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Research Article

Analysis of green infrastructure and nature-based solutions in Warsaw – selected aspects for planning urban space

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Analysis of urban green infrastructure is used to identify the concepts of its planning, implementation, and management at the level of the whole city as well as its individual parts. Green infrastructure, as a planned network of natural and semi-natural elements in cities, delivers a wide range of ecosystem services and improves urban environmental conditions. Planning the network of green infrastructure becomes a standard part of urban and spatial planning. Implementation strategies of green infrastructure in urban environment include applications of new specific elements and nature-based solutions. Green infrastructure research covers a wide range of topics. Our research focuses on the selected aspects of spatial analysis of green infrastructure in the city of Warsaw: distribution of main public green areas at the urban scale – forests and parks in the urban fabric, the forms of their protection, the use of linear elements of green infrastructure along communication routes, and the implementation of new elements of nature-based solutions in the urban environment – green roofs, green facades, and rain gardens. Based on the analysis of the studied selected aspects, recommendations were formulated for strengthening the interconnectivity of the green infrastructure system at an urban scale and implementation of new green infrastructure elements and in the intensively built-up districts where the number and size of green areas are insufficient.

Keywords: green infrastructure, urban planning, spatial analysis, nature-based solutions

1 Introduction

Strategies of the European Commission for planned network of natural and semi-natural elements and green infrastructure in cities aim to improve the environmental conditions in cities and thus the health and quality of life of citizens (European Commission, 2022). At the same time, it seems that not only the percentages of natural elements and their availability to the population are relevant, but also their interconnectedness to the landscape and rich species biodiversity.

A strategically planned network of green infrastructure can deliver a wide range of ecosystem services such as water purification, air quality, space for recreation, and climate mitigation and adaptation. Elements of green infrastructure have physical, psychological, emotional, and socio-economic benefits for individuals and society (Hudeková, Mederly & Tóth, 2018) and represent a holistic approach to connecting natural and green areas in the city.

So as for the human species, there was simply not enough time to adapt to an artificial urban environment and nature still represents a vital environment that can eliminate increased stress and mental health problems (Beatley, 2011; Kellert, 2018). The results of research at the interface of neurology, cognitive sciences, and environmental design have shown (Klichowski & Patricio, 2017) that the natural external environment significantly positively affects the cognitive functions of the human brain, in contrast to the artificial urban external environment. The quality of natural elements and green infrastructure thus represents a necessary factor for the satisfaction of the inhabitants and for the overall quality of the city (Joklová et.al, 2019; Noszczyk et al., 2022). Of particular importance is vegetation, which

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in addition to absorbing CO_2 also has other functions – microclimatic, environmental, recreational, social, and aesthetic. Greenery is understood as an effective measure to mitigate the effects of climate change, has a positive impact on public health. It is emphasized that green infrastructure elements in large cities, such as: green roofs, parks, and alleys, provide benefits for the health of the population, such as: clean air and better water quality, contribute to the protection of human health, save energy, and facilitate rainwater management. It is necessary to ensure that green infrastructure becomes a standard part of urban and spatial planning (Zachariasz, 2019; Pochodyła, Glińska-Lewczuk & Jaszczak, 2021).

Implementation of green infrastructure solutions is important especially in large urban agglomerations to alleviate accumulated environmental problems and mitigate heat island effects (Supuka, 2018; Tóth, Halajová & Halaj, 2015). As noted by Depietri (2022), urban green infrastructure is desirable to complement grey infrastructure in urban areas and synergistic outcomes result from the design and implementation of elements of urban green infrastructure. The implementation of urban green infrastructure represents a win-win solution for urban sustainability (Depietri, 2022; Derickson, Klein & Keeler, 2021).

For the planning of sustainable cities Ahern (2007) emphasizes that green infrastructure supports ecological and physical processes in the built environment including hydrology, bio-diversity, and also cultural-human activities. Green infrastructure is a concept that is closely tied to blue infrastructure and applies principles of landscape ecology to urban environments (Ahern, 2007).

According to Kováč (2018), the concept of greenery in cities should be an integral concept of the city's vision in strategic or master plan documents. The concepts of the green infrastructure are based on the morphological and climatic conditions of the city, the character of its urban structure and public spaces. Thus, each city has its own system of green infrastructure with different degrees of connectivity. The development of the system should be clearly defined in urban concepts at the level of the whole city as well as its individual parts (Kováč, 2018).

Our research focuses on the selected aspects of spatial analysis of green infrastructure in the city of Warsaw: distribution of main public green areas at the urban scale – forests and parks in the urban fabric, forms of their protection, the use of linear elements along routes, and the use of new nature-based solutions.

2 Material and methods

The main sources of data for the research of the spatial distribution of green infrastructure in the urban fabric of Warsaw were map materials, land-use planning documents, and field research. Based on data from satellite maps, selected elements of the green infrastructure in Warsaw were identified, and the data were supplemented and confronted by field research. During the field research, photographic material was also collected, documenting the individual typological groups of elements of green infrastructure. Specific attention was paid to the survey of forms of protection of green infrastructure, the survey of the spatial distribution of green areas in the urban structure and their connectivity. Attention was given also to the analysis of linear elements – plantings along communication routes. This analysis covered first and second-category routes. We also examined the implementation of current technical solutions of green infrastructure elements and nature-based solutions into the urban structure of the city – applications of green roofs or facades and rain gardens.

Maps showing the typology and spatial distribution of green infrastructure, forms of nature protection, forest areas and natural greenery, public parks, squares, greenery along communication routes as well as green roofs, walls, and rain gardens within the administrative boundaries of the city, were created and became the basis for analysis. Software technologies of computer-aided design systems (CAD software) and geographic information systems (GIS software) were used in the creation of maps. QGIS, a free open-source platform, supporting viewing, editing, and analysis of geospatial data, and 2D and 3D CAD programs (AutoCAD) were used to explore design ideas, visualize concepts and schemes simulating the green infrastructure spatial performance in the urban fabric.

3 Results and discussion

3.1 Analysis of distribution of green areas in urban fabric and their connectivity

Based on data collected during field research and analysis of satellite maps, the location of selected elements of the green infrastructure in Warsaw – the main green areas of forests and parks are depicted in Fig. 1.

The greater density of forests and natural areas occurs in the southern districts of Warsaw, less in the northern part of the city's administrative boundaries. These areas have the potential to form the so-called green belt around Warsaw. The discontinuity of the green belt occurs mainly in the vicinity of the main access roads to the city. An important corridor of green-blue infrastructure is

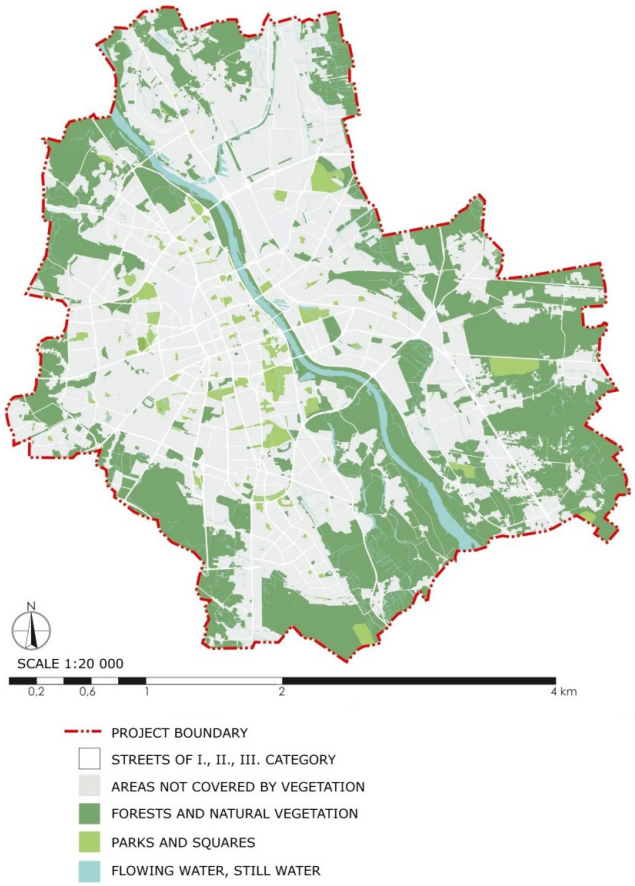


Figure 1 Distribution of green areas within the administrative boundaries of Warsaw
Source: Pochodyła, 2018

formed by the Vistula River and it connects the northern and southern parts of the city's green belt (Fig. 1).

The intensity of green areas also decreases significantly towards the city center, which is influenced by the densifying forms of built-up areas and urban development in the center.

In the central parts of the city, parks or green squares represent the main typological forms of green areas. The largest parks in Warsaw is Pole Mokotowskie (approx. 73 ha), Park Marszałka Edwarda Rydz-Śmiały (approx. 53 ha) and Park Skaryszewski (approx. 50 ha). Field observations have confirmed that the parks are considered attractive places for residents and tourists. They are often visited by users of all ages and are well maintained. In addition to the high vegetation and additional plantings, which improve the aesthetics of the places, water reservoirs can be seen in many parks, supporting the concept of connecting green and blue infrastructure (Pochodyła, 2018). The distribution and typology of the park areas vary considerably depending on the location in the city. The largest number of green squares as specific types of green spaces are in Śródmieście, in the center of Warsaw.

3.2 Forms of protection of green areas in Warsaw

The significant green areas in Warsaw are protected by various forms of protection, protected areas are located mainly on the northern and southern outskirts of the city (Fig. 2). Some forms of protection overlap, e.g. the Vistula Valley in Warsaw is established as a specially protected Natura 2000 site (Central Vistula Valley), the Warsaw Protected Landscape Area, and, additionally, it acts as an ecological corridor. In the north-western edge of the city there is a part of the protected zone of the Kampinos National Park, and in the south-eastern edge, the part of the Mazovia Landscape Park with a buffer zone. In addition to the central Vistula Valley, there are several special areas of Natura 2000 protection: Bielanski Forest, Natoliński Forest, Forest of Jan III. Sobieski and Rembertów test site. In addition, the following areas have been designated as nature reserves: Bielański Forest, Kabacki Forest, Natoliński Forest, Skarpa Ursynowska, Morysin, Czerniakowskie Lake, Zawadowskie Islands, Forest of Jan III. Sobieski, Olszynka Grochowska and Kawęczyn.

The protected green areas in Warszaw are shown in Fig. 2.

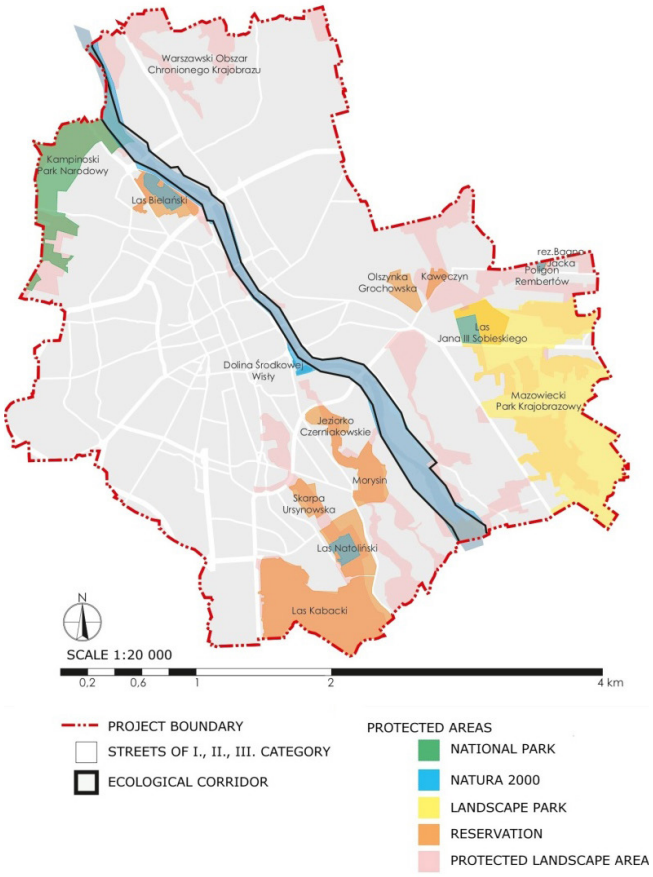


Figure 2 Forms of protection of green areas in Warsaw
Source: Pochodyła, 2018

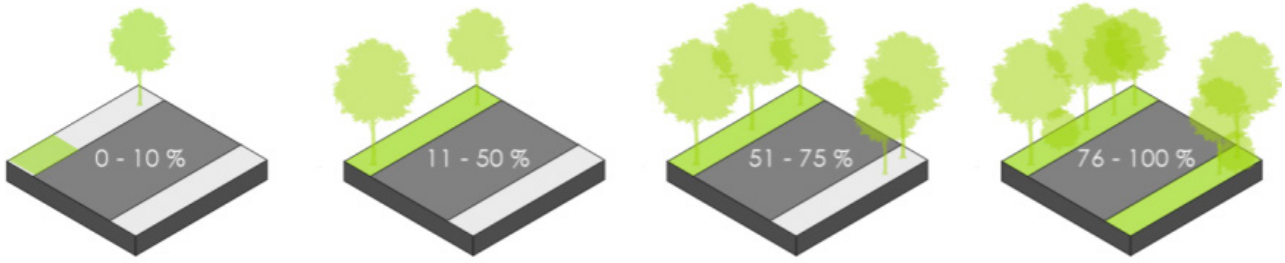


Figure 3 Planting intensity categories along communication routes
Source: Pochodyła, 2018

3.3 Linear elements of green infrastructure – plantings along communication routes

Other analyzed elements of green infrastructure were plantings along communication routes. The analysis covered first and second-class roads. According to the proportion of plantings in the relation to the length of roads, 4 categories were created for the purposes of analysis (Fig. 3).

These categories of planting intensity of the accompanying vegetation along road routes are shown in Fig. 4. Sequences of the communication routes where, in the relation to the total length of the road, plantings occupy 10–50% are marked in orange, sequences where plantings occupy 51–75% are marked in yellow, and sequences where plantings represent more than 75% are marked green. Fragments with a slight proportion of the vegetation (less than 10%) do not have a color-coding (Fig. 4). Roads with the smallest representation of accompanying vegetation are located mainly in the city center (for example Ulica Marszałkowska – Fig. 6), in the southeastern part of the city, and also along access roads from the southwest. More intensive plantings along the roads are found mainly in the southern districts of Warsaw (Fig. 4).

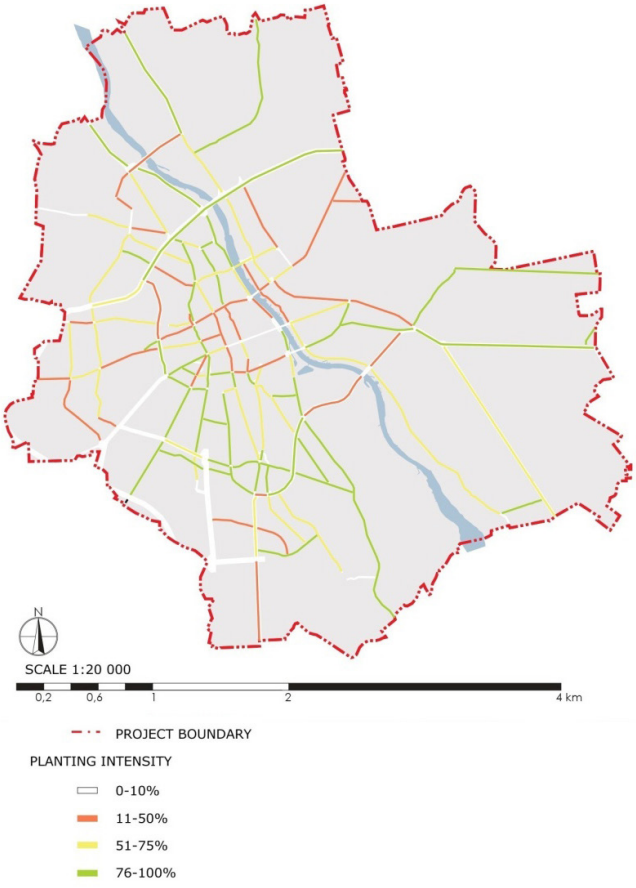


Figure 4 Categories of planting intensity of the accompanying vegetation along road routes
Source: Pochodyła, 2018

The most common forms of vegetation along Warsaw roads are strips of lawns or trees. Common species include *Tilia cordata*, *Acer platanoides*, *Acer negundo*, *Populus canescens*. Climbing plants, such as *Parthenocissus quinquefolia*, are sometimes used on noise barriers. Compositions of a low, medium, and high vegetation are less common. An interesting approach that fits into the idea of green infrastructure is the greening of tram lines, which can be seen in Warsaw, for example, on Anders Street (Fig. 6) or O. J. Popiełuszko Street (Fig. 5).



Figure 5 Green tram line along the Popiełuszko street
Source: Pochodyła, 2018



Figure 6 Examples of analyzed streets: Marszałkowska street without vegetation (left) and Anders street (right)
Source: Pochodyła, 2018

3.4 Current technological solutions, green roofs, facades and rain gardens

The use of current technological solutions was also analyzed, in applications of green roofs or facades and rain gardens. Based on the field research, 17 green roofs and 10 rain gardens were identified in Warsaw. These elements are located mainly in the central part of Warsaw. Roof gardens are located mainly on public buildings, such as the Copernicus Science Center and the University of Warsaw Library (Fig. 7). Among residential buildings, such solutions can be found, for example, in the Żoliborz Artystyczny housing estate. Green roofs are also popular in commercial buildings, e.g. C.H. Arkadia or Złote Tarasy.

The most popular green exterior wall is located on the street of I. Krasicki, or Koszykowa street. The rain gardens, which were implemented under the "Warsaw Catches Water" program, implemented by the Sendzimir Foundation 108, are located mainly at educational institutions.

The analysis of the existing elements of green infrastructure in Warsaw shows that the green infrastructure network is fragmented and dispersed. The number and size of green areas are insufficient, especially in the densely built-up urban fabric of the city center, in the adjacent neighboring districts, and in the northern part (Białołęka district). Urban development and urban densification lead to an increase in buildings and paved areas. Similar results are provided by Kuchcik et al. (2016) or Szulczewska, Giedych & Maksymiuk (2017). Kuchcik et al. (2016) report, that the ratio of biologically vital areas in older housing estates is 54.3% and in newer housing estates 40.7%. According to Szulczewska, Giedych & Maksymiuk (2017) forests cover 17% of the total city surface, and they are located mainly in urban peripheries, green spaces represented by parks, smaller pocket parks, allotment gardens, cemeteries, estate, and street greenery cover 8.8% of the city area and the distribution of green spaces in the urban fabric is uneven. Nevertheless, it should be noted that existing forest and park areas are extensive at the urban edge and the vegetation in these peri-urban areas is in good condition, having the potential to form a green belt around Warsaw. Along the communication routes, new plantings become introduced, specifically along tram lines.

Based on the analysis of the distribution of green areas in the urban fabric and their connectivity, linear elements of green infrastructure – plantings along communication routes and the use of current technological solutions, green roofs, facades, and rain gardens, the guidelines were formulated, which indicate recommendations for



Figure 7 Nature based solutions: green roof and rain garden at the Library of Warsaw University
Source: Pochodyła, 2018

implementation of new elements of green infrastructure and for management of existing resources:

- Uninterrupted continuity and interconnectivity of the green infrastructure system should be maintained or created.
- Efforts should be made to introduce new interconnecting elements of green infrastructure and to minimize the loss of greenery on the outskirts of the city (for example eco-ducts in the points of discontinuity of the green belt by the main access roads to the city).
- In areas with high natural and landscape value, recreational functions should be minimized and adapted to the capacity of the areas.
- Vegetation lanes should be introduced on bypasses, expressways, and along main roads within the Warsaw borders.
- Plantings along the communication routes should be intensified.
- Implementation of green infrastructure elements (planting and rain-water management solutions) at existing car parking areas.
- Implementation of specific green infrastructure elements in intensively built-up areas and new development areas (green walls, green roofs, and rain-water management solutions).

4 Conclusions

The research on green infrastructure and its relationship to patterns of the urban fabric is important for identifying its planning concepts at the multi-scale levels, from the whole city as well as to its individual parts. The analysis of selected aspects of the green infrastructure in the city of Warsaw showed that the green infrastructure network is in many parts of the city fragmented, the number and size of green areas are insufficient in the densely built-up areas, and only a few examples of the use of new elements of green infrastructure as green walls, green roofs, rain gardens or plantings along transport corridors were found. The analysis enabled drawing recommendations for the improvement of the conditions of the existing network, while the main recommendations include: strengthening the interconnectivity and introduction of nature-based solutions and specific new elements of green infrastructure as green walls, green roofs, rain gardens, or plantings along roads and green tramlines, to improve the environmental conditions in the areas where it is not possible to create other types of green spaces.

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