

## THE IMPACT OF LARGE-SCALE LOGISTICS, COMMERCIAL AND INDUSTRIAL DEVELOPMENT ON GREEN INFRASTRUCTURE SYSTEM: A CASE STUDY OF THE WROCLAW FUNCTIONAL URBAN AREA (POLAND)

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### ABSTRACT

**Motives:** Green infrastructure (GI) in functional urban areas (FUA) plays a crucial role in supporting sustainable development by providing a variety of ecosystem services. At the same time, peri-urban zones are becoming increasingly attractive for warehouse, logistics, and commercial investments, which can lead to fragmentation of GI and a reduction in its overall functionality.

**Aim:** The aim of this study was to analyse changes in the GI system within the Wrocław FUA and its resilience to land use pressure in the years 2006, 2012, and 2018. Based on Urban Atlas data, the study assessed the extent of industrial land encroachment into the GI system within the Wrocław FUA, with particular attention to core units (K1), which form the backbone of the system, and high-risk units (Z1), which require protective measures due to their vulnerability to degradation.

**Results:** The results indicate an increase in industrial land, especially in the outer GI ring and in connector zones, with relatively limited changes in the first ring, in the immediate vicinity of the city. The observed trends emphasize the need for continuous monitoring and the integration of GI into spatial planning at the local level.

**Keywords:** peri-urban areas, green infrastructure, spatial planning, environmental resilience, industrial and commercial development, land use change

## INTRODUCTION

Peri-urban areas have become key zones for various forms of investment, mainly due to their transitional character and high development potential (La Rosa et al., 2018; Spyra et al., 2024). As a result, open rural landscapes in these areas are increasingly being transformed into residential, commercial, and industrial development zones (Biegańska et al., 2018; Kudłacz & Karwińska, 2021; Spyra et al., 2021; Tokarczyk-Dorociak et al., 2018). The attractiveness of peri-urban zones, particularly the rural–urban fringe (RUF), results primarily from lower land prices, the availability of large plots, and good transport accessibility. These factors encourage the relocation of large commercial, industrial, and logistics facilities from city centers to suburban peripheries (Dablanc et al., 2018). In recent decades, this trend has been reinforced by the evolution of global supply chains, the growth of e-commerce, and the shift from rail-based to road-based freight transport. Consequently, logistics centers, warehouses, and retail hubs have been rapidly expanding in the metropolitan fringes (de Oliveira et al., 2018; Agudo-Sierra & Llaguno-Munitxa, 2022; UNCTAD, 2021). Their location depends primarily on access to motorways and major road networks; however, they often occupy land that until recently was used for agriculture (Antalyn & Weerasinghe, 2020).

Although the development of logistics infrastructure brings economic benefits (Marr et al., 2008), it also entails unavoidable environmental consequences (Heitz et al., 2018). Large warehouses and distribution facilities, surrounded by vast impervious surfaces such as parking lots, maneuvering and loading areas, are rarely integrated with green elements (Agudo-Sierra & Llaguno-Munitxa, 2022; Niedźwiecka-Filipiak et al., 2025). Urbanization in the peri-urban zones of Polish cities is largely chaotic (Gliwka et al., 2025; Korwel-Lejkowska, 2022; Werner et al., 2022; Wolny et al., 2017). As Kudłacz and Karwińska (2021) note, it is characterized by a high degree of spatial disorganization resulting from historical, economic, social, and legal factors, including a liberal spatial planning system. Urban sprawl negatively affect local

flora and fauna, as well as the condition of entire ecosystems (Cao et al., 2024; IUCN, 2019; McDonald et al., 2013; Montaldi et al., 2024).

The scientific literature emphasizes the need to reconcile development objectives with environmental protection through better integration of spatial and environmental policies (Feltynowski, 2023; Frantzeskaki, 2019; Spyra et al., 2021; Szarek-Iwaniuk, 2021), including the strategic planning and implementation of green infrastructure (GI) (Evans et al., 2022; Honeck et al., 2020; Niedźwiecka-Filipiak et al., 2019; Rolf, 2021; Vargas-Hernández & Zdunek-Wielgołaska, 2021). According to the European Commission, GI is defined as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” (EC, 2013). The importance of green infrastructure has been strongly emphasized in European Union policies, including Green Infrastructure – Enhancing Europe’s Natural Capital (EC, 2013), the European Green Deal (EC, 2019), the EU Biodiversity Strategy for 2030 (EC, 2020), and the EU Strategy on Adaptation to Climate Change (EC, 2021). The latest Regulation on Nature Restoration (European Parliament & Council of the European Union, 2024) further obliges Member States to restore ecological connectivity and ecosystem integrity, including in functional urban areas. In Poland, GI is supported by key strategic documents such as the State Environmental Policy 2030 (MCE, 2019), which highlights the role of GI systems in environmental protection and climate adaptation, and the National Programme for the Protection and Sustainable Use of Biodiversity 2015–2020 with a Perspective to 2030 (ME, 2015). Legal instruments also play an important role, including the Nature Conservation Act of 16 April 2004 (2004) and the Water Law (2017). The Spatial Planning and Development Act (2003, amended in 2023/2026), although not explicitly using the term “green infrastructure,” in practice serves as a key tool for its implementation.

Properly planned and managed GI helps mitigate the negative impacts of urbanization by maintaining

ecological connectivity, supporting biodiversity, mitigating climate change, and improving air and water quality as well as the well-being of residents (Degórska & Degórski, 2017; Mell, 2015; Szumigała et al., 2025; Verdú-Vázquez et al., 2020). Unlike traditional “grey” infrastructure, GI relies on ecological processes and multifunctionality, integrating various types of green areas – forests, wetlands, meadows, river corridors, agricultural landscapes, and urban greenery – along with hydrological features such as streams, reservoirs, and wetlands into a coherent system operating across different spatial scales (Davies et al., 2006; Niedźwiecka-Filipiak et al., 2019). The development of GI systems is based on identifying and protecting ecologically valuable areas, maintaining and restoring landscape continuity, and implementing nature-based solutions in spatial planning and design processes (Fňukalová et al., 2021).

In functional urban areas, GI plays a key role in balancing urbanization pressure by protecting ecological connectivity, promoting sustainable land use, and preventing landscape fragmentation (Gómez-Villarino et al., 2021; Warczewska, 2016). It is also important in ensuring access to recreational and leisure spaces for residents of cities and peri-urban zones (Solecka et al., 2022; Santo-Tomás Muro et al., 2020; Sylla et al., 2019). Considering the dynamic urbanization processes, the monitoring of GI systems has become an important area of contemporary research (leBrasseur, 2024; Mazaherylaghab et al., 2025; Slätmo et al., 2019; Sroka & Paluch, 2021). Studies explore the relationships between urbanization processes and the continuity and functionality of GI. For instance, Wang (2022) presents an approach based on identifying GI network components and determining key areas to prevent further fragmentation and degradation of natural spaces under progressive urbanization. Similarly, other authors emphasize that spatial pattern analysis and conservation prioritization are essential for limiting GI fragmentation, functional loss, and biodiversity decline (Honeck et al., 2020; Petrişor et al., 2016; Verdú-Vázquez et al., 2020).

The identification and monitoring of urbanization processes and their impact on GI are facilitated by remote sensing, the growing availability of spatial data, and GIS tools (Feltynowski, 2023; Murayama et al., 2021; Wolny et al., 2017).

## Research gap

Previous studies examining the impact of large-scale developments on the natural environment and landscape in peri-urban areas have primarily focused on visual and aesthetic aspects and on the application of nature-based solutions, including green and blue infrastructure elements, to mitigate the negative impacts of such developments within their immediate surroundings (Agudo-Sierra & Llaguno-Munitxa, 2022; Baborska-Narożny, 2019; Côté & Cohen-Rosenthal, 1998; Niedźwiecka-Filipiak et al., 2025; Roberts, 2004). Despite the extensive literature on the effects of urbanization on GI, there remains a lack of research specifically addressing large-scale buildings (logistics, commercial, industrial) as a distinct factor contributing to the potential fragmentation of GI systems in peri-urban areas. Most analyses treat urbanization as a general process without distinguishing between types of development, particularly large-scale facilities. Moreover, few studies have examined temporal changes in such developments and their cumulative effects on the structure and continuity of GI in peri-urban landscapes.

## Aim of the study

This study contributes to the body of research on the monitoring of GI systems, focusing on a single land use/land cover category (industrial land), which includes logistics, commercial, and industrial facilities. The aim is to assess the scale and extent of industrial land encroachment within the designed GI system of the Wrocław Functional Urban Area (Wrocław FUA) in southwestern Poland for the years 2006, 2012, and 2018.

## MATERIALS AND METHODS

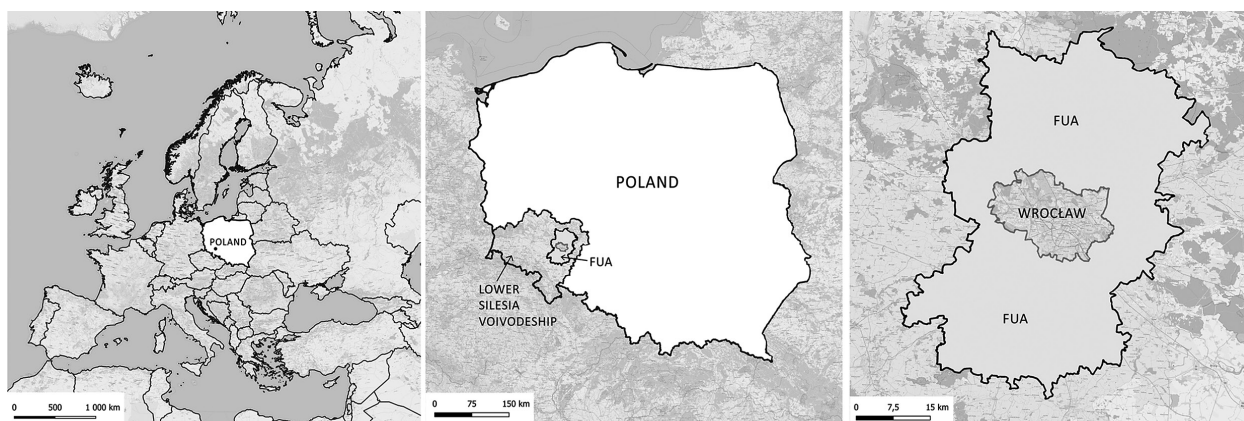
### Study area

The study area encompasses a segment of the green infrastructure (GI) system located within the boundaries of the Wrocław Functional Urban Area (Wrocław FUA) in Poland. This area is one of 58 functional urban areas in the country. It comprises a densely populated urban core (the city of Wrocław) as well as the surrounding zone, which is integrated with the city in terms of transportation and socio-economic connections (Central Statistical Office, n.d.; Eurostat, n.d.). In addition to the city of Wrocław, the Wrocław FUA includes 18 adjacent municipalities: Borów, Czernica, Długołęka, Dobroszyce, Domaniów, Jordanów Śląski, Kąty Wrocławskie, Kobierzyce, Mietków, Miękinia, Oborniki Śląskie, Prusice, Siechnice, Sobótka, Trzebnica, Wisznia Mała, Zawonia, and Żórawina. The total area of the Wrocław FUA is approximately 2648 km<sup>2</sup> (264,809.77 hectares). The location of the Wrocław FUA in relation to the map of Europe and Poland is shown in Fig. 1.

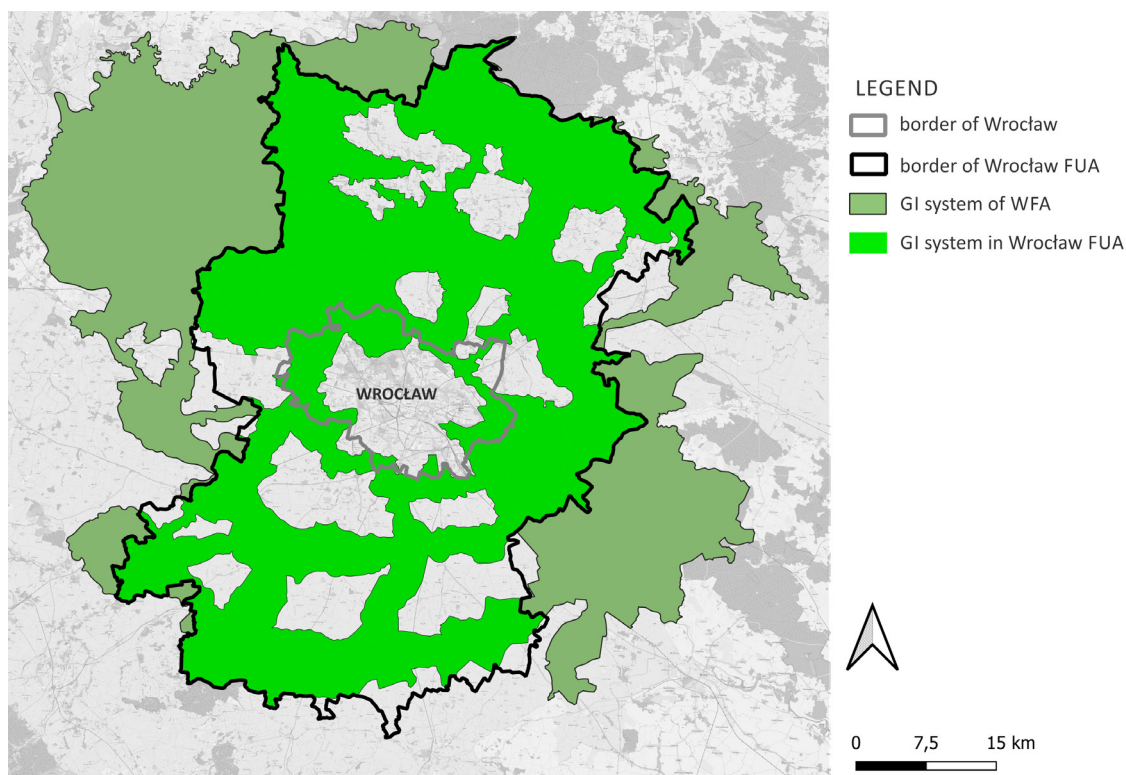
The green infrastructure (GI) system for the surroundings of Wrocław, along with a proposal for its implementation, was designed between 2014 and 2016. This work is reflected in the provisions of the Spatial Development Plan for the Lower Silesian Voivodeship 2020 (Institute for Territorial Development, 2020). The

main components of the designed GI system include three rings, as well as wedges and connectors planned on the basis of the hydrographic network, existing forest complexes, and areas covered by various forms of nature protection. Its main axis is the Oder River – an important ecological corridor of macro-regional significance – together with large forest complexes near Wołów and the Jezierzycza Valley Landscape Park. The remaining elements of the system are based on four rivers flowing into the Oder: Bystrzyca, Oława, Ślęza, and Widawa. Supporting components include the Dobra River (a tributary of the Widawa) and the Strzegomka River (a tributary of the Bystrzyca), along with other parks and forest complexes (Niedźwiecka-Filipiak et al., 2015; Niedźwiecka-Filipiak et al., 2019).

The GI system for the Wrocław area was planned with reference to a territory slightly larger than the Wrocław Functional Urban Area (FUA), in accordance with the guidelines of the Institute for Territorial Development (IRT), the institution responsible for regional planning. IRT referred to this area as the Wrocław Functional Area (WFA), though its boundaries have changed over time due to dynamic economic, spatial, and social processes occurring in the peri-urban zone of Wrocław (Study of the Functional Coherence in the Wrocław Functional Area, 2015). The examined GI system within the WFA is largely located in the boundaries of the Wrocław FUA (Fig. 2). The delimitation of the study



**Fig. 1.** Spatial location of the Wrocław Functional Urban Area (FUA) in Europe, Poland, and in relation to the city of Wrocław  
*Source:* own elaboration.



**Fig. 2.** Planned green infrastructure system of the Wrocław Functional Area (GI WFA) and the delineation of the study area within the Wrocław Functional Urban Area (FUA)

Source: own elaboration.

area to the Wrocław FUA is based on the availability of spatial data and the potential for future comparative research with functional areas of other European cities, for which data is available in the Urban Atlas. The study area, defined as the part of the GI system within the Wrocław FUA, covers 181,525.60 hectares (approximately 68.55%).

During the planning phase, the GI system within the WFA was divided into 13 types of landscape-functional units (LaFUs), with the aim of identifying its strengths and weaknesses. Individual LaFUs group areas characterized by similar land cover types – natural, semi-natural, or anthropogenic – and shared functional roles. Five types of LaFUs include areas covered to varying degrees by forest complexes or clusters, tree stands, or woody-shrub vegetation communities. Four types comprise flowing or standing surface waters and their surrounding zones, while others include orchard complexes and

units covered with low vegetation dominated by open spaces. The last two LaFU types represent areas with open spaces and built-up sites.

These units are assessed according to three main criteria:

- (1) the necessity of maintaining continuity between different components of the system (rings and wedges);
- (2) the importance of designating certain areas as structural nodes within the network;
- (3) the degree of risk posed by existing land-use plans that allow for development in designated economic activity zones (Niedźwiecka-Filipiak et al., 2019).

## Research process

This study was based on the analysis of selected data from the Urban Atlas 2018 (Copernicus Land Monitoring Service, 2021). To assess the extent

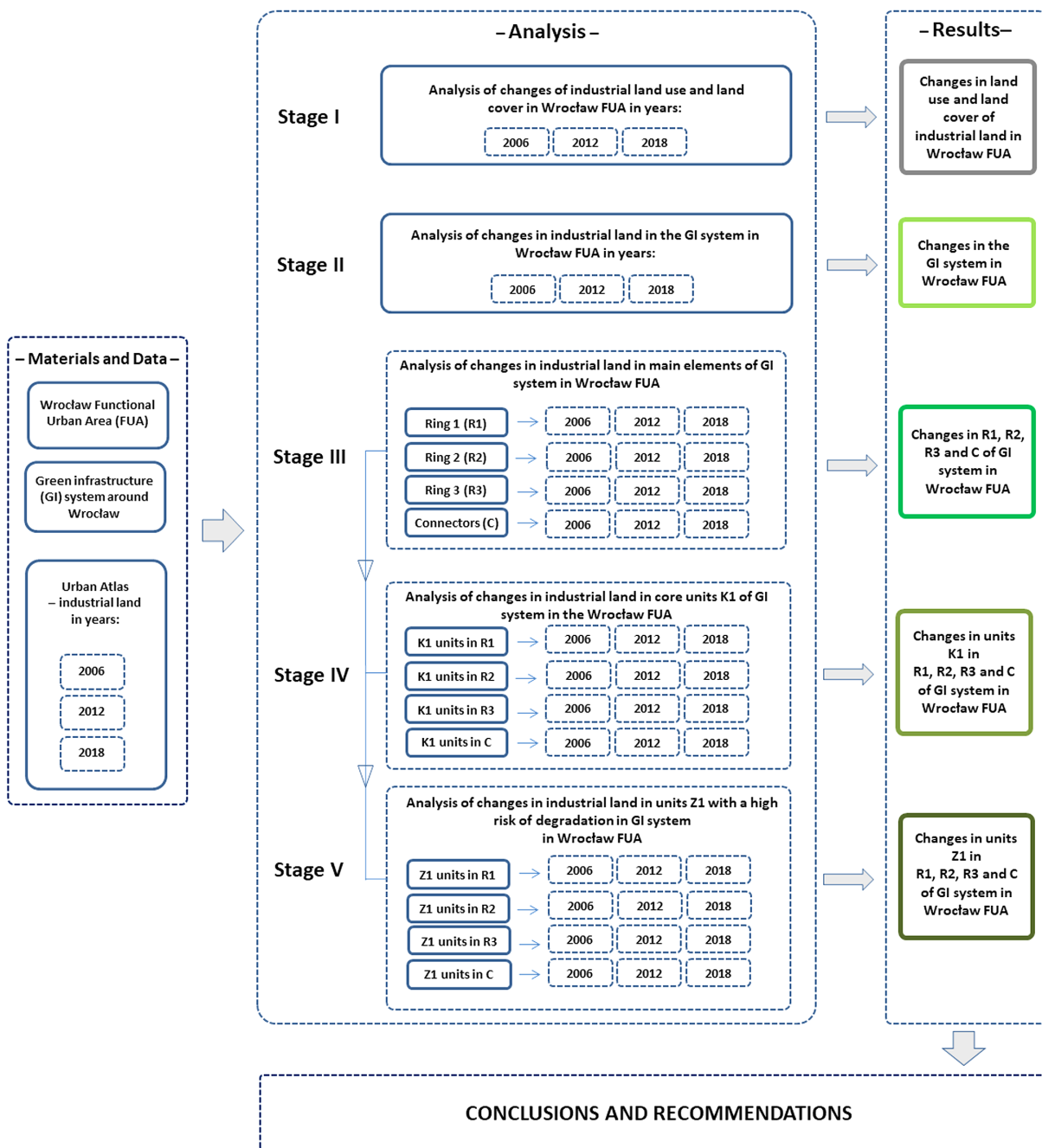


Fig. 3. Methodological workflow of the study, including data sources and GIS-based analysis of industrial land changes in the green infrastructure (GI) system of the Wrocław Functional Urban Area (FUA)

Source: own elaboration.

of retail, warehouse, and logistics development in the Wrocław FUA, data on industrial land (Urban Atlas classification) were used. This class includes areas where at least 30% of the surface is covered by artificial structures (e.g., buildings, concrete, asphalt, or compacted soil without vegetation). Moreover, at least 50% of this artificial coverage must consist of non-residential buildings or structures primarily used for industrial, commercial, or transport purposes (Copernicus Land Monitoring Service, n.d.). Hereafter, this category is referred to as 'industrial land'.

The study was conducted in several stages.

In Stage I, the surface area of the land within the Wrocław FUA was calculated for the years 2006, 2012, and 2018. This provided preliminary results regarding the changes in the extent of these areas within the Wrocław FUA.

In Stage II, calculations were performed for the industrial land within the designated section of the green infrastructure (GI) system located inside the Wrocław FUA, also for the years 2006, 2012, and 2018. This allowed for the assessment of the potential extent to which industrial areas encroach upon the GI system.

Subsequently, Stage III involved an analysis of the industrial land within the main components of the GI system in the Wrocław FUA: the first (R1), second (R2), and third (R3) rings, as well as the connectors (C) that link them.

Stage IV involved analyzing the area of the industrial land in the years 2006, 2012, and 2018 within the core areas of the GI system. The basis for this stage was the continuity assessments of the GI system conducted during the implementation phase. The goal was to identify the most critical LaFUs – those whose absence would threaten the integrity of the system. Three categories of LaFUs were defined: K1, as the primary units forming the system's core; K2, as complementary units to the core; and U, as units supporting the overall GI structure. The study focused on all K1 – category LaFUs, considered the most valuable for maintaining continuity, constituting the core of the GI system. These landscape units are characterized by large areas of high greenery and/or

extensive surface waters, with minimal built-up coverage (Niedźwiecka-Filipiak et al., 2019). For each of these units, analyses were conducted with specific reference to their location within the R1, R2, R3 rings and the connecting corridors (C). This analysis provided an answer to the question of whether, and to what extent, changes in the area of the industrial land have impacted the most essential parts of the GI system surrounding Wrocław.

In the final stage of the study (Stage V), a similar analysis was conducted for the LaFU units most vulnerable to degradation resulting from urbanization pressure. The analysis was based on earlier studies that identified units requiring the most urgent implementation of remedial or preventive measures. Within these studies, key units essential for maintaining the connectivity of the GI system (its core) were identified and hierarchized, including LaFUs located at nodal points as well as those containing areas under various forms of nature protection. Based on the provisions of municipal spatial development plans, the percentage share of LaFU areas designated for development was then assessed. As a result, each unit was assigned one of three threat levels: I, II, or III.

At Stage V, units whose landscapes were found to be most vulnerable to degradation and requiring mandatory remedial actions were marked with the symbol Z1. For these units, interventions aimed at preventing further negative processes were considered obligatory. For the Z1 units, the surface area of industrial land was also calculated for the years 2006, 2012, and 2018.

The research framework is presented in Fig. 3.

## RESULTS

The analyses conducted in Stage I revealed that in 2006, 2012, and 2018, the total surface area of industrial land within the Wrocław FUA amounted to 6313.15 ha, 6730.26 ha, and 7337.82 ha, respectively. This indicates an increase in built-up areas – such as those occupied by warehouses and industrial halls – compared to the baseline year of 2006, by approximately 6.6% in 2012 and 16.2% in 2018 (Table 1).

**Table 1.** Area and change in industrial land in the Wrocław FUA in 2006, 2012, and 2018

Year	Industrial land within Wrocław FUA [ha]	Change [%]
2006	6313.15	–
2012	6730.26	6.61
2018	7337.82	16.23

Source: own elaboration.

The analysis of land cover changes related to industrial areas within the Green Infrastructure (GI) of the Wrocław Functional Urban Area (FUA) (Stage II) revealed that in 2006, industrial land covered 2333.18 ha. By 2012, this area had increased to 2529.62 ha – approximately 8.4% more than in 2006. In 2018, the figure reached 2723.64 ha, representing a total increase of about 16.7% compared to 2006.

These results indicate that within the GI Wrocław FUA, the percentage growth in areas associated with warehouses and industrial halls was slightly higher than in the entire Wrocław FUA. Specifically, the increase was 1.81% in 2012 and 0.5% in 2018. Furthermore, the growth rate between 2012 and 2018 was 7.67% (Table 2).

The area of rings (R1, R2, R3) and connectors (C) included in the GI Wrocław FUA was subsequently

**Table 2.** Area and change in industrial land in the GI system of the Wrocław FUA in 2006, 2012, and 2018

Year	Industrial land [ha]	Change [%]	Change [%]	Difference [%]
2006	2333.18	–	–	–
2012	2529.62	8.42	1.81	–
2018	2723.64	16.74	0.50	7.67

Source: own elaboration.

**Table 3.** Industrial land area in rings (R1–R3) and connectors (C) of the GI system in the Wrocław FUA in 2006, 2012, and 2018

Year	R1 [ha]	Change [%]	R2 [ha]	Change [%]	R3 [ha]	Change [%]	Connectors [ha]	Change [%]
2006	665.53	–	776.01	–	298.75	–	592.89	–
2012	675.11	1.44	845.98	9.02	359.49	20.33	649.04	9.47
2018	722.75	8.60	914.83	17.89	380.45	27.35	705.61	19.01

Source: own elaboration.

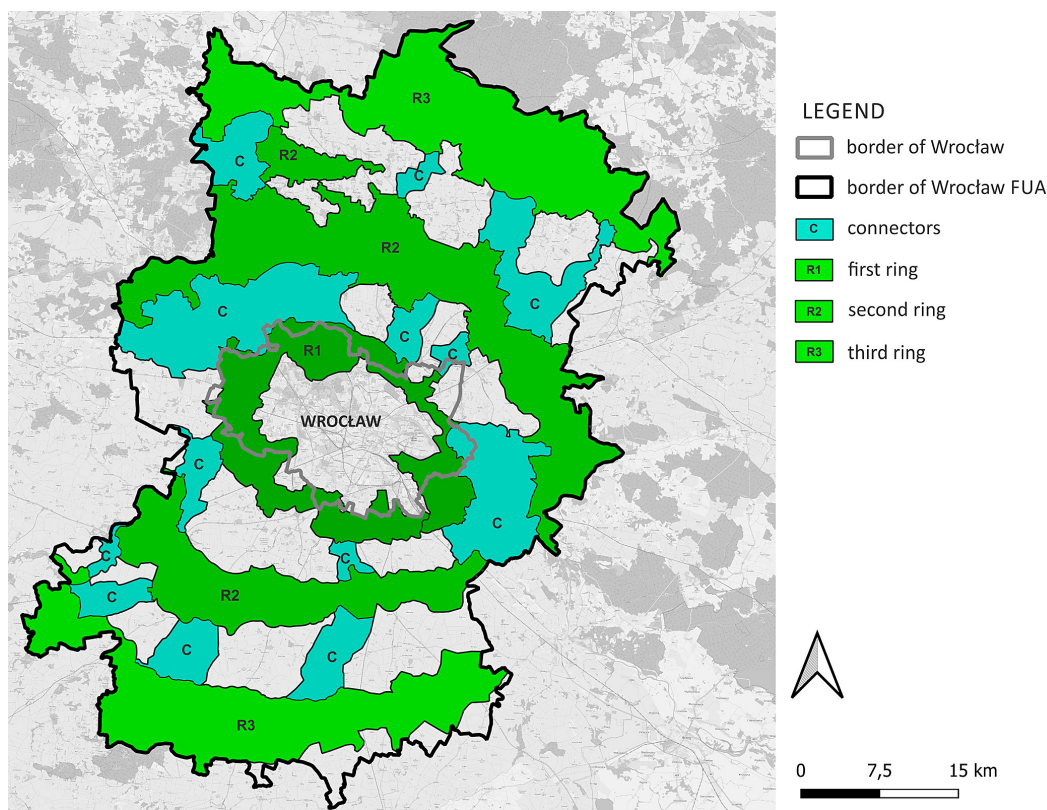
calculated. The following results were obtained: R1 – 20,591.04 ha, R2 – 54,899.29 ha, R3 – 57,904.13 ha, C – 48,131.14 ha. In relation to the entire GI system in the Wrocław area, this is respectively: R1 – 100%, R2 – 65.38%, R3 – 50.68%, C – 47.18%.

To assess whether and to what extent changes have occurred in the GI Wrocław FUA due to the development of large-scale facilities, the share of the Industrial land in the various components of the system was calculated (Fig. 4). The increases in the industrial area in 2006, 2012, and 2018 for the respective rings and connectors are presented in Table 3.

The obtained results indicate a significant increase in areas occupied by, among others, warehouse halls in the third ring of the GI Wrocław FUA and in the connectors between the rings.

It appears that the most dynamic changes (the highest percentage increase) in the industrial land occurred not in the boundary zone of the city (the first ring, R1), but in the third ring (R3), which lies approximately 26 km to 38 km from the city's border. However, despite the large percentage increase in the industrial land area in R3, the total area in this ring remains still relatively small (around 300 ha), only 82.7 ha over the study period. A greater increase in industrial land occurred in the second ring (R2), where the increase from 2006 to 2018 was approximately 139 ha, and in the connectors (C), where almost 111 ha of industrial land appeared over the same period.

In Stage IV of the study, the units (K1) that form the backbone of the GI system were identified. There are 131 such units in the surveyed part of the system. In: R1 – 16 (total c. 10,115 ha), R2 – 46 (total c. 26,392 ha), R3 – 40 (total c. 30,120 ha) and C – 29 (total c. 19,350 ha) (Fig. 5).



**Fig. 4.** Structure of the green infrastructure (GI) system in the Wrocław FUA, showing three concentric rings (R1–R3) and connecting corridors (C)

Source: own elaboration.

**Table 4.** Change in industrial land area within rings (R1–R3) and connectors (C) of the GI system in the Wrocław FUA in 2006, 2012, and 2018

Year	R1 [ha]	Change [%]	R2 [ha]	Change [%]	R3 [ha]	Change [%]	Connectors [ha]	Change [%]
2006	665.53	0.00	776.01	0.00	298.75	0.00	592.89	0.00
2012	675.11	9.58	845.98	69.97	359.49	60.74	649.04	55.01
2018	722.75	57.22	914.83	138.82	380.45	81.70	705.61	110.93

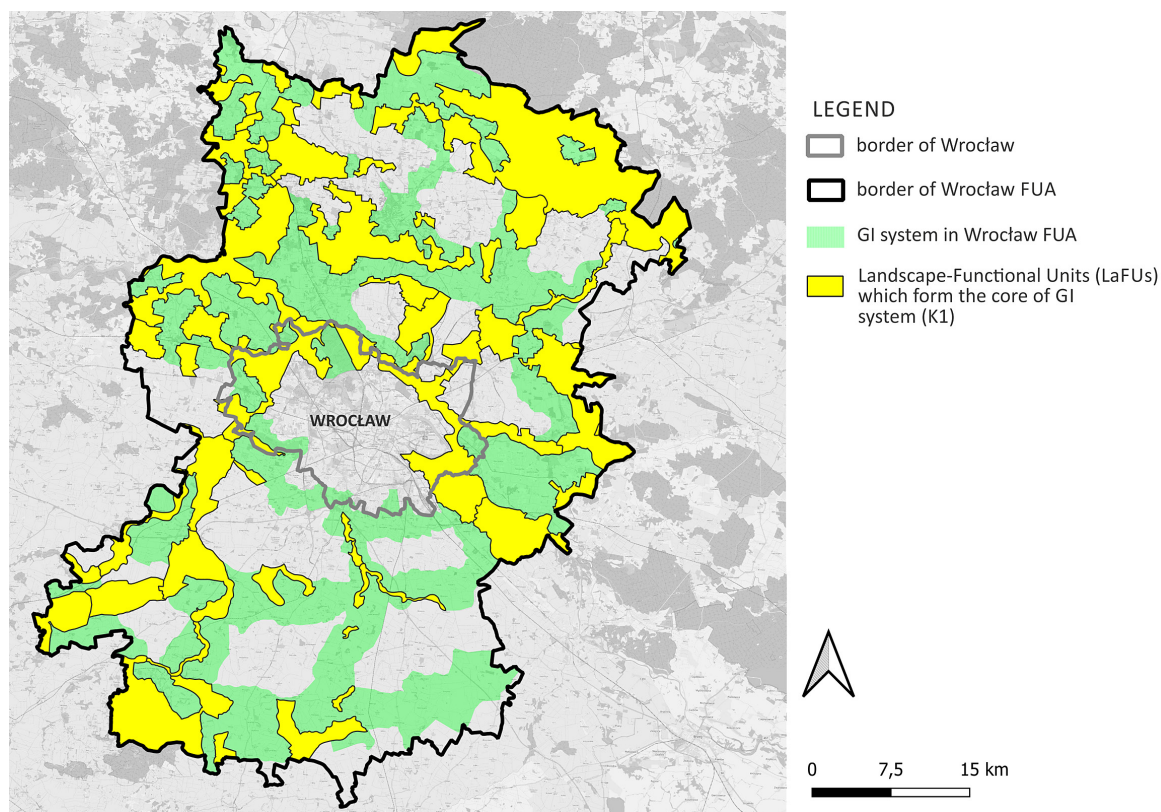
Source: own elaboration.

For the K1 units, the surface area of industrial land in 2006, 2012, and 2018 was calculated. This allowed for the determination of changes resulting from the location of large-scale investments, among other factors, within the units that are most crucial for maintaining and functioning of the GI system. The results are presented in Tables 5–7.

**Table 5.** Industrial land area and change within K1 (core) units in the GI system of the Wrocław FUA

Year	Industrial land area in K1 units [ha]	Change [%]
2006	632.23	–
2012	684.96	8.34
2018	697.92	10.39

Source: own elaboration.



**Fig. 5.** Core Landscape Functional Units (LaFUs, K1) in the GI system of the Wrocław FUA  
*Source:* own elaboration.

**Table 6.** Aggregated industrial land area and change in K1 units across rings (R1–R3) and connectors (C) in the GI system of the Wrocław FUA in 2006, 2012, and 2018

Year	R1 [ha]	Change [%]	R2 [ha]	Change [%]	R3 [ha]	Change [%]	Connectors [ha]	Change [%]
2006	217.9	0.00	177.89	0.00	114.92	0.00	121.52	0.00
2012	219.38	1.48	200.12	22.23	134.76	19.84	130.70	9.18
2018	214.15	-3.75	207.22	29.33	138.04	23.12	138.51	16.99

*Source:* own elaboration.

**Table 7.** Industrial land area and change within K1 units across rings (R1–R3) and connectors (C) in the GI system of the Wrocław FUA in 2006, 2012, and 2018

Year	R1 [ha]	Change [%]	R2 [ha]	Change [%]	R3 [ha]	Change [%]	Connectors [ha]	Change [%]
2006	217.9	–	177.89	–	114.92	–	121.52	–
2012	219.38	0.68	200.12	12.50	134.76	17.26	130.7	7.55
2018	214.15	-1.72	207.22	16.49	138.04	20.12	138.51	13.98

*Source:* own elaboration.

The results indicate that the increase in industrial land within the K1 units between 2006 and 2018 reached approximately 10%, with the most significant increase occurring between 2006 and 2012 – around 8%. Between 2012 and 2018, the increase was less than 2%, which suggests a slowdown in the processes of large-scale development, such as warehouses, industrial halls, and logistics centers.

In the next phase, the units with the highest degree of necessity for protective actions (Z1) were identified within the GI Wrocław FUA. There are 34 such units in the area covered by the study, in: R1 – 9 (with a total area of approx. 3745 ha), R2 – 9 (total area of approx. 4094 ha), R3 – 10 (total area of approx. 5415 ha) and C – 6 (total area of approx. 3663 ha) (Fig. 6).

For these units, the surface area of industrial land in each year was calculated, thereby determining changes resulting from the location of large-scale investments in units with the highest degree

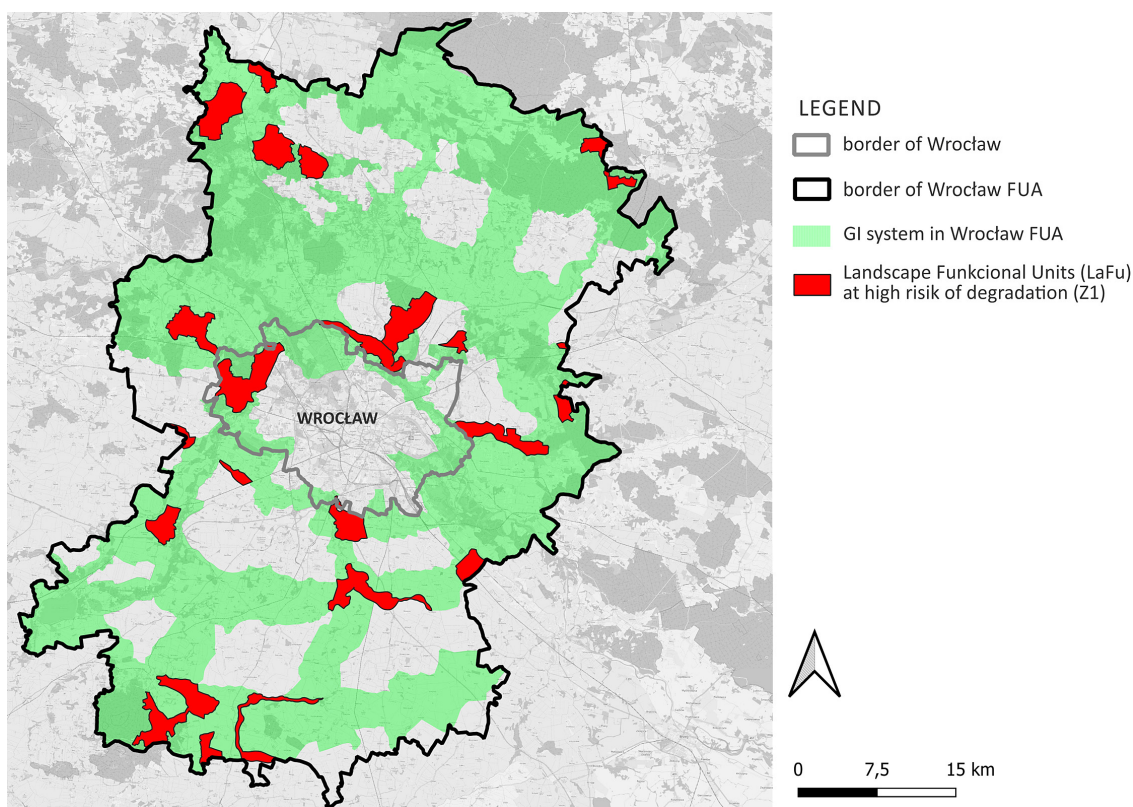
of necessity for protective actions. The results are presented in Tables 8–10.

**Table 8.** Industrial land area and change within Z1 (high-risk) units in the GI system of the Wrocław FUA

Year	Industrial land area in Z1 units [ha]	Change [%]	
2006	368.79	–	–
2012	384.71	4.32	–
2018	401.40	8.84	4.34

Source: own elaboration.

The obtained results indicate a particularly alarming change in the units located in R3. The increase in the studied areas industrial land between 2006 and 2018 exceeds 40%. In contrast, the situation in R1, in terms of GI protection, is significantly better, where over the 12-year period, the area of these lands has decreased by approximately 7.5%.



**Fig. 6.** High-risk Z1 units susceptible to landscape degradation in the GI system of the Wrocław FUA  
Source: own elaboration.

**Table 9.** Industrial land area and change (ha) in Z1 units across rings (R1–R3) and connectors (C) in the GI system of the Wrocław FUA in 2006, 2012, and 2018

Year	R1 [ha]	Change [%]	R2 [ha]	Change [%]	R3 [ha]	Change [%]	Connectors [ha]	Change [%]
2006	166.48	–	131.64	–	33.27	–	37.4	–
2012	147.34	-19.14	152.94	21.30	46.01	12.74	38.42	1.02
2018	153.88	-12.60	160.66	29.02	46.77	13.50	40.09	2.69

Source: own elaboration.

**Table 10.** Industrial land area and percentage change in Z1 units across rings (R1–R3) and connectors (C) in the GI system of the Wrocław FUA in 2006, 2012, and 2018

Year	R1 [ha]	Change [%]	R2 [ha]	Change [%]	R3 [ha]	Change [%]	Connectors [ha]	Change [%]
2006	166.48	–	131.64	–	33.27	–	37.4	–
2012	147.34	-12.5	152.94	16.18	46.01	38.29	38.42	2.73
2018	153.88	-7.57	160.66	22.04	46.77	40.58	40.09	7.19

Source: own elaboration.

## DISCUSSION

The research results show that throughout the Wrocław FUA area, between 2006 and 2018, there was an increase in the surface area classified as industrial land, occupied by shopping centers, logistics facilities, warehouses, and industrial buildings. This trend is consistent with observations in the functional areas of other cities (Dablanc et al., 2018; Gant et al., 2011). However, the study revealed a differentiation in the distribution of industrial land, with the highest concentration found in the second ring (R2), rather than in the first (R1) or third (R3) rings. This may come as a surprise, especially with regard to the first ring (R1), which typically experiences the highest urban pressure due to its proximity to the city. Higher land prices in the immediate vicinity of Wrocław may encourage investors to seek more distant locations – 30 to 40 km from the city’s boundaries, in the second ring zone. The increase in industrial land in the connectors (C) could be attributed to the radial distribution of roads extending from the city and the development of buildings along these routes. Further research could clarify both of these issues.

The increase in industrial land within GI system units in the Wrocław FUA is relatively small compared

to their total area, but it is significant enough to pose a potential threat to ecological connectivity and the functions provided by the GI system. It is therefore necessary to continue monitoring these changes and to implement more effective protection of the GI system at the local level, i.e., within individual municipalities. In the Polish planning system, regional documents, such as the development plan for the voivodeship, which incorporated the GI system in 2020, are designed with a strategic character but are not obligatory. This means that municipalities are not legally required to follow the guidelines set out in regional documents, such as the voivodeship plan. Furthermore, implementing the directions set by regional planning documents is a time-consuming process, often requiring adjustments to previously established assumptions at the local level. One such adjustment may involve the construction of a logistics or retail center.

The only obligatory document in the Polish planning system – that is, a local legal act – is the local development plan, and in the near future, starting from January 1, 2026, the general plans adopted by the municipal council will also become mandatory. The land use designations established in the local development plans, and in the future

in the general plans, for green spaces or construction areas are binding. The GI system, which is planned at the regional scale, should therefore be gradually integrated into the local development plans and the currently developed general municipal plans. It may also be necessary to review local development plans that were adopted before the inclusion of the GI system in the regional development plan. Only such a revision of previously adopted documents will ensure full protection of the GI system from excessive development, including the expansion of large-scale logistics centers, retail centers, warehouses, or industrial facilities.

Another issue is related to investments that have already been completed. Unfortunately, the development of space around logistics centers, retail outlets, and industrial facilities is often limited to basic infrastructure elements such as parking lots, roads, and sidewalks. Green spaces are frequently omitted or reduced to a minimum (Niedźwiecka-Filipiak et al., 2025). Currently, there are no established standards in Poland that require the integration of green infrastructure (GI) as an essential and integral element of land development. Introducing such standards would improve both the quantity and quality of greenery in individual investment areas, thereby reducing the negative impact of large-scale developments on the landscape and environment. At present, the primary tool for ensuring greenery within developments is the biologically active area indicator, included in local spatial development plans. However, this indicator is purely quantitative and does not ensure the inclusion of GI elements that are most beneficial for improving microclimates, enhancing water retention, supporting biodiversity, or improving landscape aesthetics (cf. Giedych et al., 2013; Giedych, 2022). As demonstrated by Andrzejewska (2024), in areas designated for commercial use, the biologically active area indicator is often set at very low levels – and in some cases, as low as 0% – which can result in a complete lack of greenery on investment plots.

The preservation of the continuity and integrity of the GI system in peri-urban areas is important not only for environmental reasons, such as the

anticipated loss of biodiversity due to the expansion of urbanized areas (Fu et al., 2018; Ren et al., 2023), but also in the context of providing numerous ecosystem services. Integrating the concept of ecosystem services into spatial planning can support sustainable development in peri-urban areas (Hou et al., 2015; Scott et al., 2013).

Strategic planning and management of GI in peri-urban areas play a significant role not only because of regulatory services but also cultural ones. The importance of green spaces located on the outskirts of cities was particularly evident during the COVID-19 pandemic, when, during global mobility restrictions, they became an essential space for mental relaxation and physical activity (Erdönmez & Atmiş, 2021; Sung, 2023; Xiang et al., 2022).

Numerous studies highlight the necessity of planning green spaces both in close proximity to residential areas and in more distant locations (Bressane et al., 2024; Browning et al., 2022; Dennis et al., 2020; Rubaszek et al., 2023). Urban residents are willing to travel longer distances to access green spaces, particularly when these areas offer opportunities for extended active recreation in attractive landscapes (Schindler et al., 2022), are connected to the city through green corridors (Žlender & Ward Thompson, 2017), or play a significant role in ensuring equitable access to green spaces in high-density urban environments (Shan & He, 2025).

For the protection of open lands that constitute an important part of GI systems in peri-urban zones, strategies that support agriculture and farm incomes are also crucial, as they contribute to the increase in agricultural land prices. Agricultural development significantly impacts the reduction of urban sprawl (Duvernoy et al., 2018; Gant et al., 2011; Görmüş et al., 2018; Rolf et al., 2018; Rolf, 2021).

## Limitations and Future Research Directions

The present study has certain limitations resulting from the characteristics of the adopted methodological approach. The analysis made it possible to identify

areas classified as industrial land in specific years within the boundaries of the planned GI system and its selected LaFUs; however, it did not provide detailed insight on how and to what extent the location of these areas contributes to the fragmentation of natural structures within the analyzed units. This limitation requires further research into land use/land cover patterns within individual GI units, with a particular focus on the spatial distribution of green areas forming the GI system, both in terms of their current state and temporal changes. In future stages of GI system monitoring, the scope of research should also be extended to include other types of development, particularly residential areas, as this form of land use is currently expanding in an uncontrolled manner under existing legal and spatial planning conditions (e.g. Kudłacz & Karwińska, 2021; Solecka et al., 2017).

## CONCLUSIONS

The study based on Urban Atlas data (2006, 2012, 2018) revealed a moderate increase in industrial land within the GI system of the Wrocław FUA. The highest relative growth was recorded in the third ring (R3), as well as in the units critical for system continuity (K1) and those most exposed to degradation (Z1). A positive finding, however, is the negligible increase in the first ring (R1), located closest to Wrocław (not exceeding 10%), along with a declining trend in some of the core and vulnerable units within the same ring.

Despite the relatively limited scale of changes, the expansion of industrial land indicates a risk of fragmentation in selected parts of the GI system. The results suggest the necessity of consistently integrating GI into local planning documents and conducting regular monitoring of changes. Protection limited to the inclusion of the GI system in the Regional Spatial Development Plan (2020) remains insufficient, as it is only of a recommendatory nature. The amendment of the Spatial Planning and Development Act in 2023, introducing new planning documents in the form of general plans, creates an opportunity to more effectively integrate GI and to reduce the risk of its fragmentation caused

by urbanisation processes, including the expansion of large-scale logistics, commercial, and industrial facilities.

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