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Fabian Miszewski[1]

GIS TOOLS SUPPORTING GREEN INFRASTRUCTURE MANAGEMENT AT THE HOUSING ESTATE LEVEL – THE CASE OF OLSZTYN

Abstract:
Motives: GIS-based tools have significant potential for broader application in supporting green infrastructure (GI) management processes at the local level. However, not all of their functionalities can be directly applied to every area; therefore, it is necessary to first identify problem areas and specific needs.
Innovation: The role of GIS tools is typically considered in the context of management at the central level. This study, however, focused on exploring the possibilities of their application at the local scale.
Goal: The aim of the study was to examine the potential use of GIS tools to support GI management at the level of a residential estate.
Methods: A critical literature review on GI management was conducted to identify the potential applications of GIS tools in supporting local GI management. The testing and analyses were performed using the QGIS software.
Results: GIS tools provide excellent support for decision-making as well as for conducting research, analyses, and activities related to local GI management. Among other benefits, they enable rapid problem detection, functional mapping, and monitoring of environmental conditions within a given unit.

Keywords: greenery, public open spaces, residential areas, sustainable development, land data mapping

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[1] University of Warmia and Mazury in Olsztyn, Faculty of Geoengineering, Department of Land Management, Olsztyn, Poland, ORCID ID: https://orcid.org/0009-0008-6705-5774, email: fabian.miszewski@uwm.edu.pl

Introduction

The management of green infrastructure (GI) is becoming an increasingly significant challenge. With the growing diversity of desired forms of public space development and the increasing need to adapt to changing environmental and social conditions, specific tools are required to support decision-making and significantly improve operational efficiency. One of the solutions applied in this context is the use of Geographic Information Systems (GIS), which are currently utilized across various domains. GIS tools enhance urban space management by facilitating data-driven decision-making (Chen et al., 2024), thereby contributing to more sustainable management of urban ecosystems (Oppong et al., 2023).

Some researchers, such as Van Oijstaeijen et al. (2020), point out that the currently available tools for GI management are not fully adapted for direct use in the decision-making process; however, they can serve as valuable decision-support tools and function as indicators. Before using GIS-based tools for GI management, effective mapping is crucial, which requires a thorough understanding of both the materials and methods used in this process (Dobrinić et al., 2025). It is also important to note that GIS-based planning tools enable the inclusion of social perspectives, particularly concerning the benefits provided by GI elements (Heckert & Rosan, 2018).

Nevertheless, GIS capabilities are often overlooked at the local level. This is likely due to a lack of knowledge about their effective use, as well as barriers related to data availability and quality. This raises questions about whether all GIS functionalities can be directly applied to local analyses, and under which circumstances they can be used for detailed assessments versus when they merely support decision-making. A major issue is the limited availability of free software that is both adequately tailored for targeted use and equipped with tools useful for local green space managers who are beginning to adopt such solutions. The gap in the existing research lies in identifying GIS functionalities that can be effectively applied in spatial planning and management at the local scale.

Understanding the potential of GIS-based tools – or those integrated into GI management systems in cities – makes it possible to identify actions that can be optimized or supported by their use. Consequently, a more efficient and sustainable approach to planning, establishing, and maintaining green areas can be achieved, while simultaneously reducing resource consumption and optimizing operational scope.

The aim of the analysis conducted for the purposes of this article was to address the following research question: What opportunities do publicly available GIS tools offer, and how can they be applied in GI management? The functionalities were examined using one of Olsztyn’s residential estates, characterized by a diverse functional structure, as a case study area.

Literature review

GI management. The management of GI in urban areas consists of several stages, including planning, implementation, and maintenance of green spaces. Managing GI on a large scale requires the involvement of different administrative levels – from the national level, which is responsible for the development of policies, strategies, and legal regulations, to the local level, where the direct implementation of developed solutions takes place, often under constantly changing environmental and socio-economic conditions (Slätmo et al., 2019).

The primary goal of GI management in cities is to ensure the sustainable delivery of ecosystem services(Trzaskowska & Adamiec, 2017). This is feasible only when decision-making processes consider several key principles of effective GI planning: multifunctionality, continuity, connectivity, practicality, diversity, integration, large-scale perspective, and appropriate management (Monterio et al., 2020). Unfortunately, merely establishing policies and indicating potential solutions is often insufficient. Significant obstacles to effective GI management include limited knowledge and low public acceptance, as well as a lack of policy integration, institutional barriers, and financial constraints (Dhakal & Chevalier, 2017; Legutko-Kobus et al., 2024).

GI management is a multi-level and complex process influenced by numerous external factors, which makes it difficult to plan with high precision without the need for site-specific interventions, particularly during the implementation and maintenance stages. Therefore, supporting GI management at the local level with appropriately selected tools is essential, as such tools provide extensive possibilities for data analysis and evidence-based decision-making.

GIS for GI. GIS tools enable effective management of GI due to several key functionalities (Fig. 1), including: assessment of the ecological value of spaces (Chang et al., 2012; Lee & Oh, 2019; Tache et al., 2023; Brom, 2023); support for decision-making at both local and supra-local levels (Halfawy et al., 2002; Chang et al., 2012; Deksissa, 2014; Lee & Oh, 2019; Caparrós Martínez et al., 2020; Mobarak et al., 2022; Bressane et al., 2024); execution of various spatial analyses (Mobarak et al., 2022; Brom, 2023; Kajosaari et al., 2024); mapping and visualization of GI-related data (Crnčević et al., 2017; Caparrós Martínez et al., 2020; Mobarak et al., 2022; Brom, 2023; Calia et al., 2023; Kajosaari et al., 2024; Allioua et al., 2024); identification of problematic areas requiring intervention (Crnčević et al., 2017; Heckert & Rosan, 2018; Lee & Oh, 2019; Mironova, 2021; Calia et al., 2023; Herath et al., 2024); integration of environmental data (Crnčević et al., 2017; Bressane et al., 2024); support for efficient spatial planning (Crnčević et al., 2017; Calia et al., 2023); evaluation of the spatial distribution of green areas, their connectivity, and fragmentation, with particular attention to the location of ecological corridors (Chang et al., 2012; Mironova, 2021; Herath et al., 2024); analysis of socio-economic factors (Deksissa, 2014; Heckert & Rosan, 2018; Caparrós Martínez et al., 2020; Kajosaari et al., 2024); increasing public awareness (Deksissa, 2014); and support for stormwater management (Eldaher, 2019).

Researchers particularly highlight the mapping and visualization of data and the crucial function of supporting decision-making, which is based on specific, data-driven analyses provided by these tools. Moreover, GIS tools are highly multifunctional, allowing the same datasets to be used for modeling and simulating different phenomena and scenarios, thereby offering a broader and more integrated perspective on complex problems. The most important component of a well-functioning GIS tool, however, is data quality, as highly accurate data allow for more reliable analyses and help reduce errors (Filho et al., 2020). In local-scale analyses, data verification is usually easier and faster due to the limited spatial extent of the study area. Nevertheless, it is crucial to ensure that the data entered into the system is as accurate as possible.

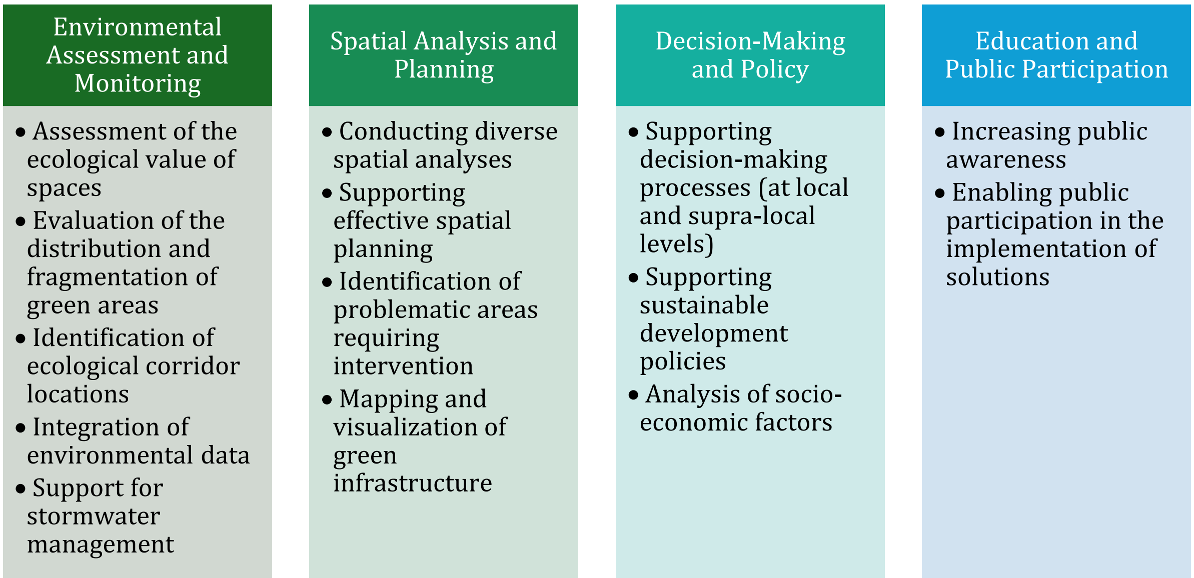

Fig. 1. Possibilities of Using GIS Tools in Managing GI at the Local Level
Source: Author's own elaboration

Materials and methods

Study framework. The research comprised four stages (Fig. 2), which included a literature review, the process of selecting criteria, analyses, and conclusions. In the first stage, a review of scientific literature on the selected subject was conducted, serving as a starting point for further analyses. The focus was primarily on the possibilities of supporting the GI management process through the use of GIS tools, as well as on characterizing different stages of GI management. The second stage, involving the selection of criteria, focused on identifying the potential applications of GIS in relation to GI management at the local level and on selecting the study area, which served as an example for testing the defined possibilities. The third stage assumed the selection of those GIS-based tools that could support GI management processes and could be implemented in the study area. Only after identifying the possible applications within the Pojezierze housing estate were the selected aspects analyzed. The final stage involved compiling the research results, comparing them with the literature, and formulating conclusions.

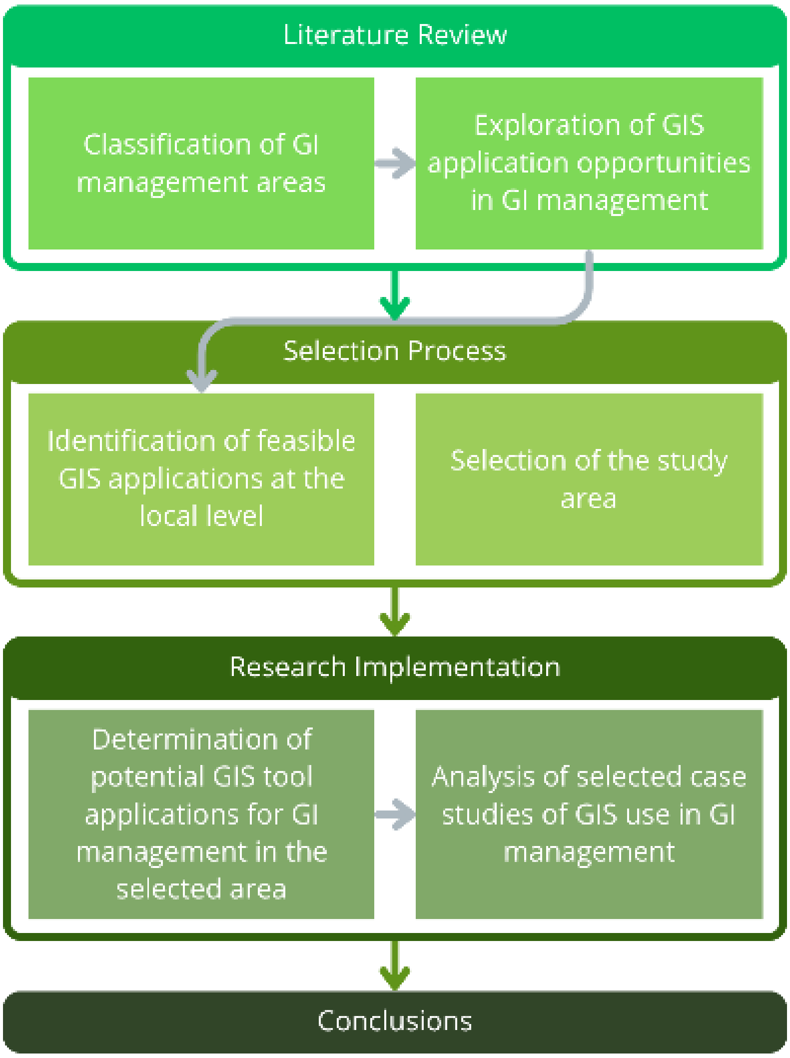

Fig. 2. Study framework
Source: Author's own elaboration

Study area. The Pojezierze estate, located in Olsztyn, Warmian-Masurian Voivodeship, was selected as the study area. It is situated in the central and eastern part of the city (Fig. 3). The estate is well-connected with other districts due to the presence of major transportation arteries, including Dworcowa, Towarowa, Leonharda, and Piłsudskiego streets, which serve as key road transport axes in this part of Olsztyn. The Pojezierze estate is characterized by a diverse range of functions within its boundaries. Its western part borders the city center and is primarily occupied by multi-family residential buildings and the Janusz Kusociński City Park. The central area is dominated by multi-family residential development located between Dworcowa and Leonharda streets, as well as by the second, less developed section of the aforementioned park. The eastern part, on the other hand, consists of extensive industrial areas, which form one of the largest industrial zones in the city. The selection of the Pojezierze estate as the core of the case study was motivated by the diversity of functions within its territory, which enables a broader examination of the potential applications of selected tools for GI management.

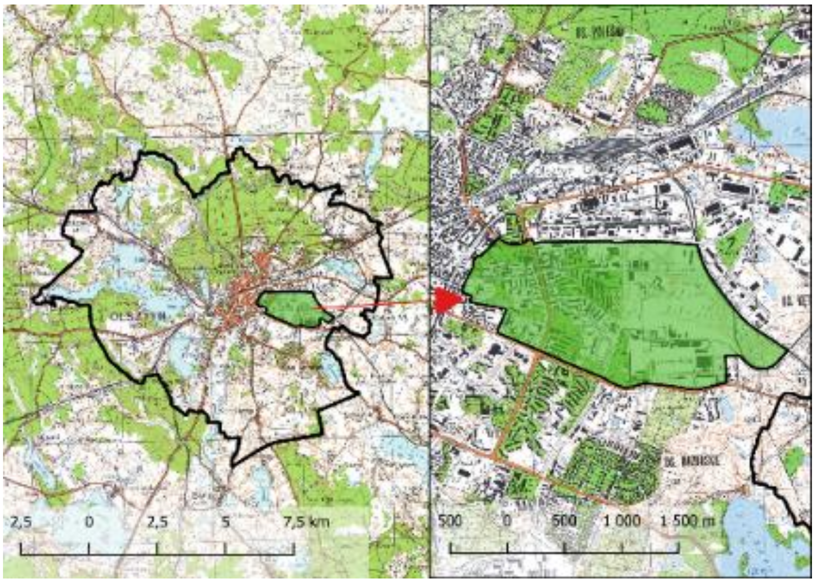

Fig. 3. Location of the Pojezierze estate within Olsztyn
Source: Author's own elaboration

Methods. The study employed a case study approach to assess the potential of using selected GIS tool functionalities in decision-making processes related to GI management at the neighborhood level. The individual possibilities for the potential use of GIS tools have been grouped into nine thematic categories. Spatial analysis was conducted on the Pojezierze estate in Olsztyn, which served as a model example for testing the functionality of the open-source GIS software QuantumGIS (QGIS) in combination with an MS Excel spreadsheet. Using QGIS, basic spatial analyses were performed, focusing on the distribution and structure of green areas, such as mapping the functional roles of space, identifying land cover forms, and mapping individual elements. GI, in order to illustrate the practical applicability of this tool in GI planning and management. The empirical part was complemented by a qualitative SWOT analysis aimed at identifying the strengths, weaknesses, opportunities, and threats associated with the application of the analyzed set of tools in managing natural infrastructure at the local level.

Data. The analyses were based on data obtained from the Topographic Objects Database (source: https://www.geoportal.gov.pl/) as well as from cartographic sources, including orthophotomaps, which were imported into QGIS 3.22.16 using the GIS Support plugin. Additionally, data derived from an original cartographic inventory were utilized.

Results

Classification of GI and GIS management areas. GI can be effectively managed at the local level using GIS tools and other supporting software. The case study demonstrates several fundamental ways in which such tools can be utilized. Although the scope of their application varies, their diversity illustrates the extensive possibilities offered by GIS tools (Fig. 4).Among the identified categories of use, nine groups related to different application areas were distinguished, which are further divided into specific possible actions. The most crucial ones, in the context of efficient functioning of the housing estate, include identifying potential problems, collecting environmental data and utilizing them appropriately, as well as mapping green areas to address the functional needs of residents. Other possibilities and actions are equally important, yet they may have less impact on how the GI management process is perceived by external stakeholders, as they focus primarily on internal problem detection and definition, effective planning of maintenance works and investments, as well as improving management processes and facilitating daily operations.

Possibilities of Using GIS Tools on the Example of the Pojezierze Estate	
Management of environmental data	• Collecting environmental data • Visualization of data • Constant monitoring of environmental condition
Conducting GI inventory	• Inventory of tree stands • Mapping of functions • Tree stand management
Planning investments related to GI	• Planning works and tasks • Planning of plantings
Marking the range of investment impact	• Designating zones of impact • Designating intervention sites • Identifying potential locations of difficulties
Stormwater management	• Determining water runoff routes • Designing retention reservoirs • Forecasting local flooding
Calculating environmental indicators	• Degree of vegetation cover and biodiversity index • Access to green areas and the number of inhabitants in relation to their area • Percentage of green areas in the total area
Mapping green areas	• Understanding the layout of green areas and green infrastructure • Designating areas intended for investments • Identifying ecological corridors
Creating a functional scheme	• Recognizing the function of the area • Functional analysis of public space • Defining functional deficiencies
Determining the spatial extent of phenomena	• Collecting data and identifying the occurrence of invasive species • Determining trends in the occurrence of social phenomena, including places where people gather

Fig. 4. Possibilities of using GIS tools on the example of the Pojezierze estate
Source: Author's own elaboration

Spatial functionality analysis of the Pojezierze estate. For the purposes of the study, basic analyses were conducted using the QGIS software, with particular emphasis placed on the possibilities identified for selected areas of GI management, as presented in Fig. 4. The analyses included the identification and mapping of functional zones, land use types based on data from the Topographic Object Database, as well as the determination of the spatial arrangement of green areas within the housing estate.

The Pojezierze housing estate in Olsztyn is characterized by a wide range of functions performed by the spaces within its boundaries. This diversity results in the division into several functional zones (Fig. 5). The dominant functions include residential (multifamily housing) and industrial uses. Additionally, service areas, transportation-related areas (main roads and transport routes), recreational and leisure spaces, as well as other areas with no clearly defined function—classified as "other"—were identified. Conducting a detailed functional analysis of the area supports the effective planning of GI in terms of its role, form, and purpose. Moreover, the presented analyses demonstrate various methods of land classification, which are useful and significant from the perspective of practical GI management and its application in spatial planning.

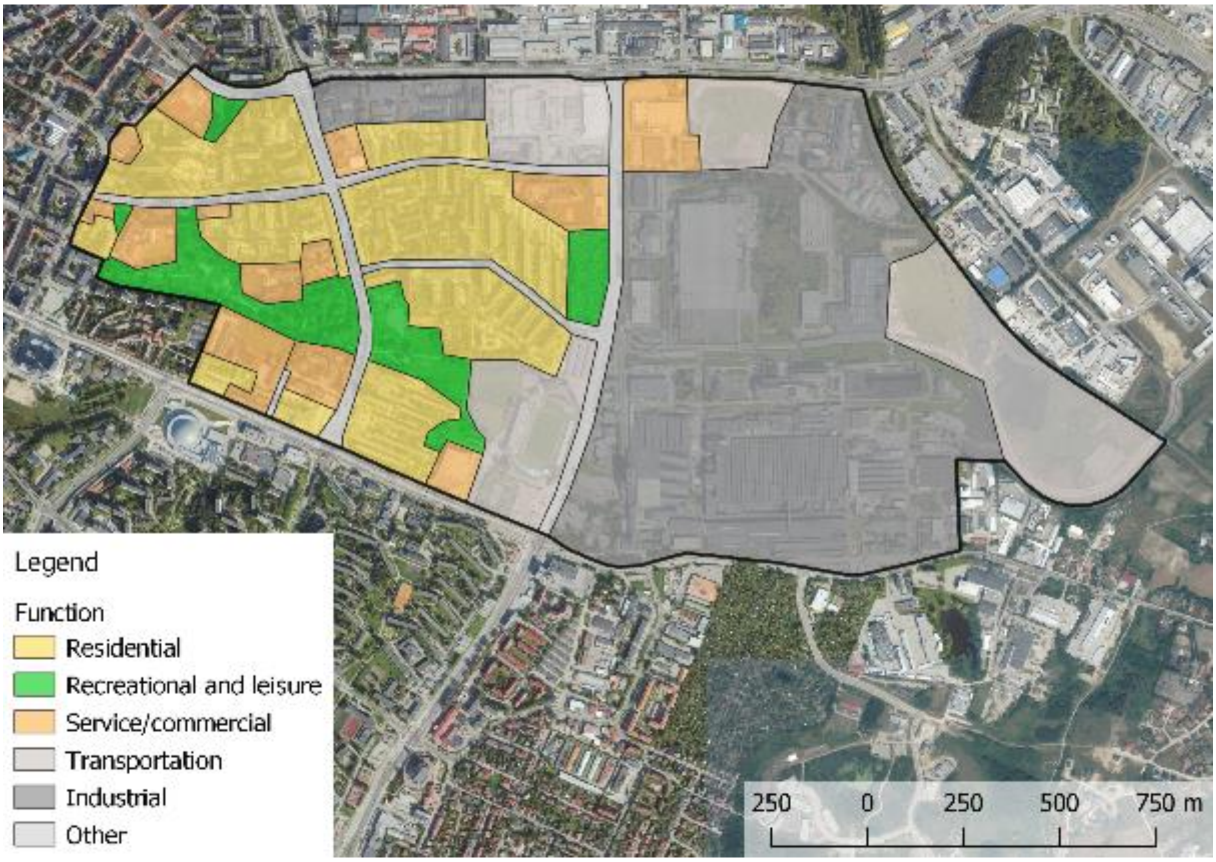

Fig. 5. Functional and spatial layout of the Pojezierze estate
Source: Author’s own elaboration using QGIS software

Analysis of land cover types. In the case of land cover types within the Pojezierze housing estate, according to the categories outlined in the Ministerial Regulation concerning the Topographic Objects Database (Journal of Laws 2021, item 1412), the following can be distinguished: transportation areas, built-up areas, surface waters, forested or wooded areas, grassy vegetation and agricultural crops, squares, permanent crops, and other undeveloped lands. The conducted analysis showed that, from a visual assessment perspective, the largest share among all land cover types is occupied by built-up areas as well as grassy vegetation and agricultural crops (Fig. 6). After calculating the area of specific land cover types and their percentage share within the estate's territory using Excel, it was found that built-up areas dominate the land cover (approximately 53%), while grassy vegetation and agricultural crops account for about 31.5%.

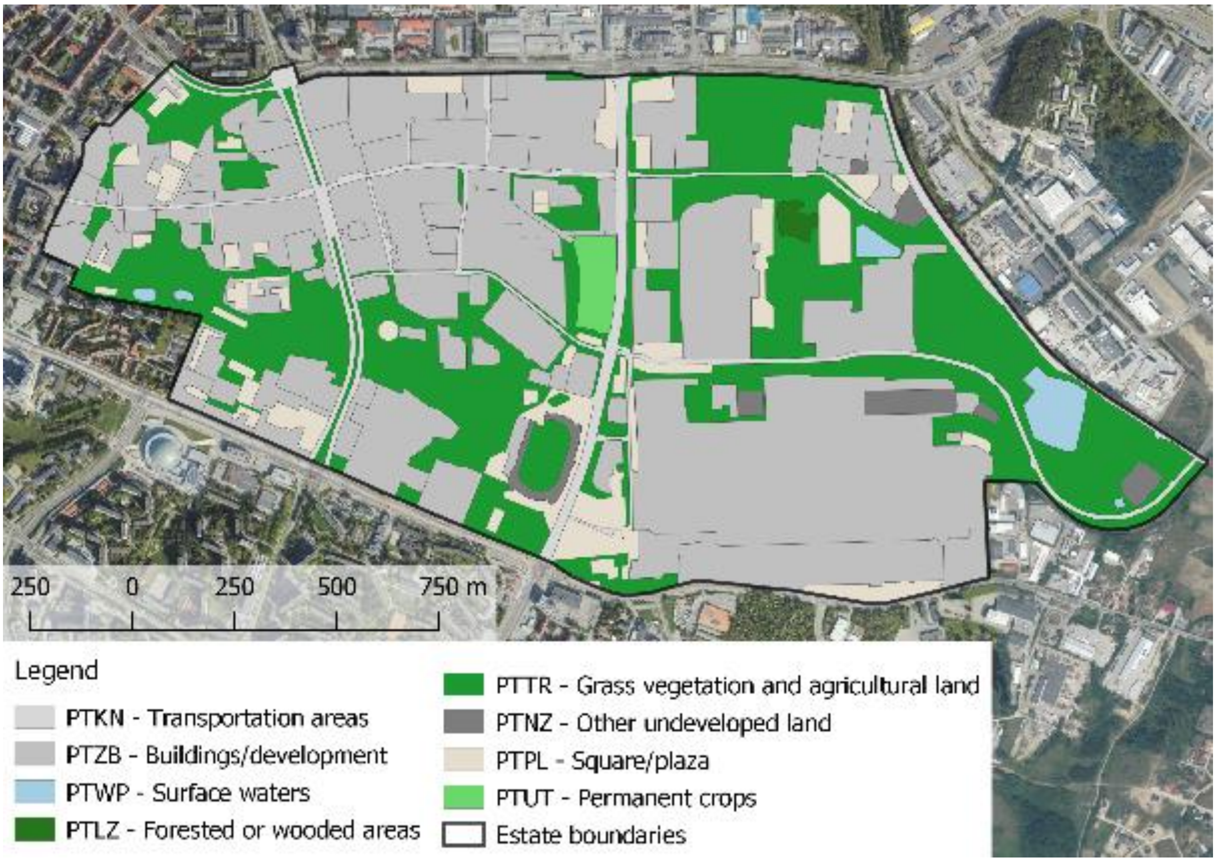

Fig. 6. Land cover types within the housing estate according to the Topographic Objects Database
Source: Author's own elaboration using QGIS software

The analysis of land cover types and the calculated indicators reveal that the housing estate faces a challenge related to a deficit of biologically active spaces that are accessible to residents and suitable for recreation. Most of the large vegetated areas are located within the industrial zone; however, these are largely undeveloped lands that serve as potential sites for future investments. To mitigate the negative impact of factories on residential areas, it would be advisable to establish buffer green zones composed of tall vegetation (trees and shrubs), which could help reduce noise pollution and limit the spread of contaminants.

Analysis of the location of GI elements The analysis aimed at determining the arrangement of green areas involved mapping key green spaces as well as other land types. To provide a clearer overview, a layer showing the location of buildings was incorporated from the Topographic Objects Database (Fig. 7). The analysis revealed the spatial distribution of green areas within the housing estate boundaries. Unfortunately, certain disparities were identified, and the system appears rather fragmented. The vast majority of public green spaces are located on the western side of the estate, primarily consisting of the city park and greenery adjacent to multi-family housing developments. The eastern part of the estate includes relatively extensive open areas that are part of the GI system; however, these areas directly border industrial zones, making their use for recreational purposes impossible. Their primary function is rather to serve as reserved land for the development and expansion of existing facilities. A significant factor negatively affecting the quality of life within the estate, and more broadly within the city, is the absence of buffer green zones separating industrial areas from residential ones. In this case, these zones are directly adjacent, which reduces both the environmental and landscape values of the area.

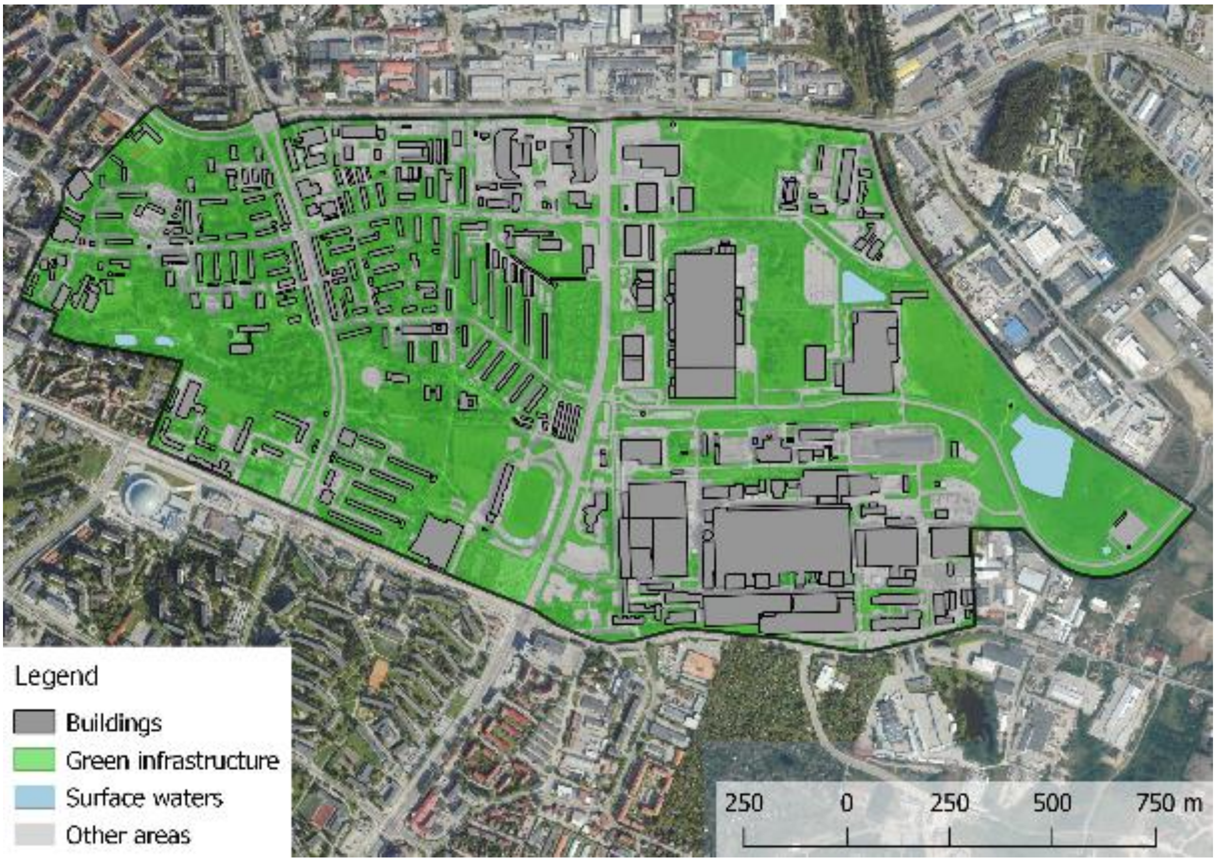

Fig. 7. Location of green areas within the housing estate
Source: Author's own elaboration using QGIS software

Among the GI elements identified within the housing estate, only the municipal park and small patches of GI located within residential areas can be classified as developed green areas. A large proportion of GI elements located within the boundaries of the housing estate are accessible to residents. Exceptions include areas situated within the industrial zone, on school grounds, or belonging to private property owners. Additionally, these elements also provide aesthetic value, particularly in the case of GI directly adjacent to multi-family housing areas and those forming part of the municipal park. However, both the forms and accessibility of high-quality GI can be improved to enhance their diversity and to ensure that residents have access to high-quality green infrastructure in their immediate surroundings (Miszewski et al., 2025).

SWOT Analysis. As part of the study, a brief SWOT analysis was conducted to identify the strengths and potential weaknesses of using GIS tools in local-level GI management (Table 1). The analysis highlighted significant opportunities offered by the implementation of the examined methods in managing GI, as well as the challenges likely to be faced by those introducing these tools at the local level. The most compelling advantages supporting the use of the selected software include enhanced targeting of actions and the ability to respond more efficiently to events and decision-making processes. The main drawbacks appear to be potential difficulties related to integrating the programs into existing conditions and the need for careful data quality management and updating.

Table 1. SWOT Analysis of the impact of GIS tools on the quality of GI management

Strengths	**Opportunieties**
• The capability to perform multiple operations on the same dataset • Universal applicability to various types of activities • The ability to utilize diverse data sources, providing a broader perspective on a given situation • The capacity to present data in a clear and audience-tailored manner • The potential to expand the system with additional functionalities	• Enhanced accuracy of decision-making • Improved management of GI • Better and more efficient planning of ongoing works • Faster response to events related to GI • Adaptation of the city to changes resulting from technological progress • Increased public participation in the GI management process
Weaknesses	**Threats**
• Challenges in data collection • Need for employee training • Requirement to regularly update data on green areas • Necessity to integrate with currently used methods	• Incomplete data • Employee reluctance to adopt new solutions • Difficulties in obtaining and updating data • Public resistance to new solutions • Low public engagement

Source: Author's own elaboration

Discussion

The conducted research demonstrates that effective management of GI in urban areas requires appropriate technical and substantive preparation. Centralized management systems do not always yield optimal results due to their overly general approach and the accumulation of numerous tasks. Therefore, it is crucial to undertake actions also at the local level, potentially decentralizing some responsibilities. The results of the conducted research indicate that GIS tools can significantly facilitate processes related to managing GI (Chen et al., 2024) at the central level and, through the identification of specific application possibilities, also at the local level. The obtained findings confirm that the use of GIS tools provides a wide range of possibilities, including data collection, processing (Crnčević et al., 2017; Bressane et al., 2024), and visualization (Caparrós Martínez et al., 2020; Mobarak et al., 2022; Brom, 2023), which can aid in identifying problems and threats related to green spaces (Heckert & Rosan, 2018; Lee & Oh, 2019; Mironova, 2021). Moreover, these tools substantially support decision-making processes and resource allocation (Lee & Oh, 2019; Caparrós Martínez et al., 2020; Mobarak et al., 2022; Bressane et al., 2024). The combination of GIS functionalities with programs like Excel enables calculation of environmental indicators and the creation of databases for infrastructure managed by a given entity. It is, however, essential not to rely solely on analysis results but to treat them as decision-support indicators (Van Oijstaeijen et al., 2020).

In the initial phase of GIS tool utilization, gathering the most comprehensive territorial data is critical to facilitate subsequent effective analyses and decision-making (Filho et al., 2020; Legutko-Kobus et al., 2024), otherwise, the undertaken actions may prove ineffective, or their outcomes may not accurately reflect reality. This necessitates detailed inventory of the area, with particular emphasis on GI elements and their immediate surroundings. Although labor-intensive, this stage reduces the risk of errors and increases the reliability of analyses and outcomes. To supplement locally collected data, one can always utilize data available through spatial information services. Key terrain characteristics to be identified include functional zoning, existing infrastructure (equipment and surfaces), transportation networks, utility networks and their types, plant species and their parameters, and land cover types.

The use of GIS tools in resource management and GI activities provides numerous opportunities, leading to their growing adoption as analytical and data processing means. Employing consistent tools could minimize disparities in policy and strategy development for GI management across cities and regions. Additionally, the accessibility and potential integration of various pre-existing datasets, supplemented with detailed field data, render GIS an ideal tool for managing extensive datasets in a centralized manner. This approach facilitates more efficient and effective management even at micro-scales, such as neighborhood levels. It aligns with principles of effective GI planning, including practicality, diversity, and integration (Monterio et al., 2020), thus promoting more sustainable GI management in cities through resource consumption reduction (Oppong et al., 2023).

Consequently, it is clear that GIS tools hold substantial potential for enhancing local-level GI management. The analyses conducted provide a basis for testing identified possibilities, though their success depends heavily on data quality and quantity. Effective GIS-supported GI management requires continuous environmental monitoring and regular data updating. In many cases, comprehensive GI inventories will be essential to ensure the data used for decision-making is current and reflective of reality.

These findings enable recognition of GIS application potential in local GI management and illustrate how relatively simple analyses can drive more efficient operations. Proper use of these tools can accelerate decision-making, improve work planning precision, and optimize resource utilization. Developing a more advanced system based on accurate territorial data could reduce errors in green space maintenance and establishment, as well as facilitate socially acceptable solutions. However, the increase in public awareness, as mentioned by Deksissa (2014), cannot be directly achieved solely through the use of the analyzed tools. GIS tools can support this process by presenting data in a more comprehensible and accessible way through visualization techniques. Nevertheless, without an appropriately tailored communication strategy or basic public skills in using such types of software, these tools alone cannot effectively fulfill this role.

The results may be employed to enhance GI management at local levels, including neighborhood areas. It is crucial to tailor the selection of GIS functionalities to the specific needs of the managing entity. A practical tool in this context is a compilation of GIS application possibilities for GI management within a selected area. However, direct application may not always be efficient due to varying environmental conditions and distinct challenges faced by different entities.

Further research should focus on identifying the needs of GI management units, the challenges they encounter, and resident expectations. Additionally, it should aim to develop tools that support shared environmental policies, investment planning, and decision-making processes.

It is important to remember that not all developed solutions are universally transferable due to factors influencing the choice of the appropriate management model. Exploring the possibility of creating common systemic solutions could harmonize GI management approaches in urban areas regardless of environmental variations and social expectations.

Conclusions

The conducted research made it possible to define the potential of using GIS tools in GI management at the local level through the analysis of a selected residential area as a case study. The obtained results clearly indicate which aspects of GI management can be easily and effectively analysed using the mentioned software, while also highlighting its limitations and potential obstacles to conducting precise analyses. These limitations are mainly related to data quality and currency, as well as human resource capacity. The empirical research led to the following conclusions:

- Effective GI management using GIS tools depends largely on the quality and currency of the data, which directly enhance the efficiency and accuracy of undertaken activities. However, this requires continuous updating of spatial datasets. Missing or incomplete data can be supplemented through map-based or field inventories.
- GIS provides a wide range of functionalities for local-level GI management, such as data mapping, visualization, and surface calculations, which effectively support decision-making processes. The integration of GIS tools with spreadsheet software (e.g., Excel) enables the calculation of environmental and spatial indicators.
- GIS facilitates the use and visualization of diverse spatial data in a manner tailored to users' perceptual abilities, thus improving the understanding of existing spatial conditions. However, it does not directly contribute to enhancing public knowledge or environmental awareness.

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