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GREEN INFRASTRUCTURE IN PERI-URBAN LANDSCAPES – A CASE STUDY FROM POLISH METROPOLITAN AREAS[1]

Key words: green infrastructure, metropolitan area, peri-urban landscapes, farms, farmland, forest land, protected areas, municipalities, Poland

ABSTRACT. Research literature emphasizes that the dynamic development of peri-urban areas more frequently results in changes in green infrastructure potential, manifested in the gradual limitation of open space, a decrease in its biodiversity and a loss of natural and cultural values. The aim of the study is to identify and evaluate the changes in the structure of the green infrastructure of selected urban and peri-urban areas in Poland. To accomplish this aim, the authors stated a hypothesis that changes in green infrastructure potential depend on the location of municipalities in relation to dynamically growing cities. The research conducted partially confirmed the research hypothesis stated in the study. In core cities and municipalities, located up to 25 km from cities, the decrease in agricultural areas is faster at a statistically significant level and in cities the value of the indicator illustrating the ratio of urban green spaces to developed areas decreases. The potential of other green infrastructure elements shows growth tendencies and is not related to location.

INTRODUCTION

Green infrastructure (GI) is promoted as an approach to respond to major urban environmental and social challenges, such as reducing the ecological footprint, improving human health and well-being and adapting to climate change [Pauleit et al. 2017]. GI has been suggested as a tool to support sustainable development by reconciling environmental preservation and other interests in landscape planning and management [Honeck et al. 2020]. Initially, GI was mainly analysed in relation to cities [Koc et al. 2017], but now, especially in Europe, more and more research is carried out in a broader territorial

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context [Sörensen et al. 2021]. It was noticed that the preservation of socially important ecosystem services provided by GI is possible only through an integrated approach to land management and careful strategic spatial planning throughout the EU [Hermoso et al. 2020]. In research on the function and "valuation" of green infrastructure, a special place is occupied by peri-urban areas, which serve as a link between rural and urban areas [Yacamán Ochoa et al. 2020].

Scholarly literature emphasizes that peri-urban areas are highly dynamic and, unfortunately, they result in a loss of open space, biodiversity, amenities and cultural values amongst other ecosystem services [Roy et al. 2014]. In Europe, peri-urban areas are growing four times faster than urban areas and are expected to double in the next 30 to 50 years [Piorr et al. 2011]. This justifies the need for research in these areas. Rapid and uncorrelated changes in the area of GI occur mainly in countries with a relatively liberal land policy and poor spatial planning. According to some authors, this problem applies in particular to Poland [Krzyk et al. 2013, Śleszyński 2015]. In a process of unsustainable urban expansion, the demand for urban growth and the increase in road infrastructure tend to predominate. This reduces the availability of open spaces and access to them, which are essential components for maintaining the health and wellbeing of urban residents, as these spaces provide multiple environmental and social benefits [Yacamán Ochoa et al. 2020]. Population aggregation and built-up area expansion, caused by urbanization, can have significant impacts on the supply and distribution of crucial ecosystem services [Wang et al. 2020]. The demand of urban land and the concentration of the urban population in urban and peri-urban areas are increasing over periods bringing massive changes in the loss of various natural capitals [Degórska 2017].

Based on the above-mentioned relations, it is hypothesized that the changes in the potential of green infrastructure will depend on the location of municipalities in relation to dynamically developing core cities. In the core cities and municipalities directly bordering with them, the share of areas classified as green infrastructure will decrease faster than in other municipalities. The aim of the study is to characterize and evaluate changes in green infrastructure in selected Polish metropolitan areas. The study both presents and assesses the spatial differentiation of indicators characterizing the distribution of selected elements of green infrastructure.

MATERIAL AND RESEARCH METHODS

The study used secondary data sources, including data from Statistics Poland (Polish: GUS) and the Head Office of Geodesy and Cartography (GUGIK), as well as research literature. The basis for analyses was a literature review, which was conducted in the second half of 2021. Based on it, indicators that quantitatively characterize green infrastructure elements in municipalities were selected. The variety of the temporal extent of selected quantitative characteristics (indicators) was dictated by the need to illustrate changes in a green infrastructure system over as long a period as possible. The spatial extent of the analyses, conducted as part of the study, covered six purposively sampled Polish metropolitan areas, namely: Warsaw MA, Krakow MA, Wrocław MA, Poznań MA, the Tricity MA (covering Gdańsk, Gdynia and Sopot) and Lublin MA. The areas were selected so as to best reflect variation in the environmental and economic (including urban) conditions characterizing different parts of Poland. The principles underlying the selection of metropolitan areas result from the assumptions taken from the research project entitled: "Urban agriculture as a challenge for the sustainable development of metropolitan areas in Poland: socio-economic, environmental, and planning-related aspects". The delimitation of these areas was based on development documents and strategies adopted by the authorities of regional self-government units. Accordingly, the analyses covered 279 municipalities, including 6 urban ones classified as the cores of the analyzed metropolises, and 273 municipalities constituting their immediate environment (Figure 1).

In order to verify how distances from the analyzed metropolitan cores impact the condition and change of green infrastructure potential, four municipality zones located within different distances from such core cities were identified: zone 1 (up to 25 km), zone 2 (from 25 to 35 km), zone 3 (from 35 to 45 km) and zone 4 (over 45 km) [Degórska 2017]. Particular attention was given to changes in zone 1, made up of units located up

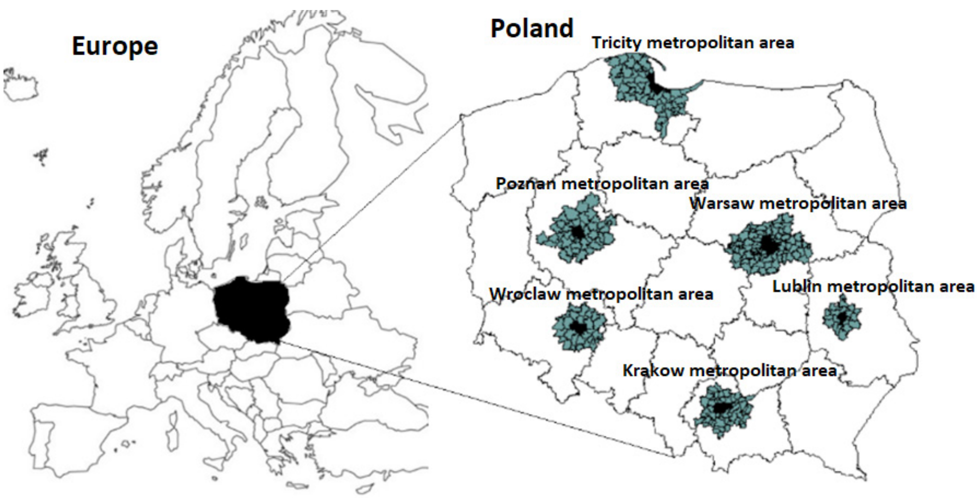

Figure 1. Metropolitan areas that qualified for the study
Source: own elaboration

to 25 km from the center of the analyzed metropolitan areas, since these areas border cities, and thus are often treated as their green rings [Cieszewska 2019]. An additional analysis was conducted for smaller towns located in individual metropolitan areas. This is because these units represent a sort of island, where urbanization processes run differently compared to neighboring rural areas. Because of that, they can distort the analysis of the impact of distance on the condition and potential of green infrastructure.

Both descriptive methods and quantitative methods were used in the study. The impact of the distance from the core on the condition of green infrastructure elements was verified using the Kruskal-Wallis test by ranks, which represents a non-parametric alternative to the ANOVA test. In the case of the rejection of the null hypothesis by the Kruskal–Wallis test, Dunn's post-hoc test, which is applied for comparisons across groups, was additionally used. The test was used to determine which groups of municipalities (located within different distances from metropolitan cores) differ from each other in a significant way. A statistical analysis of the study results was performed using the computer program STATISTICA 13.

THE CONCEPT AND GENESIS OF GREEN INFRASTRUCTURE

"Green infrastructure" is a term that has received great attention in land conservation, landscape design and land development since the end of the last century. Even though its historical roots go back to the 19th and 20th centuries, the GI concept is widely considered as new [Monteiro et al. 2020]. It is noted in scientific literature that the term GI is derived from the notion of the ecological network and the idea of greenways, in which the central issue is "connectivity". It is this attribute, as well as the connection with the concept of "ecosystem services" and "multifunctionality", that are the key elements of the concept of green infrastructure [Szulczewska 2018]. These attributes are mentioned in most GI definitions [Szulczewska 2018, Parker et al. 2019]. For example, Carol Kambites and Stephen Owen [2006] report that "Green infrastructure is taken ... to encompass connected networks of multifunctional, predominantly unbuilt, space that supports both ecological and social activities and processes". The GI concept seeks to identify and prioritize areas of high ecological value for wildlife and people and improve the integration of natural values in landscape planning decisions [Honeck et al. 2020]. Ecosystem functions are strongly influenced by land cover and land use changes. Such transformations impact the capacity of ecosystems to provide goods and services to human society [Burkhard et al. 2012]. The supply of ecosystem services is based on specific ecosystem service potentials and additional system inputs converging in an ecosystem service flow to societies [Burkhard et al. 2014].

Scholarly literature emphasizes that the assessment of assets and potentials of green infrastructure is a considerable challenge for scientists and practitioners [Wright 2011]. Barbara Szulczewska [2019] notes that this potential can be measured by taking advantage of land cover and land use data. A comparison of individual indicators in space can help to understand where immediate opportunities exist for GI implementation and which regions have lower natural capital and protected areas for GI establishment.

RESEARCH FINDINGS

A green infrastructure system has various definitions and there is a multitude of classifications and interpretations of this concept [Bruszewska 2013]. Initially, green infrastructure elements, as listed by scientists and experts, mainly included public parks, green roofs, street trees and municipal forests. Nowadays, however, a green infrastructure system is more and more often extended to include agricultural areas [Rolf et al. 2018]. In many metropolitan areas and cities, the share of agricultural areas is higher than that of urbanized areas [Pölling et al. 2016]. This also applies to the Polish metropolitan areas under analysis (Table 1).

Table 1. Share of farms' agricultural areas in total area of the municipalities within metropolitan areas

Indicators	Poland	Kruskal Wallis test (p)	Value of the indicator depending on the location					
			core city	towns in MA	zone 1 < 25 km	zone 2 25-35 km	zone 3 35-45 km	zone 4 > 45 km
Share of farm' agricultural areas in the total area in 1996 [%]	59.1	20.7 $p = 0.0009$	36.2	29.1*	67.2	63.0	63.7	62.6
Share of farm' agricultural areas in the total area in 2010 [%]	49.6	37.9 $p = 0 .0000$	29.0	27.5*	54.8	52.8	55.0	54.3
Change in the share of farm' agricultural areas in the years 1996-2010 [p.p.]	-9.5	16.43 $p = 0.0042$	-7.2	-1.6	-12.4*	-10.2	-8.7	-8.3

* Based on Dunn's test for pairwise multiple comparisons it was found that the medium rank size of a group being analyzed differs significantly from at least one of the groups ($p < 0.05$)
Source: own elaboration

According to data from 2010, both core cities and peri- urban areas had a relatively high share of agricultural areas and, in municipalities located outside these cities, the percentage of agricultural areas was higher than the country's average. The research conducted showed that the period 1996-2010 saw a significant decrease in agricultural areas, with the spatial variation in the observed changes being statistically significant. The biggest loss of agricultural areas was observed in zone 1, i.e. up to 25 km, and as the distance from the core cities grew, the share of agricultural areas decreased at a much slower rate.

Another important green infrastructure element today is forest land. However, its share in the metropolitan areas being analyzed is markedly lower than the country's average and stands at around 11% in core cities and 24.2% in zone 4, which comprises units located over 45 km from core cities. The research results show that there is a statistically significant variation in that regard and forest cover increases as the distance from the city increases. The analyses also showed that the period 2002-2019 saw an increase in the share of forests in the total area of the country, but the variation in these changes was not statistically significant (Table 2).

Another important element of a green infrastructure system is legally protected areas, characterized by natural and biological diversity. Analyzing the share of such areas (reserves and landscape parks, excluding Natura 2000 sites) in the total area of municipalities, it was found that smaller municipal entities had the largest share of such areas. This is because, in such towns forest areas, which frequently hold the status of protected areas, represent a relatively large percentage of the total area. The analyses did

Table 2. Share of forests in the total area of municipalities within metropolitan areas

Indicators	Poland	Kruskal Wallis test (p)	Value of the indicator depending on the location					
			core city	towns in MA	zone 1 < 25 km	zone 2 25-35 km	zone 3 35-45 km	zone 4 > 45 km
Forest cover 2002 [%]	28.5	17.81 $p = 0.0032$	11.0	24.9	15.2*	22.0	21.9	23.5
Forest cover 2019 [%]	29.6	19.44 $p = 0.0016$	11.4	25.4	15.5*	22.3	22.4	24.2
Change in forest cover in the years 2002-2019 [p.p.]	+1.1	6.59 $p = 0.2529$	+0.4	+0.5	+0.3	+0.3	+0.5	+0.7

* Based on Dunn's test for pairwise multiple comparisons it was found that the medium rank size of a group being analyzed differs significantly from at least one of the groups ($p < 0.05$)
Source: own elaboration

Table 3. Share of legally protected areas (excluding NATURA 2000 sites) in municipalities comprising metropolitan areas

Indicators	Poland	Kruskal Wallis test (p)	Value of the indicator depending on the location					
			core city	towns in MA	zone 1 < 25 km	zone 2 25-35 km	zone 3 35-45 km	zone 4 > 45 km
Share of legally protected areas 1997 [%]	30.0	0.750 $p = 0.9801$	16.7	33.3	23.1	21.7	30.0	28.1
Share of legally protected areas 2019 [%]	32.3	0.65 $p = 0.9856$	16.1	36.6	24.6	22.5	30.6	30.0
Change in the indicator in the years 1997-2019 [p.p]	+2.3	1.51 $p = 0.9111$	-0.6	+3.3	+1.5	+0.8	+0.6	+1.9

Source: own elaboration

not show any statistically significant differences in the spatial distribution. However, in municipalities located further away from core cities, i.e. in zones 3 and 4 (over 35 km), the share of such areas is slightly higher than in zone 1 and 2 (up to 35 km). No significant differences with respect to changes in the share of legally protected areas in the country's total area were observed in the years 1997-2019 (Table 3).

An element serving an important function for a green infrastructure system, especially in densely populated areas, is parks and estate green spaces. They can mostly be found in agglomerations, hence the highest values of the indicator of urban green spaces per 100 ha of built-up areas were observed in core cities and other (smaller) towns located within the metropolitan areas under analysis (Table 4).

However, it is worth noting that the period 2004-2019 saw a clear decrease in this indicator, which should be considered a negative trend. This is because the increase in built-up areas is accompanied by less than a proportional increase in urban green spaces. The analyses showed that the indicator illustrating the ratio of estate green spaces to built-up areas is statistically significantly lower in municipalities located further away from cities, but these are areas where the indicator showed a positive growth trend.

Table 4. Indicator of urban green spaces per 100 ha of built-up areas

Indicators	Poland	Kruskal Wallis test (p)	Value of the indicator depending on the location					
			core city	towns in MA	zone 1 < 25 km	zone 2 25-35 km	zone 3 35-45 km	zone 4 > 45 km
Parks, green areas and estate green spaces per 100 ha of built-up areas in 2004	3.6	74.18 $p = 0.0000$	11.8*	6.7*	1.3	1.6	2.3	1.9
Parks, green areas and estate green spaces per 100 ha of built-up areas in 2019	3.6	67.65 $p = 0.0000$	10.5*	6.1*	2.4	2.3	2.7	1.9
Change in the indicator in the years 2004 -2019 (parks, green areas and estate green spaces per 100 ha of built-up areas)	0.0	19.37 $p = 0.0016$	-1.3	-0.6	+1.1*	+0.7	+0.4	0.0

* Based on Dunn's test for pairwise multiple comparisons it was found that the medium rank size of a group being analyzed differs significantly from at least one of the groups ($p < 0.05$)

Source: own elaboration

DISCUSSION

The analyses showed that green infrastructure systems located within Polish metropolitan areas, similarly to European ones, are characterized by a large share of agricultural areas [Cieszewska 2019, Rolf et al. 2018]. This is because most of the cities analyzed were located in areas with very good conditions for agricultural production, with farmland prevailing over other land uses to date. In core cities and municipalities that directly border them, the share of agricultural areas is 29% and 54.8%, respectively. Due to their huge spatial importance, Rolf et al. (2018) refer to them as "an Elephant in the Room of Urban Green Infrastructure". Likewise, Katarzyna Bruszewska [2013] notes that agricultural areas represent an important, yet often underestimated, or even ignored, green infrastructure element. Urban and peri-urban agricultural areas represent linkage to other green infrastructure elements (ensuring connectivity) and serve numerous economic, environmental and social functions that are highly valued by residents [Zasada 2011]. However, intensive urbanization processes in recent decades have resulted in a gradual decrease in such agricultural areas. Increase in dispersed development, as well as other factors, including the impact of an attractive urban labor market, speculations, etc., additionally accelerate the processes of farmland abandonment [Sroka et al. 2019]. In Polish metropolitan areas, an increasing decrease in agricultural areas is mainly observed in core cities and municipalities located in zone 1, i.e. up to 25 km from municipal entities of this type.

Another very important green infrastructure element is forest land. Its share in cores and municipalities within zone 1 (up to 25 km) is relatively small and accounts for 11% and 15%, respectively. The share of forest land is, thus, comparable e.g., to the situation around London (around 13%) and significantly lower than e.g., in Paris's external zone (around 29%) [Cieszewska 2019]. Despite high urbanization pressure, both in cities and municipalities located in their immediate vicinity, the share of forests in the total area of the analyzed areas shows a very positive growth trend. Thus, it seems that the provisions of spatial planning and management act, as well as those of the act on the protection of farmland and forest land, fulfill their tasks in that respect [Ciesielska, Cesielski 2017]. Although the lowest share of farmland is observed in core cities and municipalities located in zone 1 (up to 25 km), positive trends were recorded there as well. It should be noted that forest land is a highly valuable element of a green infrastructure system. It contributes to increasing biodiversity, maintaining environmental connectivity and delivers a range of services to society [O`Brien et al. 2017].

The research conducted also shows that legally protected areas account for over 25% of the total area of Polish metropolitan areas. Thus, the share of such areas in the so-called green rings of cities is close to the level in municipal entities in Europe [Cieszewska 2019]. The analyzed indicator characterizing the share of legally protected areas (excluding NATURA 2000 sites) in metropolitan area municipalities shows a relatively stable level over time and space, which means that it is not negatively impacted by urbanization processes. It should also be noted that because of a higher degree of protection, compared to e.g., farmland, such areas are not converted to other uses as intensively.

The research conducted shows an alarming phenomenon connected with the value of the indicator that quantitatively illustrates the size of urban green areas per 100 ha of built- up areas. The analysis results confirmed that the total area of parks and estate green spaces is increasing more slowly than the total area of built- up areas. Thus, there is a tendency towards a limitation of urban green areas, which results from numerous housing and road investments [Niewiadomski 2013].

SUMMARY

The green infrastructure potential in Polish metropolitan areas seems to be relatively high, compared to the European average. Agricultural areas account for by far the biggest share in the green infrastructure system (outside the metropolitan core of – over 52%), which is a result of historical developments. There is still a debate in research literature concerning the valuation of ecosystem services delivered by agricultural areas, with some authors not regarding them as green infrastructure elements. Nevertheless, in recent years more and more attention has been paid to the need to recognize previously unappreciated functions of these areas and the growing potential of urban agriculture. Protected areas constitute another very important element of a green infrastructure system. Their share outside core cities exceeds 25% and shows a modest upward tendency. Forest land also accounts for a relatively large share (around 20% on average). The spatial distribution of different elements of the green infrastructure system is varied and, as a rule, core cities and areas located up to 25 km away from them have a smaller share of forest land and legally protected areas and a markedly larger share of agricultural areas. In cities, there is also a relatively high indicator of urban green spaces compared to built-up areas. In zones located further away from cores, i.e. over 25 km, the variation in all the indicators analyzed is small and not significant statistically.

The research conducted partially confirmed the research hypothesis stated in the study, namely: changes in green infrastructure potential depend, to a large extent, on the location of municipalities in relation to dynamically developing cities. In cities and municipalities located in zone 1 (up to 25 km), there is a statistically significant decrease in potential, but it only applies to agricultural areas. Apart from huge pressure on agricultural areas, in core cities and other (smaller) towns located in metropolitan areas, the value of the indicator illustrating the ratio of urban green spaces to built-up areas decreases. This means that the latter increase faster than green spaces. However, a positive growth trend in the share of forests and areas covered by various forms of environmental protection was observed in all groups of municipalities.

However, these analyses should be considered as preliminary and requiring elaboration, especially in the context of preserving the connectivity and coherence of a green infrastructure system. An urgent need for the inventory of agricultural areas and the valuation of their functions should be a research area. It is also important to propose ways and forms of protecting agricultural areas, as over the last several years there has been a trend of excessive conversion of agricultural areas to non-agricultural uses, which significantly reduces their share in the green infrastructure system in Poland.

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ZIELONA INFRASTRUKTURA W KRAJOBRAZACH PODMIEJSKICH – STUDIUM PRZYPADKU POLSKICH OBSZARÓW METROPOLITALNYCH

Słowa kluczowe: zielona infrastruktura, obszar metropolitalny, krajobrazy podmiejskie, gospodarstwa rolne, grunty rolne, grunty leśne, obszary chronione, gminy, Polska

ABSTRAKT

W literaturze naukowej podkreśla się, że dynamiczny rozwój obszarów podmiejskich skutkuje coraz częściej zmianami w zakresie potencjału zielonej infrastruktury, co uwidacznia się stopniowym ograniczaniem otwartej przestrzeni, zmniejszeniem poziomu jej bioróżnorodności oraz zatracaniem wartości przyrodniczych i kulturowych. Celem opracowania jest identyfikacja i ocena zmian w strukturze zielonej infrastruktury wybranych obszarów miejskich i podmiejskich w Polsce. Dla realizacji przyjętego celu postawiono hipotezę, według której, zmiany w potencjale zielonej infrastruktury zależą od lokalizacji gmin w stosunku do dynamicznie rozwijających się miast. Przeprowadzone badania pozwoliły na częściowe potwierdzenie postawionej w opracowaniu hipotezy badawczej. W miastach rdzeniach oraz gminach położonych do 25 km od miast, odnotowano istotne statystycznie szybsze zmniejszanie powierzchni użytków rolnych. Ponadto, w miastach zmniejsza się wartość wskaźnika, obrazującego relację gruntów zieleni miejskiej do obszarów zabudowanych. Potencjał pozostałych elementów zielonej infrastruktury wykazuje tendencje wzrostowe i nie jest powiązany z lokalizacją.

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