
GREEN INFRASTRUCTURE AS A VERY IMPORTANT QUALITY FACTOR IN URBAN AREAS – WARSAW CASE STUDY

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Abstract. This study seeks to show – by reference to the example of Poland’s capital city – the important role played by green infrastructure in a city’s spatial structure, as well as the functions served as an important element of urban space exerting an influence on people’s quality of life. The article describes the spatial structure characterising Warsaw’s green infrastructure, its different component parts, and its connections with undeveloped areas surrounding the city. Attention is paid to the different shares that biologically active areas account for in the different Districts making up Warsaw. Also, predictions are made regarding likely directions of change in the city’s land-cover structure.

Key words: green infrastructure, human wellbeing, climate change, Warsaw.

Introduction

Definitions in the field of green infrastructure in urbanised areas typically resort to a network approach, based on conceptual assumptions that make reference to ecological systems, and hence to patches and corridors. This true is above all for the establishment of networks between areas linked functionally that are important from the point of view of efficiency of green urban systems having the best possible linkage with external ecological networks made up of undeveloped areas of high natural value (Degórski 2009). Green infrastructure in the cities plays a great many different roles that go a long way in determining the quality of life of inhabitants (Ahern 2007; Wright 2011; Norton et al. 2015). There is no doubt that a key function of green infrastructure from the point of view of person residing in an urbanised area is the increased safeguarding of health that such infrastructure can ensure. For this reason, amongst others, the last decade has seen a great deal of attention paid to research on this particular aspect (Benedict & McMahon 2006; Pauleit et al. 2011; Wolch et al. 2014; Abreu-Harbich et al. 2015; Klemm et al. 2015; Norton et al. 2015). This has taken place in the context of efforts to reduce the negative impact of the urban heat island phenomenon on human organism, as well as to adapt towns and cities to climate change (Gill et al. 2007; Byrne & Yang 2009; Błażejczyk et al. 2014; Brown et al. 2015; Byrne et al. 2015).

According to the European Union definition (2013), the green infrastructure as a strategically planned network of natural and semi-natural areas with environmental features is designed and managed to deliver a wide range of ecosystem services, such as water purification, air quality, space for recreation, and climate mitigation and adaptation. Moreover, this network of green (land) and blue (water) spaces can improve the environmental conditions and thus the health and quality of life of urban inhabitants. It is worth to quote the fact that green infrastructure planning is a successfully tested tool to provide environmental, economic and social benefits through natural solutions and help reduce dependence on 'grey'.

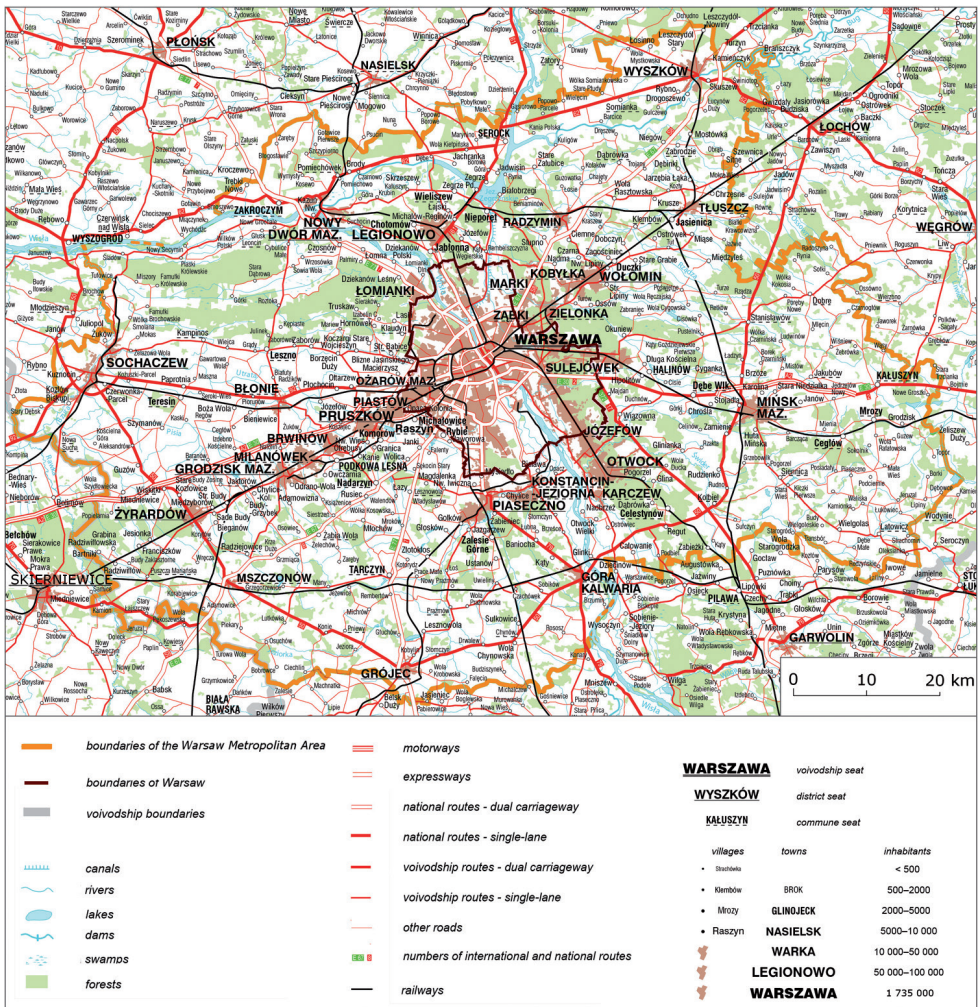


Figure 1. Warsaw's location as set against major natural units

The work described in this paper has sought to use the example of Poland's capital, Warsaw, to illustrate the important role that green infrastructure plays in a city's spatial structure, as well as the functions it serves as an important element in urban space, influencing people's quality of life

life. The objective has thus been to determine the overall natural function provided by the green infrastructure within the spatial structures of a representative urbanised area, as well as the role it plays in increasing the quality of life enjoyed by the inhabitants.

The analysis was dedicated to Warsaw, a city inhabited by 1.735 million people (as of 2014), and covering an area of 517.24 km², that still has very favourable natural linkages with surrounding areas. Ecological continuity with the systems beyond the city limits is assured by the valley of a large river (the Vistula) – also a major N-S axis of the city, as well as by large woodland areas which serve as “green lungs” of Warsaw, together with even more extensive areas just beyond city limits, namely the Kampinos National Park to the north-west, the Mazowiecki Landscape Park to the south-east, the Legionowo Forest to the north-east and the Chojnów Forests to the south-west (see Fig. 1).

The development of green infrastructure as a basis for raising the living standards of city-dwellers

Experience to date, reflecting both theoretical and empirical research and long-term monitoring of the functioning of green infrastructure system in urbanised areas, points to investment in such infrastructure as being very much justified from the economic point of view. A principle underpinning the EU’s environmental policy dictates that prevention is better than cure; not only because of the naturally-justified functional solutions involved in strengthening of the ecological system, but also on account of lowering of the costs that would otherwise be incurred in addressing the negative consequences associated with civilisation. In this regard, it is particularly important that the functioning and effectiveness of ecosystems in core of urbanised areas be retained, in line with the basic truth that a great part of services provided link up very closely with the shaping of people’s quality of life, as well as the reinforcement of the urban system’s resistance to negative factors of exogenous nature (e.g. climate change) or endogenous nature (air pollution, damage to soils, and so on).

A key part in improving the quality of life for inhabitants of local communities is to raise their immunity to civilisation diseases that anthropogenic factors may cause or induce. A major role in this can be played by an increased share of green infrastructure, given unambiguous demonstrations of benefits in many long-term studies of both an environmental and a medical profile (Ahern 2007; Thompson et al. 2011). Enhanced green infrastructure in a city’s land-cover structure is found to have a positive impact on mental health, as well as on overall health and wellbeing, of the inhabitants (Thomson et al. 2011).

It has also proved possible to indicate a statistically-significant inverse correlation with the risk of skin problems as well as respiratory system or circulation disease (Kuchcik & Degórski 2009; Pugh 2012). In the case of vascular disease, cardiac arrests in particular, heatwave conditions are shown to be promoting factors at our latitude, with research done in Warsaw itself showing that the impact of this kind of atmospheric circulation is to raise the number of deaths significantly (by around 16%) – in comparison with the mortality occurring under atmospheric conditions more typical for the warm half of the year. The greater numbers and rates of death mainly reflect the development of a heat island, in which the temperature is several degrees higher even than within the same city, but in the more open areas located on the outskirts.

City-centre areas are also likely to become severely polluted, even more so during heatwaves, with unhealthy compounds present, including the carcinogenic benzo(a)pyrene, PM10 and PM2.5

particulate pollution and nitrogen oxides. On very hot days, sunlight combines with the pollutants from car exhausts and other sources thus generating tropospheric ozone, this still further increasing the risk of health problems with respiratory system.

Overall, more and more research attention is now being paid to the relationship between green infrastructure and the quality of life in cities, in a wider context of changing climatic conditions, and the adaptation thereto of urbanised areas (Matthews et al. 2015).

The main components to Warsaw's green infrastructure

In the contexts of both, the quality of life and adaptation to climate change (and first and foremost, the rising temperatures especially burdensome to the inhabitants of large cities), a very important component to urban spatial structure is not merely the presence of green infrastructure, but the fact of its being linked in with natural systems at the regional and supra-regional levels (Degórski 2013). This is true about Warsaw, which was classified – in the expert report entitled the Concept for the Spatial Organisation of the Country until 2030 (*Konceptcja Przestrzennego Zagospodarowania Kraju do roku 2030*) – as a city enjoying a very favourable geographical location, given the presence of both the valley of a large river and direct connection of green space with large forest complexes (Degórski 2007).

Warsaw stands out against other European capital cities in having both woodlands and the still quite natural valley of a large river within its administrative boundaries. Green space can be regarded as one of Warsaw's most valuable assets, given the context of assumed climate change and the necessity to safeguard the quality of life people enjoy, as far as that is possible.

Warsaw's green infrastructure imbues many parts of the city with a specific character and atmosphere, while at the same time representing an element of the city space that plays now – and will in future likewise play – a major role in cooling the city. Negative influences of heat and heatwaves are limited by green infrastructure, same as the most severe impacts of urban heat island phenomenon. A particular role in shaping thermal conditions in the city is played by tall greenery, in the presence of which the air temperature may be lower than in adjacent built up areas by as much as 3-4°C. Given that areas without buildings also report higher values for air humidity, this is in general a more favourable environment for the human organism. In contrast, a lack of greenery or green space (especially tall trees) in public spaces such as squares, greens and roadside pavements, leads to a situation where users of all of these are fully exposed to insolation. A method of easing the burden that this factor imposes is deliberate planting of shade trees. The differences in the amount of heat affecting built in surfaces and the green ones are always found to be large, not least (though not only) because the latter force the movement of air, thus allowing cooler air to penetrate into housing-estate areas. Greenery is also beneficial for the at-least partial regeneration of polluted air that it brings about. Also for this reason, green infrastructure needs to be perceived as a key factor improving the quality of life of city-dwellers.

It is typical for green space in highly-urbanised areas to take the form of city parks or other areas of planned greenery. However, in Warsaw's case, a large green area needs to be treated as representing a separate category, given the amount of woodland, as well as habitats along the Vistula, developed only to a limited degree. Reconciliation of the functions in nature protection with those relating to recreation and climate is thus a necessity, though where climate change is concerned the key role played by green areas is cooling the city, facilitating air exchange, and improving the

sanitary situation. Furthermore, most of Warsaw's woodland or forest complexes require a special approach imposed by the Protective Forest, Landscape Park or Area of Protected Landscape status, enjoyed in particular by the green land along the Vistula, not least thanks to its designation as a *Natura 2000* site, and/or the presence of other forms of nature conservation, cultural heritage status and the existence of a special cultural landscape (as in the case of the Warsaw Escarpment). These are places where an age-old process has linked cultural and natural factors in such a strong way that protection is extended for natural and cultural reasons at the same time. Good examples of this phenomenon are the aforementioned Warsaw Escarpment – in its Ursynów District stretch, as well as the nearby Natolin Wood.



Figure 2. The spatial distribution of green areas, as well as inland water, in Warsaw, in 2006

Source: author's own elaboration, based on Corine Land Cover data (2006).

The most important components of Warsaw's natural system are thus woods and areas of urban green space, notably parks, as well as wild green areas within the Vistula Valley. Warsaw continues to feature a large share of land that has not been built on. Green space together with farmland and waters account for nearly half of the area within the city limits (Fig. 2). Bearing in mind that urbanisation is mainly continuing on farmland, it is worth considering the area of green space in Warsaw, excluding land used in agriculture (Fig. 3).

Figures 2 and 3 present the spatial distribution of the largest patches of greenery (25 ha or more), revealed using Corine Land Cover 2006 methods (European Environmental Agency 2007).

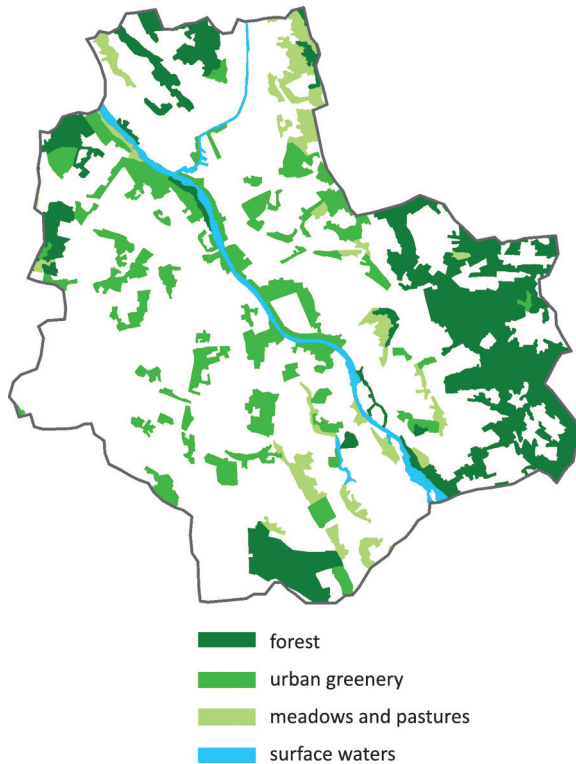


Figure 3. The spatial distribution of green space (excluding arable land) in Warsaw
 Source: author's own elaboration, based on Corine Land Cover data (2006).

Forests

Forests cover some 7,258 ha, or nearly 14% of Warsaw's administrative area (Fig. 3). When other areas with trees and shrubs are added, the proportion increases to nearly 20%. Warsaw is one of few European capitals with such extensive forest complexes, accounting for a significant share of the city's area. Given their Protective Forest status, these areas are of particular significance in shaping urban living conditions. The largest of Warsaw forest complexes are the following:

- Bemowo Wood (*Las Bemowski*), located within Warsaw Bemowo and Bielany districts and partially in the commune of Stare Babice, immediately beyond the city limits, is the third largest forest complex in Warsaw. Thanks to its location as well as its valuable natural features and size it is an important ecological corridor linking the Kampinos National Park with the urban agglomeration (it is the most frequent travelling route for elk *Alces alces*), and playing an important climatic role in the city.
- Bielany Wood (*Lasek Bielański*), covering 151.83 ha of Bielany district, including 130.07 ha of Bielany Wood Nature Reserve and 21.76 ha of its buffer zone. This is the city's largest remaining (and still species-rich) fragment of the primaeval broadleaved forest that once covered much of the Mazowsze region. The unique location of this complex on four of the old flood terraces of the Vistula River makes it an area of key importance for the ventilation and aeration of Warsaw.

- Bródno Wood (*Las Bródnowski*) of 134.08 ha in Targówek district, with an important linking function, since it connects the city with the undeveloped areas to the north-east, providing aeration for the entire city.
- Kabaty Wood (*Las Kabacki*) of 924.72 ha, located in Ursynów and Wilanów districts, representing one of the most important natural areas within the boundaries of Warsaw, is the largest Nature Reserve in Mazowieckie Voivodship (province-region).
- "My Mother's" Wood (*Las Matki Mojej*) of 14.25 ha, located in Wawer district, is a part of the Sobieski Wood (*Las Sobieskiego*) Forest Sub-District. The habitats here are rather nutrient-poor, with fresh or dry coniferous forest dominated by Scots pine and birch.
- Sobieski Wood (*Las Sobieskiego*), also located in Wawer district, covers some 516.60 ha, making it Warsaw's second largest forest. 100 ha of its area is set aside as a strict protection (conservation) zone, the so-called King Jan III Sobieski Nature Reserve, with new mixed pine, oak and lime forest. The relief here is diverse, with the eastern part featuring nutrient-poor pine forest on an extensive area of dunes. The central part consists of flat land covered with mixed forest, and the western part merges with the former two and is covered by broadleaved forest of ancient oaks on more fertile soil.
- Białołęka Dworska Woodlands (*Lasy Białołęki Dworskiej*) of 230 ha, located in Białołęka District, with trees growing on the tallest dunes in Warsaw. There are also some open areas there with typical sandy grassland habitat. Stands are mainly of pine, birch and oak, with the site type representing fresh mixed/coniferous forest.
- Linde Wood (*Uroczysko Las Lindego*), i.e. a 48.33 ha patch of old woodland in Wola district, with a prevalence of coniferous forest site types, and a stand that includes robinia, Scots pine and red oak. The undergrowth and forest-floor vegetation is very well-developed, with cherry dominating. It is a typical example of a piece of urban woodland serving the role of "forest park".
- Młociny Wood (*Uroczysko Las Młociny*), i.e. a 98.09 ha patch of woodland in Bielany district, adjacent to the area within the Vistula River floodbanks. It represents a key site auxiliary to the ecological corridor that the river represents. The stands growing here are among the oldest in Warsaw, with more than half aged 100 years and over (mainly pine, oak, alder and ash). The wettest parts also support patches of riparian woodland.
- Na Kole Wood (*Lasek Uroczysko na Kole*), i.e. a 48.33 ha in Wola district, which came into existence when municipal land was reforested between the Wars. It is mainly coniferous forest, and this area supports robinia, Scots pine and red oak, with well-developed lower layers in which the undergrowth is dominated by cherry.
- Nowa Warszawa Wood (*Uroczysko Nowa Warszawa*), i.e. an area of almost 200 ha in Bielany district, which is a complex of mainly young (40-60 year-old) stands of pine planted after World War II. Pine monoculture dominates, though oaks, birches and aspens appear sporadically as admixture species. The site is important as part of the buffer zone for Kampinos National Park, and it has a major climatic role as an ecological corridor linking Kampinos with the Młociny Wood.

Urban parks

Parks are another key element to Warsaw's urban green space, exerting a major influence on local conditions, especially in the zone being most highly urbanised, defined in Warsaw's Study on Physical Development Conditions and Directions (*Studium uwarunkowań i kierunków zagospodarowania przestrzennego*) as the urban zone proper. The current administrative setup of Warsaw comprises 76 such parks, covering around 715 ha in total and originating from various periods. For example,

Warsaw's central "Saxon Garden" (*Ogród Saski*) represents the Baroque period, whereas the upper and the lower part of the Arkadia Park are examples of dating back to Romantic era. There are also 19th-century landscaped parks, namely Sielecki Park and Praga Park (Park Praski); as well as parks founded in 20th-century, such as *Skaryszewski* and *Morskie Oko* Parks. Examples of Modernist-style include Wielkopolski and Dreszera Parks.

Various greens, small parks and other smaller areas of greenery are also an important component of urban green space. Given that these are most often located in the immediate vicinity of human living quarters, they provide residents with contact with nature, and offer shady places for rest or children's play (where the greenery is taller), this being crucial on hot days, or those with the heatwave status, with high temperatures and intense insolation. Warsaw can at present boast of some 160 areas of this kind, covering almost 160 ha in total. The largest of these include:

- *Skwer Opaczewski*, in Ochota District, covering 2.69 ha,
- *Skwer im. A. Grotowskiego*, again in Ochota, covering 1.76 ha,
- green space on Powsińska and Okrężna Streets, Mokotów district, covering 1.97 ha,
- *Zieleniec Wielkopolski*, again located in Ochota District, and covering 4.95 ha.

Ecological corridors

The main components of the urban network of protected areas called into being by virtue of domestic or European Community law related to nature conservation, as well as the linkages between the intraurban system and the natural surroundings of the city include ecological areas as well as structures and areas of outstanding biotic potential. The most important such components in Warsaw are the following:

1. The Vistula (Wisła) Valley ecological corridor, protected as *Dolina Środkowej Wisły* ("Middle Vistula Valley) *Natura 2000* site (SPA), and Warsaw Area of Protected Landscape (APL). This is a belt of meadows, woodland and scrub not built on, representing the principal corridor via which Polish capital is ventilated. Within Poland's natural system, this corridor serves as an ecological corridor of Europe-wide significance. It is characterised by the presence of important plant communities, while the status of Special Protection Area under the EU's Birds Directive extends to the whole *Natura 2000* site, i.e. including the part within the city limits. The Warsaw section of this corridor includes Wyspy Zawadowskie and Ławice Kiepińskie Nature Reserves, which encompass not only islands in the river channel, but also land along the banks. The APL is protected in its own right, but it also represents a buffer zone for the land protected as a part of some higher forms, i.e. Landscape Park, National Park, Nature Reserve or *Natura 2000* site. ensuring the continuity of linkage between these protected areas. It also encompasses a heritage mansion park, as well as areas for rest and recreation as well as construction of summer houses. Among other things, the Vistula Valley serves as an ecological corridor for seasonal movements (and attendant stopovers) of birds migrating within Europe, or even beyond.
2. The woodland ecological corridor in the right-bank Warsaw, encompassing the Mazowiecki Landscape Park (of 23,702 ha) located in Warsaw Wawer and Wesoła districts, as well as the aforementioned Warsaw Area of Protected Landscape. From the climate point of view, this area is very important for regeneration of air moving in from the east. In turn, within its non-urban (Vistula Valley parts), the Warsaw Area of Protected Landscape has is aimed to protect forest complexes (notably those beyond the boundaries of the Landscape Park) and safeguard ecological linkages between them. However, in current legal circumstances, private land, not only within the APL, but also within the Landscape Park, can be subject to development and

may be threatened by it. The very attractiveness of the landscape makes it in particular subject to urbanisation pressure – i.e. pressure to build, hence it is likely that it will be more and more difficult to protect these areas from development, resulting in consequent reduction of area under forest and fragmentation of the corridor.

3. An aquatic ecological corridor encompassing the Vistula as such, plus various other smaller watercourses and channels, along with a set of connected lakes that are actually oxbows along former channels of the Vistula (notably the Jeziorko Czerniakowskie–Jeziorko Wilanowskie–Jeziorko Powsinkowskie hydrological system). As has been noted, the Vistula (Wisła) itself is a part of the Middle Vistula Valley *Natura 2000* site (SPA). While the c. 31km section of Vistula within Warsaw has been regulated to a great extent, the river retains some aspects of its wild character, and its course is frequently described as a braided river course. Oxbow lakes are still created, and there are minor channels with numerous picturesque islands, ranging from shifting sandy shelves to more permanent structures overgrown with willow scrub or even fully-developed riparian forest. The sandy islands, shelves and banks represent an essential habitat for many breeding bird species that enjoy protection and/or are included in the Endangered or Threatened categories. These are also places along migration routes where birds and other animals make stopovers to recover strength. Large rivers are known to be followed by migrating birds. As regards climatic aspects, these waters play a key role in cooling the city and ensure more favourable bioclimatic conditions on hot days or in the course of heatwaves. The limited use made of the Vistula in recreation is actually a reflection of its poor water quality, which hinders the development of beach and bathing areas. Nevertheless, it is impossible to ignore the major potential resource present here.

Naturally valuable habitats protected in the form of Nature Reserves

There are 11 Nature Reserves within Warsaw, which represent key elements of the city's green infrastructure. These are:

- the *Bagno Jacka* (Jacek Marsh) Reserve, covering 19.45 ha in Wesoła district, protecting the Habitats Directive-listed *Sphagnum* bogs, characterised by marshy birch forest, alder carr with birch, marshy pine forest, and moist pine forest.
- the *Jeziorko Czerniakowskie* (Lake Czerniakowskie) Reserve, covering 47.6 ha in Mokotów district and representing a natural body of water with a surface area in excess of 14 ha, some 1.65 km long, 0.11 km wide and with a maximum depth of 4.2 m (it is in fact one of several oxbow lakes on the Vistula flood terrace forming a chain from Siekierki south to the mouth of the River Jeziorka);
- the Kawęczyn Reserve, covering 69.54 ha in Warsaw Rembertów district;
- the *Las Bielański* (Bielany Wood) Reserve, covering 130.35 ha in Bielany district;
- the *Las Kabacki* (Kabaty Wood) Reserve, covering 902.68 ha in Ursynów district;
- the *Las Natoliński* (Natolin Wood) Reserve, covering 105 ha in Wilanów district;
- the *Las im. Jana III Sobieskiego* (King Jan III Sobieski Wood) Reserve, covering 114.44 ha in Wawer district;
- the Morysin Reserve – a 130.35 ha area located in Wilanów district, in the interfluvium between the Sobieski Canal and the Wilanówka River;
- the Olszynka Grochowska Reserve, covering 56.95 ha in Praga Południe district;
- the *Wyspy Zawadowskie* (Zawadowskie Islands) Reserve, covering 56.95 ha in Praga Południe district;

- the *Ławice Kiełpińskie* Reserve, located where the Bielany and Białołęka Districts meet, with 88.26 ha of the 803 ha area falling within the boundaries of Warsaw.

Naturally valuable habitats protected as Areas of Ecological Utility

Areas of Ecological Utility (*Użytki Ekologiczne*) serve to protect what remains of ecosystems, where the protection of biodiversity is of continued relevance. Such Areas within Warsaw include:

- the "Czesław Łaszek" Warsaw Escarpment AEU, covering 0.405 ha in Mokotów district,
- the "Janusz Kusociński" Warsaw Escarpment AEU, covering 0.592 ha in Mokotów,
- the Lake Imielińskie AEU, covering 3.9595 ha in Ursynów,
- the Powsin and Powsinek AEU, respectively covering 1.66 and 2.85 ha in the Warsaw Escarpment part of Wilanów district,
- the Młociny Wood AEU, covering 4.81 ha in Bielany.

Nature-and-landscape complexes

Nature-and-landscape complexes (*Zespoły przyrodniczo-krajobrazowe*) represent valuable areas of natural and cultural landscape, whose scenic views and valuable aesthetic features are worthy of protection. The Warsaw system of green infrastructure includes 5 such areas, namely:

- Arkadia, i.e. a 14 ha area in Mokotów district adjacent to the Królikarnia Park,
- Dęby Młocińskie (the Młociny Oaks), i.e. a 9.26 ha area in Bielany district,
- Olszyna, i.e. a 2.23 ha of Bielany,
- the Park of SGGW (Warsaw University of Life Sciences), i.e. a 1.65 ha in Mokotów district,
- Zakole Wawerskie, i.e. a 55.6186 ha area in Wawer district.

Warsaw's ecological and climatic shield

The 148,409.1 ha Warsaw Area of Protected Landscape was established in 1997 to preserve ecological balance between areas of green infrastructure and built-up areas, to assure the inhabitants of Warsaw agglomeration good climatic/health and recreational conditions, to nurture natural linkages between areas covered by higher-order forms of protection, and to offer buffer-zone protection to such areas. The Area was divided into two designated zones, i.e. zone of special ecological protection (with areas of high biotic potential) and an urban-planning protection zone (mainly within the city). The aim was to extend protection against urbanisation pressure to areas with the most valuable natural and landscape features. The Warsaw APL is also called a system for ecological shielding of the city. Next to the aforementioned areas along the Vistula Valley, as well as the wooded belt in the right-bank Warsaw, the APL forms a whole system of spatially-interlinked sites designed to ensure aquatic and forest continuity right across the agglomeration. In this way a cohesive natural system linked with areas outside Warsaw was established, with spatial connections and buffer-zone facilities for areas enjoying higher-order protected area status.

The Warsaw APL, along with Kampinos (Kampinoski) National Park, Mazowiecki Landscape Park and Chojnów (Chojnowski) Landscape Park, makes up a system of ecological shielding for Warsaw, with ecological corridor along the Vistula Valley offering a land route, an aquatic route and an air route through the capital. This means the implementation of the idea that Warsaw should be surrounded by a ring of forests: from the Chotomów and Legionowo Woods in the north-east, to the Otwock and Celestynów Woods and then Chojnów, Sękocin, Nadarzyn and Młochów Woods in the south

and south-west, and *Puszcza Kampinoska* – the largest and most valuable forest complex – in the west. The Study of Spatial Development Conditions and Directions for Warsaw foresees naturally valuable areas as being incorporated into the so-called Natural System of the City, which will also include belts serving to ventilate the city, including river valleys (above all that of the Vistula and associated oxbow lakes), as well as the Wilanów corridor and the Warsaw Escarpment.

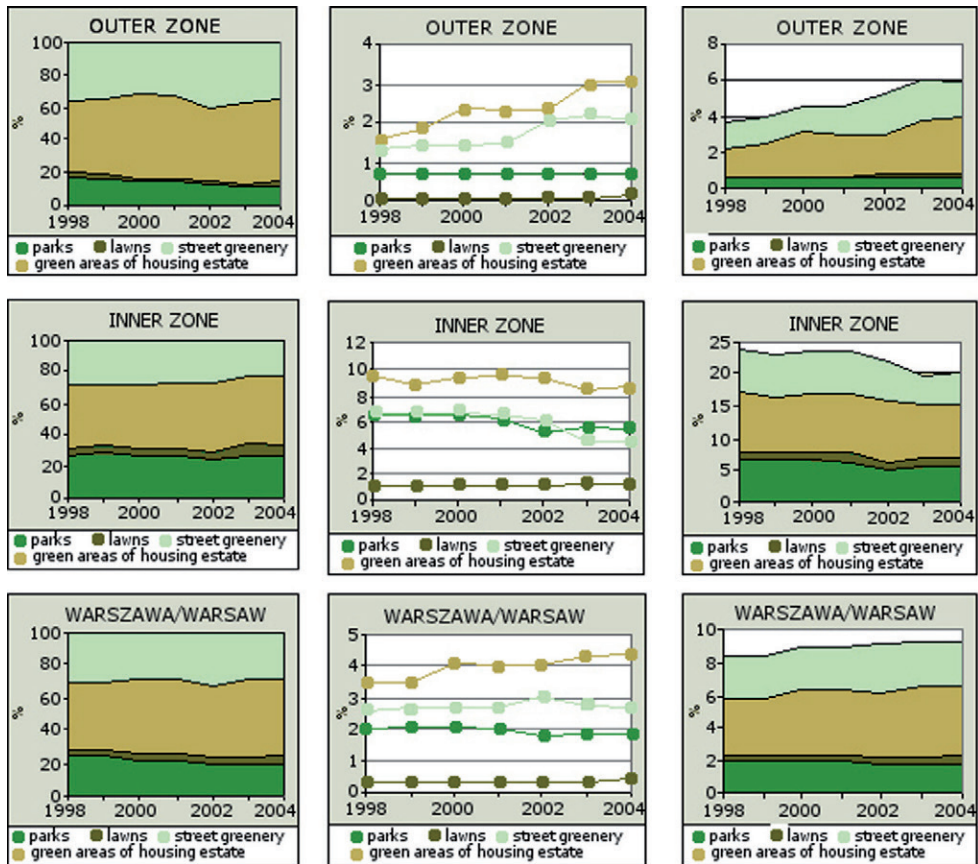
Spatial differentiation in Warsaw green infrastructure

Warsaw is a city where the share of green infrastructure is (remains) high across the entire urban area. If farmland is included, the figure is almost 50%, and this is undoubtedly a very positive feature from the point of view of the functioning of Warsaw natural system as a whole. Green infrastructure plays a significant role in easing the negative consequences of possible climate change and the resulting worsening of the urban heat island effect, as well as the generally burdensome nature of living in a large agglomeration. If agricultural areas are excluded, the percentage of green areas in Warsaw is close to 33%. According to H. Odum (1971), this is still a quite balanced state between urbanised space and green areas, sufficient to ensure natural bases for a large city to go on functioning.

Nevertheless, Warsaw seen as an urban organism formed from smaller administrative units, at district level has to be seen in a different light, as in fact very disparate internally, with differences in the share of green infrastructure areas ranging from as low as 2% noted in Ursus district, up to the ca. 62% recorded for Wesoła. Where the favourable (one-third of the area still green) threshold is concerned, qualifying districts are Rembertów (ca. 46%), Wawer (ca. 43%), Bielany (ca. 40%) and Targówek (ca. 35%). At the other end of the ranking there is the aforementioned Ursus (ca. 2%), Wola (ca. 12%) and Włochy (ca. 16%). Here the situation at the more local level has to be defined as critical. The remaining districts obviously fall in between, with green infrastructure accounting for between 18% and 28% of the area, which is nevertheless below the threshold given by H. Odum (1971), providing natural bases for the functioning of a large city.

Changes in Warsaw's green infrastructure area

Research into changes taking place in areas of green space since 1995 points to districts in which the retention and even development of urban green space (and especially the tall form thereof) would have been particularly important, but which have in fact continued to lose such greenery. Detailed analysis of the various forms of green infrastructure shows a major difference in the directions of ongoing processes in the inner zone (zone within the boundaries of the former municipality of Warszawa-Centrum) comprising the highly-urbanised core of Warsaw, as compared with the districts surrounding that core area – see Fig. 4. It is obviously highly negative from the point of view of Warsaw's adaptation to high air temperatures if the area of green space in the most highly urbanised part of the city continues to decline, which is most especially true when it comes to parks, street greenery and – to a lesser extent – greenery on housing estates. The aforementioned zone of communes surrounding the core has in fact witnessed a rise in area for all categories of green space. In between, there are districts of the zone in which some forms of green space have been lost, like parkland in Bielany, lawns in Bemowo, street greenery in Wesoła, and housing estate greenery in the districts of Bielany, Rembertów, Targówek, Wawer, Wesoła and Wilanów.



* cumulative share

Figure 4. The structure of urban green space and the shares accounted for by parks, lawns, housing-estate greenery and street greenery in the geodetic area of the studied site categories in the years 1995–2004 (according to Degórska and Deręgowska 2008)

Warsaw's green infrastructure in the light of prospective plans and programmes for the development of the city

The sensitivity of cities, and especially large agglomerations, to the negative effects of climate change is increased due to the intensive process of urbanisation of space (especially metropolitan areas) – as a result of which land vulnerable to flooding or inundation is also built on, as are areas of green space in the suburbs or among the housing estates. In result soil becomes sealed off from the elements and its capacity to retain water is impaired. Add to that the impact on drying out areas of wetland, and the deliberate filling-in of small ponds, channelling and/or covering-over of small watercourses and ditches, as well as the huge urbanisation pressure on areas not thus far built on, and it becomes clear how the natural protection of the city against flooding becomes impaired. Likewise, the rapid development of the built-up area can easily swallow up many valuable areas of green space, including within corridors serving to ventilate and cool the built-up city-centre areas.

A steadily increasing density of buildings in built-up areas is an unavoidable phenomenon, unfortunately. Therefore, it is very important for the spatial development of each urban organism to be based around the proper planning of spatial structures, including areas maintained as green space whose overriding purpose will be effective ventilation of the city, as well as high-quality living conditions for inhabitants.

The strategic documents drawn up for Warsaw, i.e. both the Study on Spatial Development Conditions and Directions (*Studium uwarunkowań i kierunków zagospodarowania przestrzennego*) and the Strategy for the Development of Warsaw until 2020 (*Strategia rozwoju Warszawy do 2020 r.*), assume that the area of urbanised space within the city will keep increasing. This is unavoidable, given the need to supply new land with a residential function, as well as the still-limited transport accessibility of the central area from the suburbs. This all adds credence to the view adopted by P. Śleszyński (2012), that the obstacles facing commuters into Warsaw give paradoxical hope for the activation of development work in extensively managed areas within the city's administrative boundaries. Śleszyński also shows how the core of Warsaw continues to feature what is – by the standards of Western European cities – a relatively low index for density of habitation in urbanised areas, and even in the very centre of the capital, given that the value of 10,000 people per km² is barely exceeded. Corresponding values are 2-3 times as high in analogous areas of Madrid or Vienna, let alone centres of London or Paris. It should thus be stressed at this point that Warsaw continues to have at its disposal a large supply of free land for development within the city limits, as well as sites needing to be transformed, rehabilitated or have their function changed. Such areas should be the first places to be built up. The city still enjoys possibilities to plan for good access of inhabitants to green infrastructure, provided of course that appropriate areas are indicated in Warsaw's Study on Spatial Development Conditions and Directions, with protection then being implemented via local Spatial Development Plans.

The longer time horizon is associated with relatively weak further demographic development. This means that further progress with housing construction could well involve a greater and greater role for single-family housing, given the likely increased popularity of this kind of housing, as inhabitants of Warsaw become steadily richer with time. Analyses carried out by G. Buczek and P. Śleszyński (2008) on the potential for available sites to absorb new construction of various categories, in relation to the binding (2006) Study on Spatial Development Conditions and Directions – showed that there is enough space within the city limits to allow for a 1.4 m increase in population, which is to say a near-doubling of the number of inhabitants. An analysis of Warsaw's demographic development through to the year 2035 does not anticipate such a large demand for new development land, mainly new land for housing, as compared with what was foreseen by the 2006 Study. In line with the city's spatial policy set out in that document, the greatest areas of land for development (especially of housing) are offered by right-bank Warsaw, and notably Białoleka and Wawer districts, but also by left-bank areas in Wilanów, Ursynów, Wola, Mokotów and Włochy. This is also associated with the need to develop green infrastructure, not least in the form of parks and housing estate greenery. This is especially true for Włochy, Wola, Mokotów and Wilanów, as well as Ursus, which is not even mentioned in this context, despite major underdevelopment of green space now, to say nothing of the future. Where Wawer is concerned, there is a great need for effective solutions to safeguard forest land against development, while ensuring the fuller and better adaptation of woodland areas for recreational functions (a particular priority, given the lack of publicly-owned managed green space in that district). Almost by definition, it is in these districts that the greatest

losses of open areas will occur in the next 50 years, mostly of farmland, and only to some degree of areas with trees and scrub.

The least-favourable forecastable changes in Warsaw's green infrastructure up to 2070 include the further loss of forest or wooded land, and areas with trees and shrubs more generally. Specifically, this might mean a reduction in green space from 17% to around 14% of Warsaw area, if the loss would mainly affect more isolated areas today supporting trees or scrub. The figure might even go as low as 12-13% if some forest areas will also be affected. This would be a reflection of the ownership structure of Warsaw's forests (excluding the smaller areas with more limited tree or shrub cover) – as much as 3,200 ha of the total forest are of 7,100 ha remains in private hands. It can thus be anticipated that, barring any change in the legal conditioning, privately-owned land under trees will be the first to experience a change in its designation as forest, but the pressure to build housing may also eat into forest complexes proper. At the present time, built-up areas are ever more inclined to encroach upon Mazowiecki Landscape Park. Some losses of forest will also inevitably result from the planned building of a motorway, whose assumed course will again cut across forest complexes in the Mazowiecki Landscape Park.

There is a marked decline in the share of undeveloped green areas that currently ensure favourable conditions for the influx of clean air into the urbanised core of Warsaw. It is anticipated that, beyond the city-centre built-up zone, urbanisation processes will mainly be encompassing what is currently farmland. It can be estimated that the share of open areas together with farmland will be reduced very considerably – from 50% now to around 35-37%. As has already been mentioned, it is arable land that will be most affected by this change (Fig. 5).

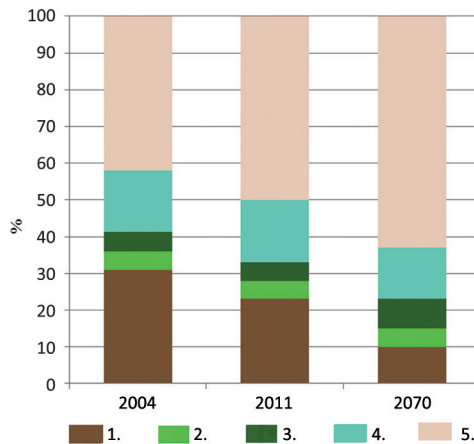


Figure 5. Changes in the area of green infrastructure in the 2004-2011 period, as well as the forecast for the years up to 2070; 1 – building and communication infrastructure, 2 – wooded and shrub areas, 3 – greenery, 4 – green areas and water in the Vistula band, 5 – other green areas and arable land

Source: author's own elaboration on the basis of 2011 Registry of Land and Buildings as well as the Corine Land Cover database after Błażejczyk *at al.* (2014).

In line with the city's spatial policy as expressed in the *Strategy for the Development of Warsaw up to 2020*, it is assumed that the green belt along the River Vistula will be effectively protected (thanks to *Natura 2000*). Nevertheless, some loss of green space along Vistula will take place as the so-called "waterfronts" take shape, with boulevards, river moorings and areas allocated for other

services associated with the planned revival of the riverbank area. However, in line with the *Strategy*, the key changes should concern the quality of space, with a river park (Vistula Park) being developed, that will combine recreational functions with protection of animate nature and the landscape, and will function as Warsaw's most important corridor ensuring free air flow.

As Warsaw lacks a binding document of the "programme for the development of green infrastructure in the city" kind, it is very difficult to predict further changes in this regard. Given the nature and scale of changes that have taken place in the last 10+ years (Degórska & Deręgowska 2008) affecting park greenery, greens, squares, street trees and housing estate green spaces, it is possible to foresee that the urbanised core of Warsaw will go on losing housing-estate greenery, while a small reduction in the area of parks, greens and street greenery may also come about. On the other hand, districts subject to the very intense development of new multi-family residential housing are expected to increase their areas of parks, squares and greens considerably. By 2070, almost doubling of these areas if foreseen, as well as a far more even distribution of the aforementioned forms of urban green space across the different districts of Warsaw.

The city's spatial structure as regards ventilation in the light of current or planned spatial development

The main factors influencing the ventilation of a city are – on one hand – the the strength and direction of the wind, and – on the other hand– the spatial structure of the city itself (including its green infrastructure). Warsaw is prevalently under the influence of westerlies, and the construction of the city exerts a major influence on modifying the stream of masses of air flowing into the city. The influx of air from the east and south-east is limited by the forest complexes within the Mazowiecki Landscape Park, as well as by multi-storey residential buildings on the Bródno and Targówek housing estates. Nevertheless, forest complexes represent zones of regeneration of the air flowing in above the city (areal influxes). The main channel via which Warsaw is ventilated is the Vistula Valley. Masses of air flow along it, mostly from the north and north-east. Also the influence of the spatial structure on wind strength is of significance – it determines the effectiveness of airing. 30 years of study of mean wind speeds measured at the periphery and in the centre of Warsaw suggest a nearly-60% difference between values recorded at the two places (means of 4.1 and 1.7 m/s respectively). Wind speeds in the city centre are far lower than in the suburbs (Kosieradzka 2011).

Also of major significance for the effectiveness of city ventilation is the internal system via which the place is aired. Air circulation on the local level is induced by differences in temperature – and resultant differences in pressure – between the city centre and its surroundings. As a result of these differences, the evenings and nights see a breeze circulation (with air currents directed downwards inside the city, causing upward displacement of heated air from over the centre). In Warsaw, in addition, the circulation of air is rendered more complex by the spatial structure and location of the river. During the warm part of the year, the Vistula Valley and surrounding land are characterised by lower temperatures than other areas, with this being of significance for the shaping of the urban heat island. A major function in maintaining good sanitary and thermal conditions in city interiors is played by aeration corridors. Keeping these clear and unblocked is expected to be one of major challenges for the upcoming decades. According to an ecophysiological study (2006), only the corridors of the Vistula, Wilanów district, the area below the Warsaw Escarpment and Bemowo have been included almost in their entirety within the so-called natural zone. The remaining areas

are characterised by their affinity with the zones under development, and in result most of the corridors are not safeguarded against becoming built up. Nevertheless, an overall analysis of spatial distribution of the corridors aerating the city allows it to be stated that these permit the influx of fresh air in many places, from all geographical directions. However, the corridor configuration that would have been planned in an ideal world has already been depleted markedly by the very active urbanisation processes.

Summary

The Warsaw area is characterised by a high share of green infrastructure within the overall spatial structure of the city and its surroundings. Presented here, the multifunctional role in shaping the urban system is a key factor promoting resistance to the threats posed by civilisation, above all (though not solely) climate change. With a view to Warsaw's natural system being further strengthened as regards its resistance to endogenous and exogenous factors, with the quality of life for inhabitants also raised, it is necessary for steps to be taken forthwith to improve the functioning of – and real protection offered to – the natural system, as well as the system by which air is exchanged and regenerated. It is necessary to point to the following targeted actions that may be regarded as of greatest importance:

- A spatially cohesive and effectively managed system of green space constituting an ecological network for Warsaw needs to be created, and it should be linked up with natural surroundings at regional level. The ecological network should be built out of biocentres linked together by ecological corridors that are spatially contiguous with Warsaw's "green ring". Such a ring would obligatorily have to be marked out in the spatial development plan for Warsaw's metropolitan area, as an area of permanent natural use. Besides the areas encompassed by different forms of nature protection, the network should also include all of Warsaw's forest complexes, green recreational areas (including larger patches of urban green space), and corridors allowing for the exchange and regeneration of air, albeit with the exclusion of corridors serving transport functions.
- Warsaw's ecological network and system of ventilation should be taken into account in all of the city's planning and strategic documents; boundaries of areas included within the network should be precisely defined, first and foremost boundaries of forests and urban green space of all different categories. Also green areas associated with the proposed ecological network, local protection plans and ventilation system should be accounted for in the strategic documents, and prohibitions on further building development in such areas should be introduced.
- The share of areas with tall greenery should be increased, including where these serve recreation-related functions. Areas of this kind should be distributed more evenly across the city, and should link up with the Warsaw ventilation system. There should be further progress with street trees offering natural shade for pavements, as well as shade for squares, greens and play areas as elements of great importance for the cooling of the city. Efforts also need to be made to enhance movement of air allowing for better penetration of the heart of the built-up area, and also offering partial protection from insolation, especially on hot days or in the course of heatwaves.
- Urban-planning practice should make a wider use of green roofs, terraces and ceiling-roofs, as well as green walls, most especially in housing-estate areas where the share of biologically active land is now very low.

- Warsaw's woods and forests should be kept in good condition and protected against building; this should be justified by the need to retain their climatic potential and to protect biodiversity and places suitable for recreation.
- Efforts should be made to increase the area of tall greenery, including woods in areas feeding into the ecological corridors. Close cooperation with local authorities in the suburban zone will be required to this end as well as the establishment of a "green ring" around Warsaw as an ecological structure with a high degree of forest cover and spatial persistence.
- Efforts should also be made to ensure saturation of Warsaw districts with the so-called blue infrastructure that is of great significance in cooling the city and ensuring places of recreation "friendly" to the human organism, especially on hot or very hot days. Essential activity here includes protection of all surface waters against disappearance and degradation, reinstatement of certain former bodies of water and watercourses, and the construction of new ones. In densely built-up areas, in city-centre in particular, this greater saturation would be achieved by way of small architectural items (cascades, fountains, water curtains and so on).
- There is a need to depart from an imprecisely defined spatial structure of the so-called natural system of the city that allows building to take place, even of multi-family. Law provisions allow for building in areas serving in the exchange and regeneration of air and in other areas valuable from the biological and recreational points of view, even if these have already been formally qualified as elements of the aforementioned natural system.
- A programme should be devised for the development of Warsaw (including city-proper) green space, forest and waters, with the aim being for these taken together to account for not less than 1/3 of the city area, and with guaranteed protection against any change of future planning designation.
- Monitoring of biologically active areas should commence, in order for their share and role in newly-arising developments to be determined.

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