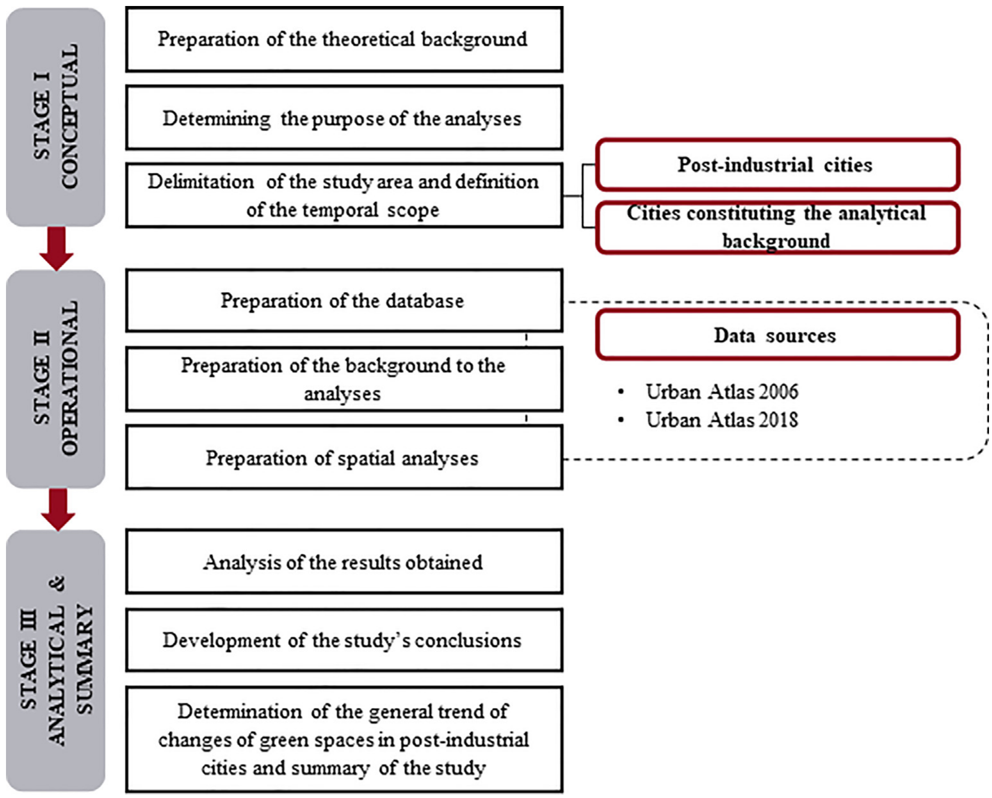


Fig. 3. Stages in the research procedure.

of tools, such as Cartesian intersect of spatial data matrices, relational joins, dataset subdivision into subsets based on descriptive and geometric attributes, and other plugins, including functions for calculating statistical parameters. In the analytical and summary stage, conclusions of the research were drawn up on the basis of the results obtained.

2.3.1. Research background analysis

In order to diagnose the state of green spaces in the largest cities in Poland, the materials collected in the database (Urban Atlas layers for 2006 and 2018) were adjusted to the assumptions made (selection in terms of attributes identifying land cover categories and restriction to the range of administrative boundaries of the analysed cities). In further steps, the area of green spaces was calculated and their share in the total city area in 2006 and 2018 was determined. The total area of green spaces in each city was calculated using the analytical tools of the QGIS software, allowing the area of polygon objects to be computed on a vector model.

2.3.2. Hexagonal analysis in post-industrial cities

In order to identify zones where there was an increase or decrease in green space in the context of development intensity, the authors decided to divide the area of each of the 12 cities into basic assessment fields (BAFs). As Jakiel (2015) points out, the use of BAF is one of the fundamental issues to be taken into account when undertaking research that demonstrates spatial features. The shape and size of a single BAF can affect the results of the analyses conducted (Sudra, 2016). A variety of BAFs can be found in the literature. They can be squares, triangles, or hexagons (Cegielska et al., 2019, Różycka-Czas et al., 2019), or figures with irregular shapes. BAFs in the form of administrative units or regions are also common (Cegielska et al., 2018).

In this study, analyses were based on a regular hexagonal grid with a single mesh area of 0.5 km^2. The choice of this analysis option was not random, for the resulting mosaic of fields was independent of the administrative boundaries or the spatial policy pursued in the various parts of the cities. In addition, the scientific literature identifies a number of advantages resulting from the use of a hexagonal grid, such as being bordered by six rather than four neighbouring fields (Birch et al., 2000), higher precision and legibility of final visualisations (Carr et al., 1992). The selection of the size of a single BAF was also guided by the research conducted to date in urban areas (Bereitschaft, 2018; Ivan et al., 2015).

Zones with different development intensities were determined based on the total development area in each BAF. Based on the values obtained, three zones were separated for all cities: low, medium, and high development intensity according to Jenks' method of natural breaks (Jenks, 1967). The nature of the changes taking place in the demarcated zones was then verified quantitatively and spatially, identifying, based on Urban Atlas spatial data, the places where green spaces decreased or increased between 2006 and 2018.

2.3.3. Analysis of the directions of green space transformations in post-industrial cities

Spatial data on land cover categories in 2006 and 2018 were used to show the directions in which green spaces were transformed. These data were geoprocessed to identify sites showing greenery-related changes. The authors analysed which land cover categories were transformed into green spaces and vice versa. The authors also calculated the area of each recorded change and prepared summaries of the total areas within the transformed land cover categories. These areas were calculated using the analytical tools of the QGIS software, which allows the area of polygon objects to be computed on a vector model. A Sankey diagram was used to graphically visualise the changes – each node represents the reclassified Urban Atlas land cover categories and the size of the node is proportional to the total area of change. The flows between nodes represent the direction of transformation (Soundararajan et al., 2014; Xie et al., 2020).

3. Results

3.1. Research background analysis

In 2006, the average green space coverage in 32 Polish cities was 29.38 %. It remained at the same level in 2018. The highest value was recorded in Zielona Góra (2006: 61.73 %; 2018: 61.43 %) and the lowest in Częstochowa (2006: 10.04 %; 2018: 11,08 %) (cf. Table 1).

In 2006, the average green space coverage in the 12 analysed post-industrial cities was 27.35 %. In 2018, there was a decrease of 0.10 % in this figure. The highest share of green spaces in the total city area was recorded in Katowice (2006: 52.85 %; 2018: 52.43 %) and the lowest in Kraków (2006: 14.29 %; 2018: 13.92 %) (cf. Table 1).

Of all 32 cities analysed, green spaces increased in 14 of them between 2006 and 2018, with only two post-industrial cities in that number. These are Łódź with an increase of 2.10 % (i.e., 615.45 ha) and Szczecin with an increase of 0.59 % (i.e., 176.39 ha) (Fig. 4).

It should be noted that the majority of the analysed post-industrial cities saw a decrease in the share of green spaces in total city area of between −1.27 % and −0.14 %.

3.2. Hexagonal analysis in post-industrial cities

When analysing the zones with an increase or decrease in green spaces in the context of development intensity, it is worth noting the general trend observed in all the post-industrial cities analysed. Only the low intensity development zone saw a 0.09 % (246.94 ha) rise in green spaces in the total area of the cities between 2006 and 2018. In the remaining zones, there was a drop in the area of green spaces: −0.13 % (-379.87 ha) in the medium intensity zone and −0.05 % (-143.14 ha) in the high intensity zone. A detailed summary for each post-industrial city is depicted in Fig. 5.

Table 1
Share of green spaces in total city area in 2006 and 2018.

City	2006 (%)	2018 (%)	Change (%)
Warsaw	**27.90**	**27.71**	**−0.19**
Łódź	**18.99**	**21.09**	**2.10**
Kraków	**14.29**	**13.92**	**−0.37**
Katowice	**52.85**	**52.43**	**−0.42**
Gdańsk	**28.13**	**27.99**	**−0.14**
Poznań	**27.30**	**26.35**	**−0.95**
Szczecin	**30.07**	**30.66**	**0.59**
Wrocław	**21.12**	**20.77**	**−0.35**
Zabrze	**32.67**	**32.09**	**−0.58**
Gliwice	**22.74**	**22.36**	**−0.38**
Olsztyn	**37.90**	**37.10**	**−0.80**
Bydgoszcz	**40.44**	**39.16**	**−1.27**
Lublin	21.11	20.72	−0.39
Gdynia	53.72	53.76	0.03
Kielce	28.41	29.44	1.04
Toruń	36.77	37.64	0.87
Rzeszów	10.48	10.78	0.30
Opole	15.47	15.68	0.21
Gorzów Wielkopolski	17.91	17.45	−0.46
Zielona Góra	61.73	61.43	−0.29
Częstochowa	10.04	11.08	1.05
Radom	12.56	13.19	0.62
Płock	19.59	20.53	0.94
Koszalin	44.41	44.28	−0.13
Chorzów	38.40	38.07	−0.33
Dąbrowa Górnicza	30.64	30.72	0.08
Tychy	35.08	35.52	0.44
Ruda Śląska	38.06	38.07	0.02
Rybnik	37.70	38.75	1.05
Bytom	39.85	37.39	−2.45
Sosnowiec	31.96	31.52	−0.44
Białystok	29.91	28.60	−1.31

Source: own elaboration based on the Urban Atlas.

In the case of the city of Łódź, it is worth noting that it recorded a growth of the area of green spaces in the total area of the city in each of the development intensity zones. The value obtained for the low intensity zone in Łódź—1.28 % (375.02 ha)—is a clear outlier, which also translates into a total positive balance for the zone in all post-industrial cities. An increase in green spaces in the low intensity development zone was also achieved in Szczecin (0.44 %, i.e., 132.29 ha), Warsaw (0.11 %, i.e., 56.38 ha) and Kraków (0.10 %, i.e., 32.05 ha). The remaining post-industrial cities saw a decline in the area of green spaces in the said zone, with the largest drop in Poznań (-0.46 %, i.e., −120.42 ha).

In the medium intensity development zone, an increase in the area of green spaces in the total city area was recorded in Łódź (0.79 %, i.e., 231.02 ha) and Szczecin (0.17 %, i.e., 50.95 ha). The remaining post-industrial cities in this zone saw a decline in green spaces, with the largest cut in Bydgoszcz (-0.87 %, or −152.24 ha).

In the high intensity development zone, only Łódź (0.03 %, i.e., 9.41 ha) and Wrocław (0.001 %, i.e., 0.21 ha) experienced a gain in the area of green spaces in the total city area. For the remaining cities, a decrease in the area of green spaces was found. It is worth mentioning that the results obtained from the analysis of this zone do not show outliers and remain at similar levels, as can be seen in Fig. 5.

Considering the spatial distribution of changes in green spaces (Fig. 6), it was observed that, in many cases, losses of these spaces are located where linear structures are constructed (Fig. 7C), mainly transport infrastructure (roads, railways, and tramways). This is mainly taking place in cities such as Gdańsk (construction of the S6 road and Al. Macieja Płażyńskiego), Łódź (construction of the A1 motorway), Warsaw (construction of S2, S8, and No. 61 roads), Gliwice (construction of the A1 motorway and road No. 902), Zabrze (construction of road No. 902), and Kraków (for new tram lines). In the case of Gliwice and Zabrze, these losses account for the vast majority of all changes in these cities.

The areas where green spaces changed took the form of both single, small-scale structures (Fig. 7B), as well as large complexes (Fig. 7A). Loss of green spaces in large-scale sites was observed in five post-industrial cities. Gdańsk expanded its harbour, Bydgoszcz the warehouse halls of Panattoni Park Bydgoszcz and the Nitro Chem plant, in Olsztyn the loss occurred within the airport, while in Katowice and Kraków there was an addition to the existing housing stock. Newly created, large-scale green spaces can be observed primarily in four post-industrial cities. They are mainly intended for family allotment gardens (Gdańsk), city parks (Łódź), or are the result of a change in area classification from agricultural, semi-natural areas, wetlands to forests (Warsaw, Łódź, Kraków).

Interestingly, in Szczecin, Poznań and Wrocław, the observed changes showed a tendency to disperse over the area of entire cities; thus, larger complexes cannot be indicated. The remaining developments not identified above represent scattered small-scale changes resulting from individual investments, which cannot be listed in full due to their large number.

3.3. Analysis of the directions of green space transformations in post-industrial cities

The authors chose a Sankey diagram to present data showing the direction in which green spaces changed between 2006 and 2018 (Fig. 8).

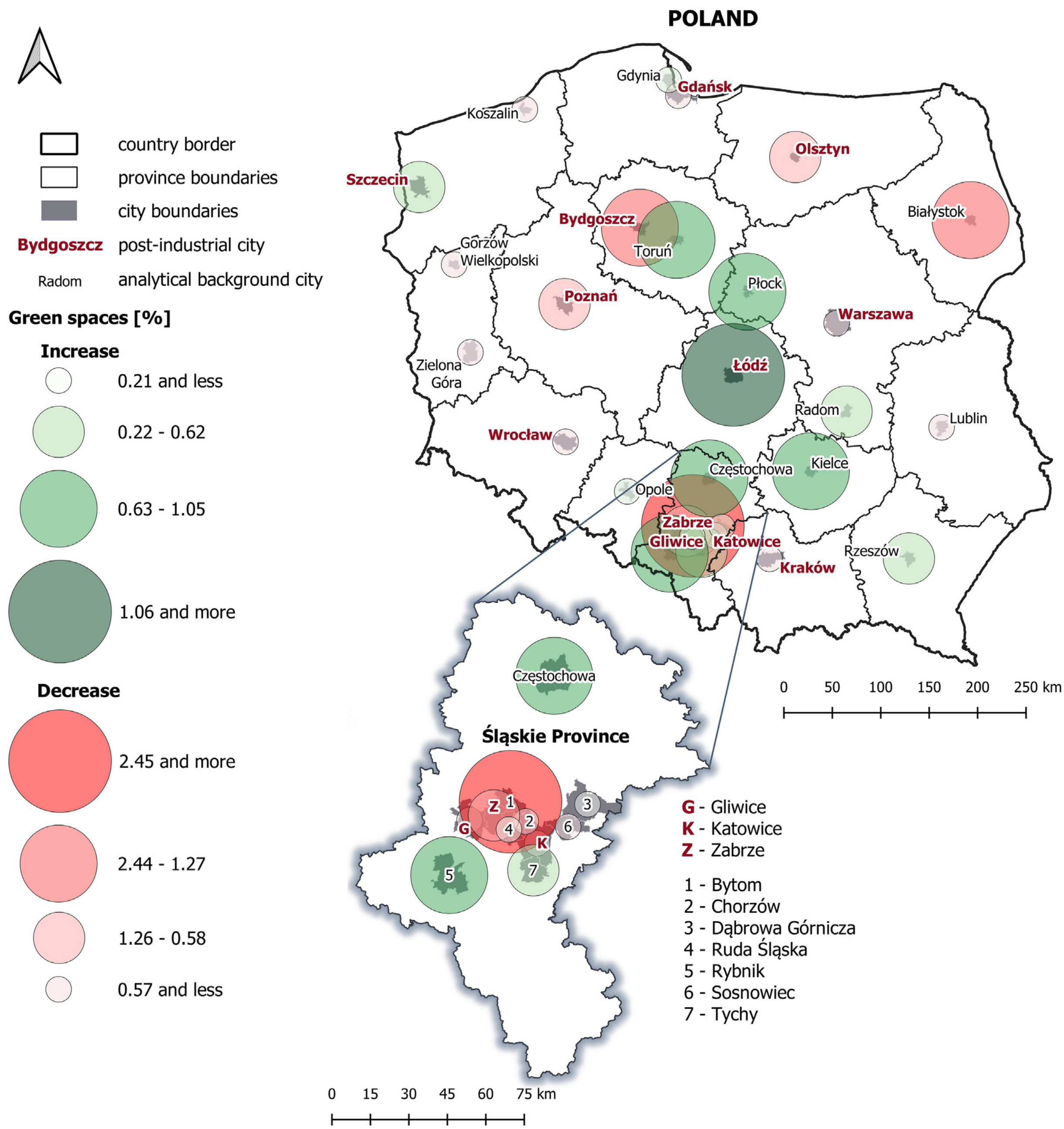
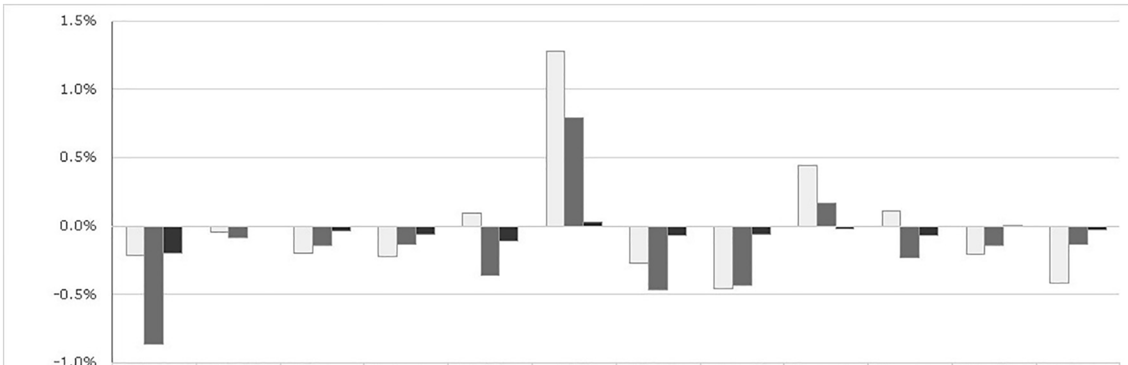


Fig. 4. Change in the share of green spaces in total city area from 2006 to 2018. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 8 depicts only those green spaces which were transformed in the studied period. Of all green spaces from 2006, only 2.62 % were transformed into other land cover categories, losing their green character. In 2018, only 2.28 % of all green spaces were created by transformation as a result of land cover changes. Nearly 97 % of green spaces were not transformed at all.

When analysing the growth of green spaces in post-industrial cities, it should be noted that as much as 87.79 % of the land that emerged as green spaces in 2018 was agricultural in 2006. The transformation of agricultural areas into green spaces is the main direction for the creation of green spaces in post-industrial cities. These areas require less technical and economic input due to their semi-natural character. This change is secondary succession. In second place, but with a much smaller percentage (7.01 %) were green spaces created from mine, dump, and construction sites, i.e., land used in industry. The creation of urban green spaces in the area of mine, dump, and construction sites is definitely more costly and time-consuming. Industrial units made up 3.45 % of green spaces. The other categories i.e., urban fabric, transport units, water and other natural areas showed a marginal share of newly created green spaces (1.75 % in total).

In terms of the loss of green spaces in post-industrial cities, the dominant trend between 2006 and 2018 was the creation of industrial units (24.80 %) on sites previously classified as green spaces. During the period under review, newly created urban fabric accounted for 23.53 % of the loss of green spaces. Elsewhere, mine, dump, and construction sites and transport units accounted for 17.40 % and 16.29 % of the loss of green spaces, respectively. Newly created agricultural areas (11.09 %) and water and other natural areas (6.89 %) accounted for the smallest share of green space loss.



	Bydgoszcz	Gdańsk	Gliwice	Katowice	Kraków	Łódź	Olsztyn	Poznań	Szczecin	Warszawa	Wrocław	Zabrze
□LOW	-0.21%	-0.04%	-0.20%	-0.22%	0.10%	1.28%	-0.27%	-0.46%	0.44%	0.11%	-0.20%	-0.42%
■MEDIUM	-0.87%	-0.09%	-0.14%	-0.14%	-0.36%	0.79%	-0.46%	-0.43%	0.17%	-0.23%	-0.15%	-0.14%
■HIGH	-0.20%	0.00%	-0.04%	-0.06%	-0.11%	0.03%	-0.06%	-0.06%	-0.02%	-0.07%	0.00%	-0.03%

Fig. 5. Change in the share of green spaces in the total area of post-industrial cities by development intensity zone between 2006 and 2018.

4. Discussion

4.1. The impact of green spaces on shaping green urban resilience in post-industrial cities

The urban system, which consists of many interdependent elements such as space, environment, and people, has been adopted as the basic unit in resilience research (Berry, 1964). Together, these components form a functionally coherent whole (Walker et al., 2004; Desouza and Flanery, 2013) that should be prepared for all sorts of negative stimuli flowing to the inside of the urban system. In research on the concept of urban resilience, Meerow and Baud (2012) single out urban infrastructure as one of the aspects that create urban resilience. In addition to buildings, transport infrastructure, and utilities, and Dicken (2007) include green spaces in this subsystem, thus indicating that they are an important element in shaping urban resilience.

Godschalk (2003) argues that environmentally resilient areas, which include green spaces, should be diverse, redundant, autonomous, interdependent, adaptable, and collaborative. The characteristics listed are attributes of green resilience. Green spaces in their structure are diverse (they are formed by forests, shrubs, grasses etc., that is elements with different resilience potential) and autonomous (they can function without the involvement of human activities) (Trovato, 2021; Zuniga-Teran et al., 2020). In addition, green spaces are often a field for cooperation between residents and municipal authorities, thus fulfilling the feature of collaboration (Krekel et al., 2016; Guo et al., 2019). In the light of this study, the area of green spaces in post-industrial cities ranges from around 10 % to around 50 % of the total city area. Thus, in some cases, it can be pointed out that green spaces fulfil the feature of redundancy, which is extremely important from the point of view of shaping urban resilience, since a small decrease in the area of green spaces will not adversely affect resilience. It can be concluded that green spaces in the city meet all the characteristics required to classify them as areas responsible for shaping resilience, including the creation of green resilience.

The positive impact of green spaces on forming urban resilience has been offset over the years by industrial areas, which by their nature can be described in opposite terms. Industrial sites, which are often private, are not a field for cooperation, but merely a place for business. The interdependence of industrial areas focuses mainly on industrial location factors, such as the orography of the area, and not on the broad interdependence between urban subsystems (Shah et al., 2021). Thus, taking that into account industrial areas are not a resilient component of the urban system.

Importantly, the role of green spaces in post-industrial cities is very diverse however, the cleansing and reclaiming function needs to be emphasised as it contributes to alleviating the negative effects of long-lasting industrial activity which was well documented in previous studies. Kurade et al. (2021) calls this type of green space function on brownfield sites a green biotechnology tool for sustainable rehabilitation of the environment. Properly planned reclamation of degraded brownfield sites is the first step in efforts to restore their usage potential (Ashraf et al., 2019). Combining design work on green spaces with its practical implementation can bring economic benefits (e.g., attracting new investors), social benefits (e.g., increased quality of public spaces in the city), as well as natural benefits (e.g., increased environmental benefit stream related to ecosystem services) (Kazak, 2018).

4.2. Land cover transformation trends in post-industrial cities

The increase in the area of land designated for green spaces in 14 of the 32 cities analysed, including two post-industrial cities (Łódź and Szczecin), certainly had a positive role in the process of shaping local microclimate and urban resilience. When boosting their green resilience, the analysed post-industrial cities first created green spaces on agricultural land. This is primarily due to forest succession in agricultural areas and the fact that land adjacent to urban boundaries is often abandoned, which was well documented in previous studies, e.g. Czesak et al. (2021). Thus, these cities used the least costly way of creating green spaces. Creating green spaces in semi-natural areas is a far more cost-effective solution than interfering with the urban fabric to develop them. This is also apparent from the research carried out. High-intensity development areas are characterised by the smallest increases in green space firstly due to spatial constraints, and secondly due to the cost-intensity of green investments in city centres (Noszczyk et al., 2022).

One of the best examples of post-industrial cities developing according to the principles of green urban resilience is the of Łódź. Green spaces, which already have a significant share in the city's land cover, are steadily being added. Examples include the new city parks in Bałuty and Widzew districts. In order to create more green spaces, Łódź authorities are amending planning and revitalisation documents by withdrawing from the sale of land for, e.g., residential purposes.

One remedy for the recovery of post-industrial cities is the revitalisation process, which in its essence is supposed to bring a degraded urban area out of crisis (Starczewski et al., 2022). Revitalisation guided by green spaces can be another element creating

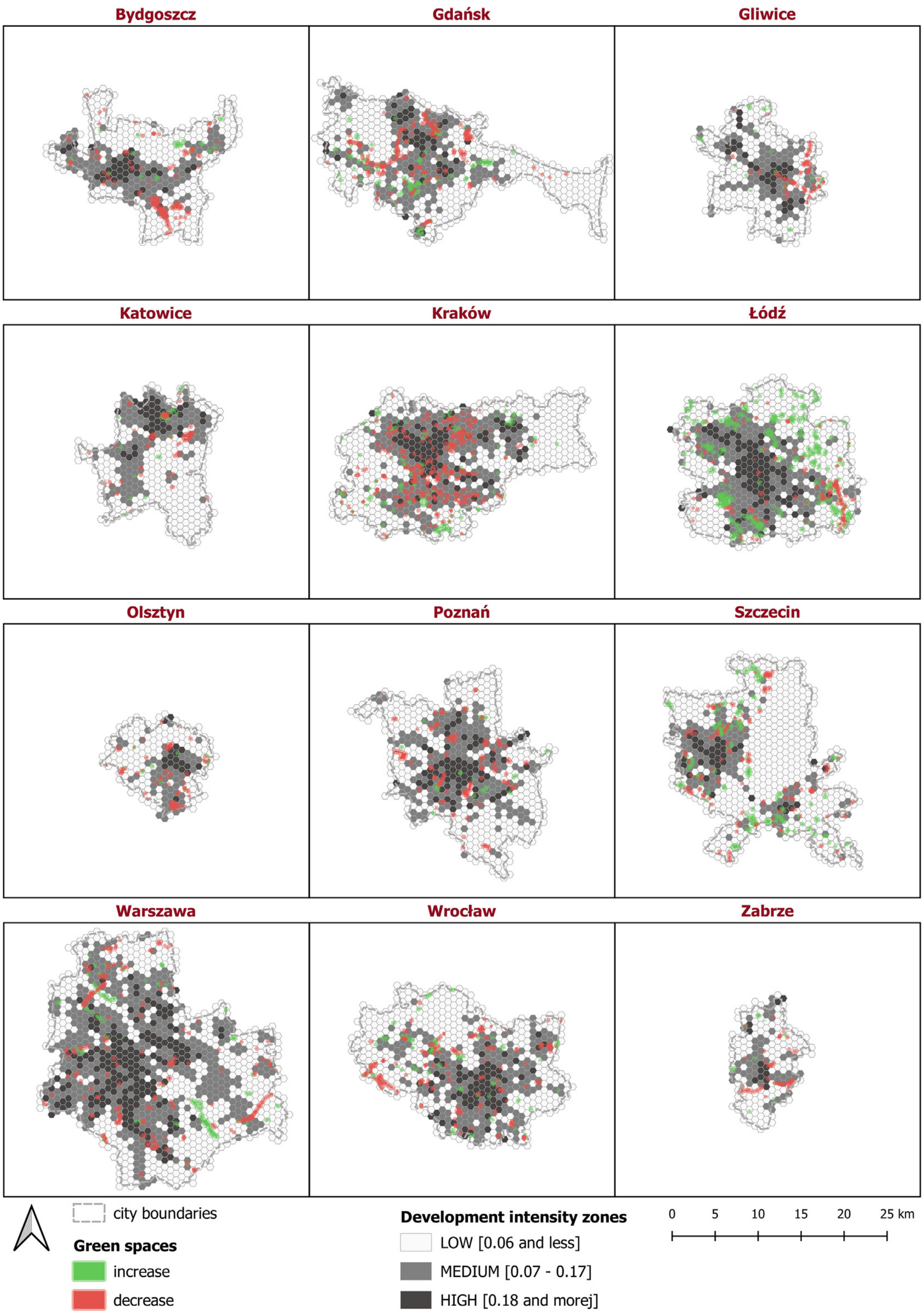


Fig. 6. Spatial distribution of changes in the area of green spaces in post-industrial cities by development intensity zone between 2006 and 2018. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

urban resilience, as exemplified by the Pettinissa greenway in Reggio Calabria, Italy, where according to Quattrone (2017), the whole revitalisation premise was based on different types of green spaces. Revitalisation based on strategies to introduce green spaces results in a strengthened identity of place and an emotional connection of residents to the region. Creating a unique landscape based on its industrial character can also affect the quality of urban life and the biodiversity of natural spaces in line with sustainable development policies (Erixon et al., 2013).

The ways in which post-industrial areas can be shaped vary and depend, among other things, on the size of the area and the financial resources available. There is also a wide range of possibilities to develop these areas with greenery, which contributes to the development of brownfield sites and activates the development

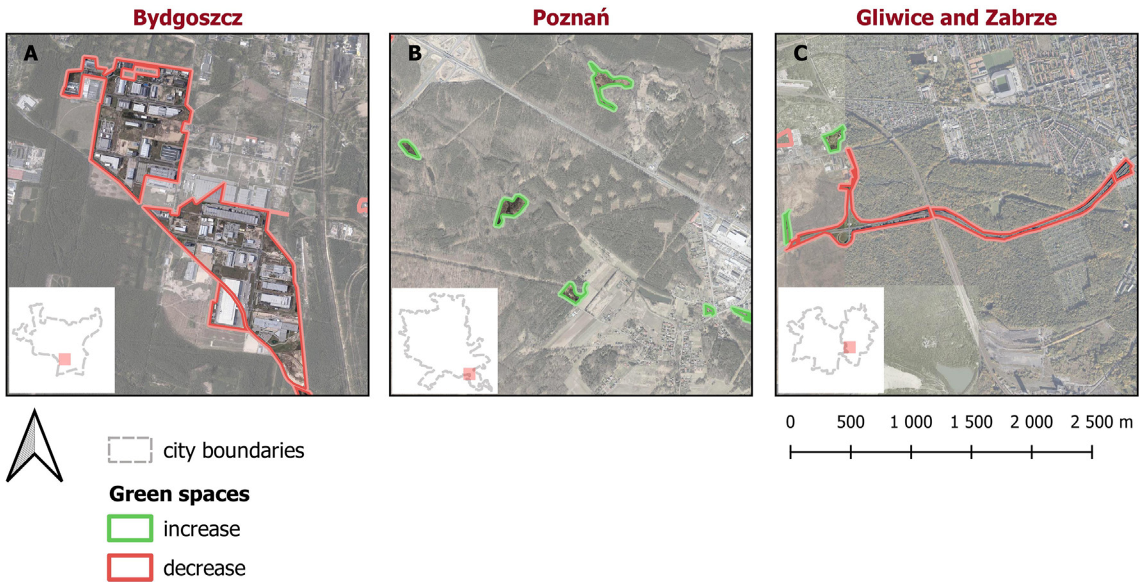


Fig. 7. Types of green space changes. A: clustered large-area changes, B: scattered small-area changes, C: linear changes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

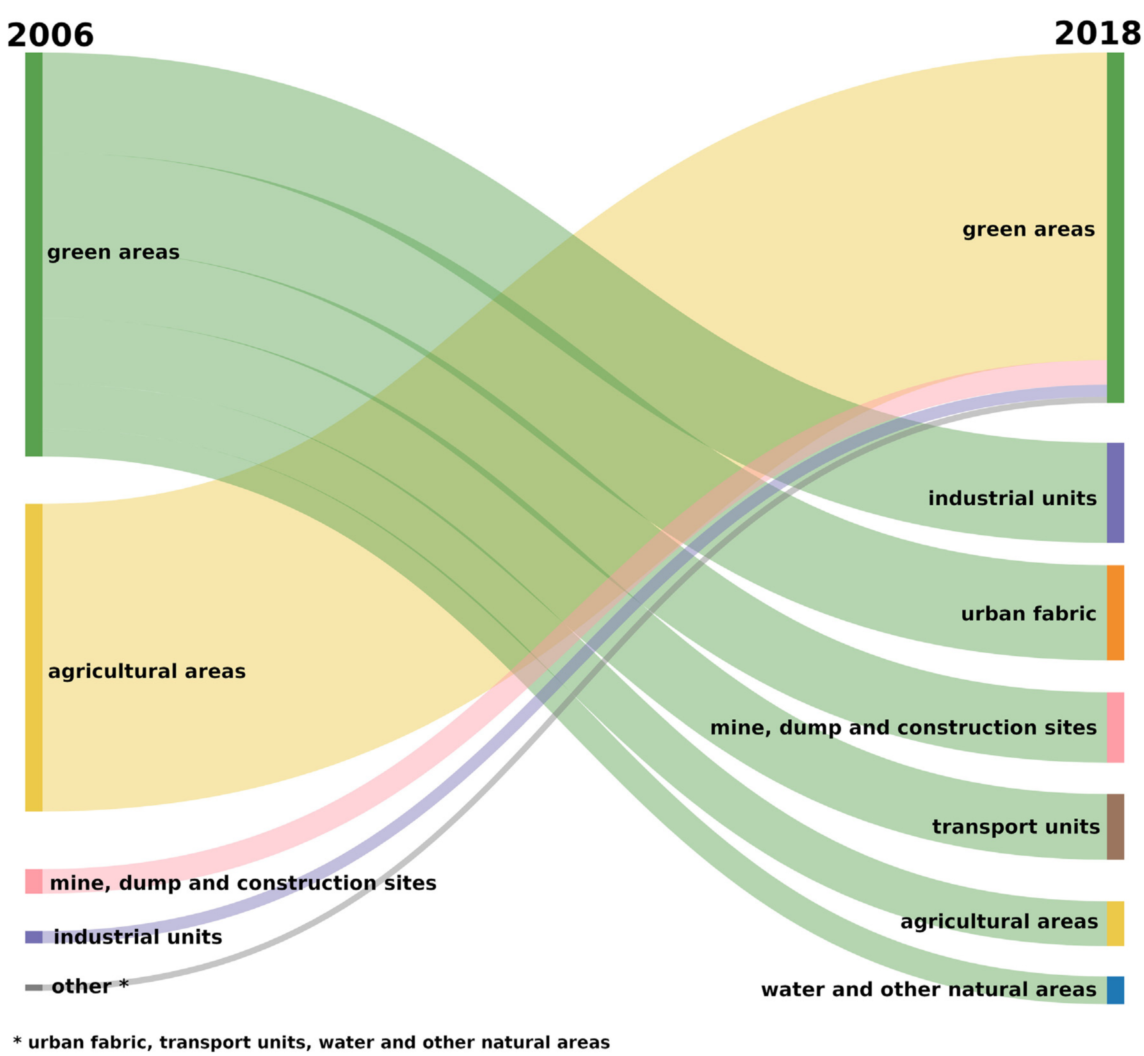


Fig. 8. Directions of green space transformations in post-industrial cities in the years 2006–2018. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of tourism. This often translates into profit and the promotion of the city. Newly designed greenery helps revitalisation without negating the industrial past, as well as develops new ecosystems in areas that have been deprived of them through industry. Wilkosz-Mamcarczyk (2018) points out that thoughtful design solutions using 'green revitalisation' are increasingly being seen in the Silesia (Poland) area. These are not yet applied on such an extensive scale as in the case of Emscher Park, Germany; however, further new projects give hope that many spatial solutions based on greenery may be developed in Silesia in the future.

Meerow and Newell's (2017) research demonstrates that city planning based on green spaces and green infrastructure can lead to increased urban resilience. Their testing ground was Detroit, an industrial city that has been regaining socio-economic stability after an economic crisis through systemic revitalisation, including that of green spaces (Sattler, 2013). The space in the city was dominated by industrial areas (mainly automotive industry) that negatively impacted urban resilience. The process of de-industrialisation and inappropriate spatial policies led to the city's decline (Leandro-Reguillo and Stuart, 2021). Meerow and Newel (2017) also used GIS methodology through which they indicated that concentrating green infrastructure activities, of which green spaces are a part, in specific locations will lead to a healthier city, boost its resilience and mitigate the negative impact of derelict brownfield sites on the urban fabric.

4.3. Heritage of post-industrial cities

It should not be forgotten that brownfield sites, together with their infrastructure, buildings, often constitute cultural heritage (Rogatka and Ciesiółka, 2016). Despite the intensive changes in land cover during the period under study, numerous traces of functional transformation and former industrial activity remained in the spatial structure of the analysed post-industrial cities, which should be considered of architectural and urbanistic value. For example, one of Kraków's post-industrial districts, Grzegórzki, has preserved numerous fragments of buildings that are a historical legacy and testify to its specific post-industrial character, which manifests in characteristic brick buildings. They have been revitalized and currently deliver restaurant services, they also perform tourist and recreational functions. It is an example of one of the few post-industrial districts in Kraków that, despite intensive transformation and loss of its original function, has retained numerous features alluding to its past and emphasising its unique post-industrial character. Similar examples can be found in other Polish cities: Łódź and the revitalisation of the post-industrial Księży Młyn (Cysek-Pawlak and Pabich, 2021), Gdańsk and the reuse of port infrastructure (Krośnicka et al., 2021), the revitalisation of the Old Brewery in Poznań together with the reclamation of Park Dąbrowskiego (Pazdur-Czarnowska and Yatsiuk, 2021). In addition, new and innovative forms of green spaces, such as roof gardens (intensive and extensive), vertical walls, or pocket gardens can emerge during the process of revitalising the post-industrial fabric and also during the process of preserving the post-industrial heritage, clearly enhancing green urban resilience (Rosso et al., 2022; Agnoletti et al., 2022).

Some of the buildings and housing complexes developed in the 21st century in Kraków's post-industrial areas are located in dense urban fabric and do not have any spatial and functional connections to green spaces, and thus benefit from the gains associated with green urban resilience to a very limited extent. Negative opinions about 'concretosis' in Poland emerging in research and pop culture have led to some changes in this negative trend. Gyurkovich and Gyurkovich's (2021) study of Polish multifamily residential architecture between 2000 and 2020 is optimistic and shows that, in recent years, developers have started to pay more attention to the quality of buildings and the surrounding space, including, above all, green spaces.

5. Conclusions

The concept of urban resilience, with a particular focus on its green component, is gaining popularity in the contemporary shaping of urban centres. Green space functions are particularly important in cities with a dominant role of industry, which for many years has had a negative impact on urban resilience. In order to regenerate and develop green urban resilience, it is necessary to minimise the past and current impact of urban 'weak points', such as brownfield sites, by establishing new green spaces in post-industrial cities. This treatment improves both local and supra-local conditions.

The following conclusions emerge from the research: (a) The general trend in Poland's largest cities is that green spaces are growing (excluding post-industrial cities), whereas in post-industrial cities (with the exception of Łódź and Szczecin), the exact opposite is observed; (b) The greatest losses of green spaces are seen above all in parts of post-industrial cities with medium and high building intensity – it is here that the intensification of construction activity (e.g., extension of transport systems) is observed. Only in the outer zones, with low intensity development, was an increase in green spaces noted; (c) It was found that the predominant direction of green space acquisition in cities has been the change of agricultural areas into green spaces. Conversely, the main direction of loss of green space in post-industrial cities has been the creation of new industrial units and the expansion of the urban fabric, which, as a rule, consumes much greenery. In post-industrial cities, only a marginal percentage of green spaces emerge from industrial areas.

Unfortunately, post-industrial cities do not develop their urban resilience on the basis of green urban resilience. What is worse, they create new industrial units using green spaces. The worrying trend of a decline in the proportion of green spaces in post-industrial cities may have important ramifications. In times of climate crisis, the environment needs a shift away from rapid urbanisation and the development of urban habitats towards creating sustainable, resilient, and green cities. This direction is all the more welcome in post-industrial cities, which have had a negative impact on humans and the planet for decades. They appear to be one of the weakest links in building the global urban resilience chain, and therefore action needs to be taken as soon as possible to change urban policies with a focus on restructuring and green revitalisation, in order to promote green urban resilience solutions. Therefore, the results of this study can be used as a basis for making recommendations for urban policies, with a view to their application in urban practice by local governments and stakeholders.

CRediT authorship contribution statement

Tomasz Starczewski: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing, Resources, Formal analysis. **Krzysztof Rogatka:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Resources, Formal analysis. **Anita Kukulska-Kozieł:** Methodology, Formal analysis, Visualization, Conceptualization, Software, Writing - original draft, Writing - review & editing. **Tomasz Noszczyk:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Formal analysis. **Katarzyna Cegielska:** Formal analysis, Methodology, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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