Instytut Geografii i Przestrzennego Zagospodarowania im. Stanisława Leszczyckiego
Polska Akademia Nauk

Marek Degórski, Jacek Wolski, Andrzej Affek, Bożena Degórska,
Anna Kowalska, Edyta Regulska, Jerzy Solon

Summary Report

Development of a case study of important urban ecosystem services on a regional and local scale

Report prepared for the Project Coordinator - Adam Mickiewicz University in Poznań

Usługi świadczone przez główne typy ekosystemów w Polsce – Podejście Stosowane
Projekt finansowany ze środków Mechanizmu Finansowego EOG 2014-2021

Warszawa, 31.12.2021

1. INTRODUCTION

The essence of the problem of the quality of life in cities and attempts to improve it through the use of ecosystem services are emphasized by numerous research papers, the results of which are currently presented in the world literature for various geographical regions (Balzan et al., 2021; Klimanova et al., 2021; Stange et al., 2022; Vidal et al., 2022). Also in Poland, in the last decade, the interest in ecosystem services in cities has increased (Kronenberg, 2012; Degórski, 2017; Zwierzchowska and Mizgajski, 2019), although there is still relatively little work in this field compared to foreign literature. From the application point of view, it is particularly important to use the results of spatial differentiation of ecosystem services in urban areas for spatial planning and land management, the main effect of which is to achieve the well-being of residents.

The aim of the third stage of the implemented task concerning ecosystems of urbanized areas under the project "Services provided by the main types of ecosystems in Poland - applied approach", which this report concerns, was to develop a case study of important services of urbanized ecosystems on a regional scale. The object of spatial analysis was Warsaw. Ecosystem services indicators were selected from the set of 78 indicators proposed by the Team, described in the first stage of the project, and supplemented with new proposals, the implementation of which became possible due to the current data availability. Therefore, they constitute an original and innovative approach in assessing the benefits of urban ecosystems, as well as an extension of the range of indicators developed by I. Zwierzchowska and A. Mizgajski (2019), related to the abundance and spatial distribution of green infrastructure in the largest cities of our country, relating to services such as regulation of the local climate, use of green infrastructure for recreation, capture of rainwater, or preventing floods through the valley retention capacity.

The indicators (9) developed by us at this stage of the project include - important from the point of view of the role of blue and green infrastructure (BGI) in the urban system - regulating services (preventing flooding and urban floods; regulation of the chemical composition of the atmosphere; purification of the air from particulate matter generated by of humans; reduction of surface water erosion) and cultural (various aspects of recreation and environmental education in nature). The selection of services and the indicators describing them was based on the analysis of the significance of phenomena and processes taking place in the city space from the point of view of the well-being of its inhabitants. Indicators refer to potential, use or unmet demand. In the case of several analysed services, the proposed indicators are characterized by a high coincidence with other services, creating bundles of closely related benefits.

The indicators were calculated for all 18 districts of Warsaw and/or for 143 areas of the Municipal Information System (hereinafter referred to as subdistricts) (Fig. 1), as well as for different land use types.

Figure 1. City districts and subdistricts (units of the Municipal Information System (MSI) in Warsaw

2. REGULATING SERVICES

2.1. Purification of the air from particulate matter generated by humans

This service belongs to *Regulation and Maintenance* section and *Transformation of biochemical or physical inputs to ecosystems* division in CICES V5.1. It can be further described as the fixing and storage of atmospheric aerosols (particulate matter, including PM2.5 and PM10) by a species of plant, animal, bacteria, fungi or algae that mitigates its harmful effects and reduces the costs of disposal by other means. The subject of measurement is the use of trees to reduce particulate matter air pollution from anthropogenic sources, and the number of trees per person is the indicator. As source data we used the high-resolution (10×10 m) Copernicus layer *Tree cover density* valid for 2018. Tree cover (in %) in city districts and in types of residential areas (multi-family, multi-family with an increased share of greenery, single-family, single-family in forested areas) were obtained by calculating the mean of all cells in a given spatial unit using the *Zonal Statistics as Table* function in ArcGIS 10.2. After correction due to different input data, the average crown size of 18.8 m^2 derived from the Map of Tree Crowns for Warsaw (http://zzw.waw.pl/2021/02/26/miliony-warszawskich-drzew-na-jednej-mapie/) was adopted for the transformation of tree cover into the number of trees. Then, the number of trees obtained in the reference unit was divided by the population obtained in 2015 from telemetry measurements (Warsaw City Hall data). The obtained indicator values ranges from 0.8 (Ursus district) to 22.7 (Wesoła district) (Fig. 2). The number of trees per person is clearly lower in central districts and higher in peripheral districts (with the exception of Ursus). In Warsaw as a whole, the average number of trees per person within single-family residential areas is 1.1, and in the case of single-family forested residential areas as much as 6.2. Residential areas with multi-family buildings are characterised by a low number of trees per person (only 0.1). The situation is slightly better in multi-family residential areas with an increased share of greenery (0.3).

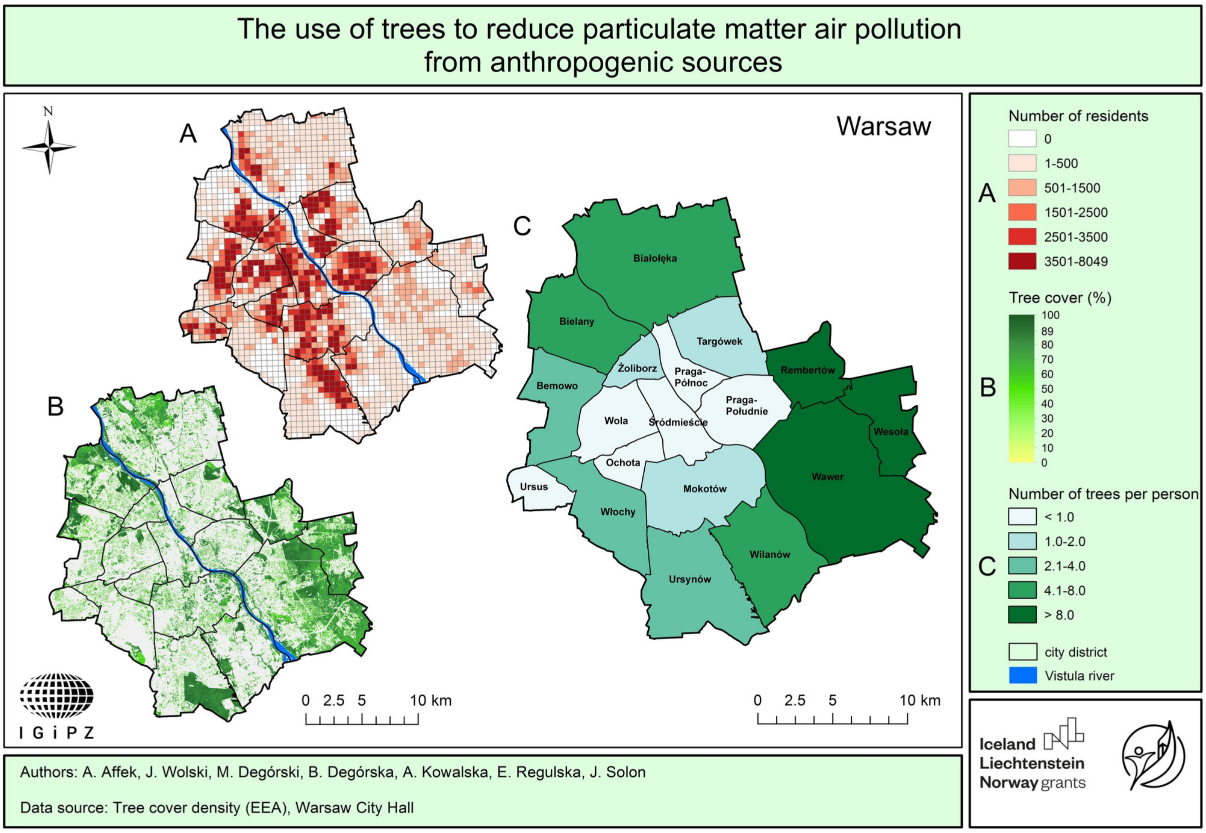

Figure 2. The use of trees to reduce particulate matter air pollution from anthropogenic sources

2.2. Erosion reduction by vegetation

This service belongs to the *Regulation and Maintenance* section, *Regulation of physical, chemical, biological conditions* division of CICES V5.1. It involves, among other things, mechanically protecting the soil surface from the physical force of water, reducing surface runoff, increasing the potential for water to soak into the soil, and maintaining the compactness of the soil surface through root systems. Vegetation intercepts rain, reducing its energy and preventing splash erosion. It also slows water runoff, and anchors and strengthens the soil through the root system. Overall, surface erosion is reduced by vegetation due to a combination of surface roughness, infiltration, and interception. All of this has the effect of reducing surface erosion compared to an analogous area not covered with vegetation. The subject measurement is the effect of urban vegetation on reducing water erosion on land of different slopes, and the indicator of this service is the area-weighted average coefficient of reduction of surface erosion by vegetation.

The coefficient of reduction of erosion by vegetation can be defined as the ratio of the amount of soil eroded from a field with specific vegetation cover to the amount of soil eroded from a reference plot identical in lithology and location in relief that is in so-called black fallow.

The rate (coefficient) of erosion reduction by vegetation is an indirect indicator of the ecosystem service known as Control of erosion rates.

The erosion control service forms a bundle with other regulating services belonging to the *Regulation of physical, chemical, biological conditions* division, such as *Buffering and attenuation of mass movement* (2.2.1.2) and H*ydrological cycle and water flow regulation (Including flood control, and coastal protection)* (2.2.1.3) from the group *Regulation of baseline flows and extreme events*, and *Weathering processes and their effect on soil quality* (2.2.4.1) and *Decomposition and fixing processes and their effect on soil quality* (2.2.4.2) from the group *Regulation of soil quality*.

The procedure for obtaining the results included several steps:

1. Distinguishing 5 slope classes from the digital terrain model;

2. Identification of soil susceptibility to erosion (in four classes) based on lithology and literature indicators;

3. Based on 1 and 2, identification of areas representing the 5 classes of potential erosion;

4. Determination (based on literature data) of erosion reduction coefficient for different types of plant communities, marked on the vegetation map of Warsaw.

5. Calculating the erosion reduction coefficient for areas representing potential erosion classes 2, 3, 4, and 5, weighted by the area covered by particular plant community types.

The erosion reduction coefficients averaged over subdistricts show a relatively large scatter of values, ranging from 0.0039 (highest potential erosion reduction) in the Kabaty Forest to 0.182 in the Szamoty subdistrict (Fig. 3). In general, areas with the highest erosion reduction in Warsaw are found in the peripheries, particularly in the following subdistricts: Stara Miłosna (0.0081), Groszówka (0.0068), Aleksandrów (0.0056) in the eastern part of Warsaw, and Młociny (0.0065), Las Bielański (0.0076) and Dąbrówka Szlachecka (0.0096) in the north-western part. At the same time, these areas belong to the subdistricts with the highest share of areas in the 2-5 class of potential erosion (above 38% of area).

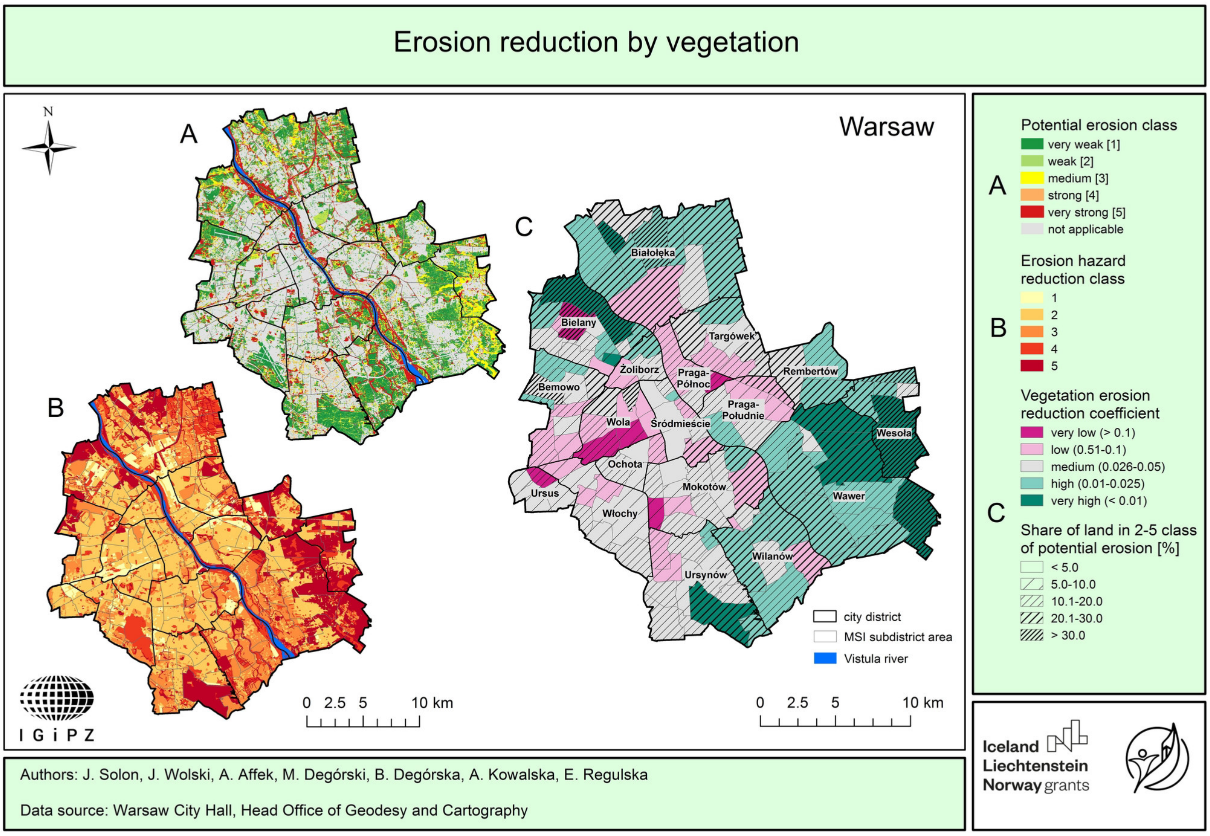

Figure 3. Erosion reduction by vegetation

2.3. Counteracting flooding and urban floods

The service belongs to the *Regulation and maintenance* section of the *Regulation of physical, chemical and biological conditions* division of CICES V5.1. The ecological dimension of the service is the regulation of water circulation in the conditions of its excess, using the properties of soils and tree canopy, and the functional dimension - mitigation or prevention of potential damage to human health and safety, as well as to the economy and infrastructure. The service can be provided primarily through unsealed soils enabling the infiltration of excess water associated with torrential or long-lasting rain or sudden and abundant thaws, as well as thanks to tree crowns conditioning, among others, interception processes. Therefore, the subject of measurement is the ability of the substrate and tree canopy to regulate water conditions, and the indicator is the average value of the infiltration-interception coefficient.

In order to illustrate the benefits of counteracting urban flooding and floods, an indicator was used that takes into account the infiltration and retention properties of the soil lithological material, the degree of soil permeability (share of non-sealed areas) and the degree of tree canopy as a potential interception area, divided into deciduous and coniferous trees. For the analysis, a map of surface formations was used, prepared on the basis of soil and agricultural maps, obtained from the Architecture and Spatial Planning Office of the Warsaw City Hall and high-resolution raster layers, developed by the European Environment Agency as part of the Copernicus Earth monitoring program based on satellite images of the Sentinel-2 satellite. Raster layers have a resolution of 10 × 10 m and are from 2018.

The mathematical formula of the WPII coefficient is the expression:

WPII = (A × B) + (C × D)

where:

A - weights of infiltration properties of lithological material determined on the basis of: (1) permeability classification of lithological material (Pazdro and Kozerski, 1990) - from impermeable rocks (clays, clay loams, marls) to well and very well permeable (mixed sands, medium-grained, loose sands) and weak loam) and (2) connections of rocks as a soil substrate with the Systematics of Polish Soils (PTG, 2019) - from black earth developed in heavy loam (weight 0.1) to podzolic soils developed in loose multi-grained or slightly loamy sands (weight 0.8);

B (Imperviousness Density 2018) - non-capped surface expressed by the degree of soil permeability (values of 0.0-1.0 for the range of 100-0% of completely impervious surface);

C (Tree Cover Density 2018) - potential interception area expressed by the degree of crown closure (values of 0.0-1.0 for the range of 0-100% of the ground area covered by tree crowns in the vertical projection);

D (Dominant Leaf Type 2018) - tree foliage type. Due to the size of interception, the average value of 10% (weight 0.1) reduction in precipitation was assigned to conifers, and 20% (weight 0.2) to deciduous trees (Puchalski and Prusinkiewicz, 1990; Wagner et al., 2013).

The values of the WPII index were calculated using the raster algebra (after rasterizing the vector map of surface forms to a resolution of 10 × 10 m), and then calculating the average of all cells in a given spatial reference unit using the *Zonal Statistics as Table* function (ArcGIS 10.2).

The average value of the infiltration-interception coefficient in subdistricts ranges from less than 0.40 in the densely populated areas of Śródmieście, Ochota and Wola to over 0.70 in the districts of Wawer (including Anin, Międzylesie, Miedzeszyn, Aleksandrów subdistricts), Mokotów (Powsin) or Bielany (Bielański Forest, Młociny) (Fig. 4). Generally, the lowest values are characteristic mainly for the downtown part of the city with high soil sealing (at least 0.23 - Mirów in Wola), while the highest - peripheral areas with loose development of single-family houses, and above all forest areas characterized by the best permeability of the subsoil (podzolic soils formed in loose and multi-grained sands) and a significant interception of compact tree crowns. These include the extensive forested areas such as the Kabaty Forest (max. 0.93), the Bielański Forest, and the forests of the Mazowiecki Landscape Park, part of which is located within the administrative boundaries of Warsaw (south-eastern part of the city).

The presented spatial differentiation of the indicator within subdistricts is strongly correlated with land use. Low values of the indicator are recorded in areas occupied by large-area commercial facilities (0.09), while the highest – in forest areas (0.84), and then undeveloped green areas with the dominance of trees (0.71) and arranged greenery (0.69).

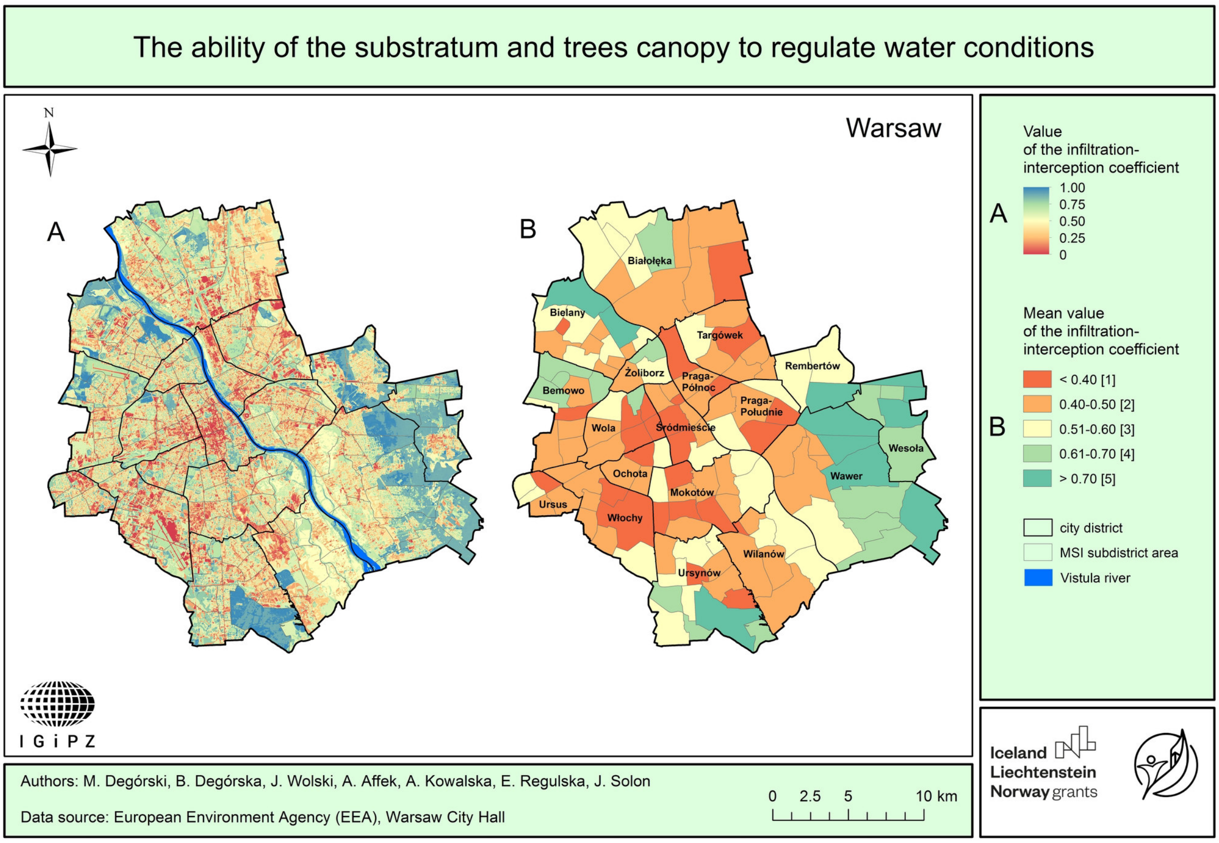

Figure 4. The ability of the substratum and trees canopy to regulate water conditions

2.4. Regulation of the chemical composition of the atmosphere

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It can be further described as the regulation of the concentrations of gases in the atmosphere that impact on global climate. The subject of measurement is the use of vegetation to regulate the chemical composition of the atmosphere, and the indicator is the mean total annual productivity. As source data we used the newly published (August 2021) high-resolution (10×10 m) Copernicus layers *Total Productivity Season 1* and *Total Productivity Season 2* valid for 2020, jointly representing the total annual gross primary production. Total annual productivity (in PPI × day, where PPI is the value of the plant phenology index; (Jin and Eklundh, 2014) for subdistrict areas and particular land uses were obtained by calculating the mean of all cells in a given spatial unit using the *Zonal Statistics as Table* function in ArcGIS 10.2. The obtained indicator values ranges from 270 (Mirów subdistrict area) to 1554 (the so-called royal part of the Wilanów district) (Fig. 5). Generally, the lowest values are characteristic mainly of the downtown part of the city, while the highest of almost the entire Wilanów district, the areas at the border of Mokotów and Wawer, and the eastern part of Białołęka. Higher values are associated with large undeveloped and post-agricultural areas (e.g. the "wild" Vistula valley), extensive forest areas (Kabaty Forest) or rural settlements with meadows. High productivity is also characteristic of airports with adjacent areas subject to building restrictions (Okęcie, Bemowo), old cemeteries (Powązki). When it comes to particular land uses, low values are recorded in areas occupied by commercial facilities, offices, industrial, warehouses, transport infrastructure, but also by dense multi-family housing. The areas with the highest productivity are those related to agriculture, "wild" and arranged greenery, as well as allotment gardens and green sports and recreational facilities.

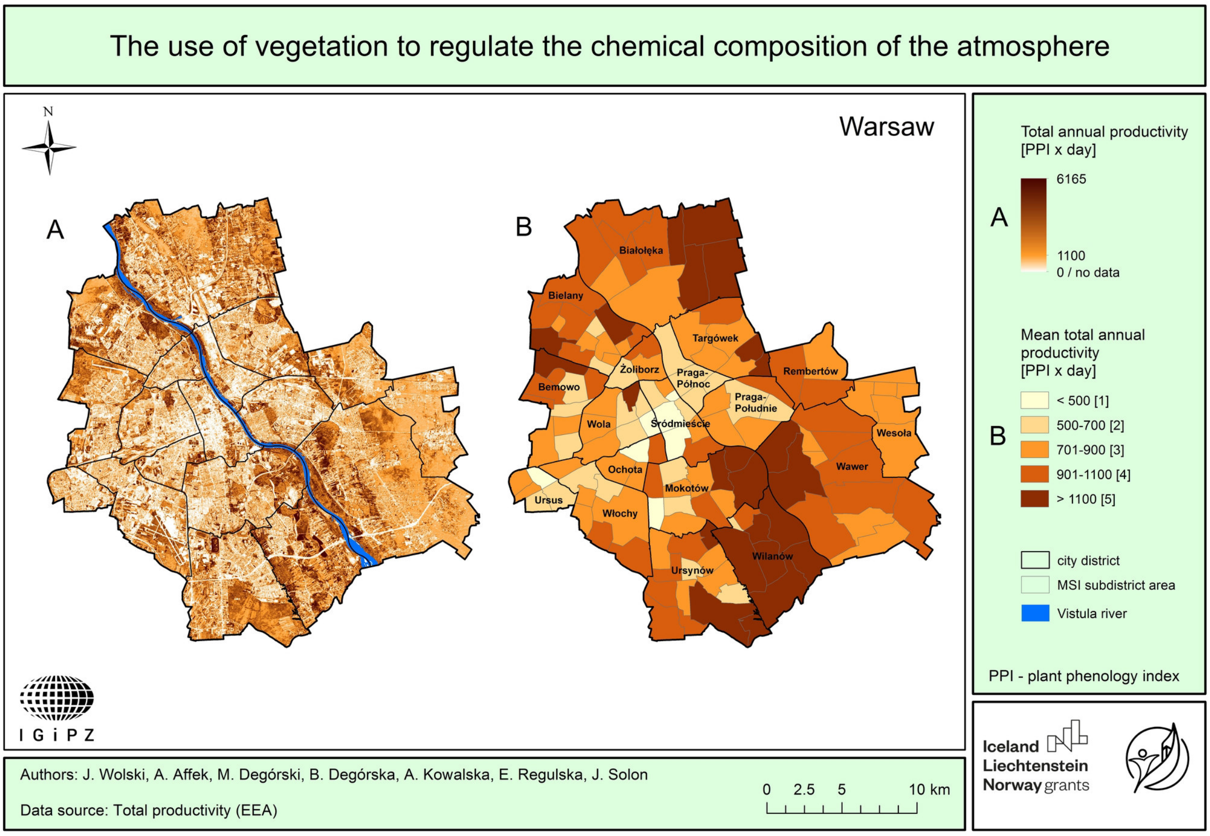

Figure 5. The use of vegetation to regulate the chemical composition of the atmosphere

2.5. Regulation of air temperature and humidity

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It can be further described as the mediation of ambient atmospheric conditions (including micro- and mesoscale climates) by virtue of presence of plants that improves living conditions for people. The subject of measurement is the unmet demand to reduce the effect of urban heat island, and the temperature difference form the reference area is the indicator. Multispectral images recorded by the Landsat 8 satellite were used to directly present the unmet demand for reducing the urban heat island, i.e. lowering the temperature in urbanized areas. The Land Surface Temperature (LST) was calculated primarily from the B10 thermal channel, originally recorded at a resolution of 100 × 100 m, and channels B4 and B5 at a resolution of 30 × 30 m to introduce a correction for different ground emissivity.

In order to best capture the surface urban heat island effect and its spatial diversity as well as the need for temperature reduction that can be satisfied by ecosystems (mainly vegetation), the following assumptions were made as to the conditions at the time of recording the satellite image:
- noon hours (11.00-13.00),
- peak of the growing season (optimally June),
- no precipitation (also within 3 days before the recording of the scene),
- no clouds,
- air temperature > 26 °C,
- wind speed < 5 m/s,
- follow-up solar radiation (on a plane on which the direct component of radiation falls perpendicularly) > 900 W/m^2.

One, almost cloudless (0.84% clouds) scene recorded at 11:34 local time on June 20, 2013 (scene ID: LC81880242013171LGN01) was selected for the analysis. This scene is the only one from 2013-2021 that meets all the adopted criteria. Historical, ground-based meteorological data were obtained from https://www.meteo.waw.pl/. The selected scene is from Landsat Collection 2 Level-1and fully encompasses Warsaw within its administrative borders. The layer presenting data from the B10 thermal channel was already in pre-processing resampled to a resolution of 30 × 30 m and as such, together with the other 10 layers, was obtained from the USGS database using EarthExplorer (https://earthexplorer.usgs.gov/).

For LST calculations, a modified so-called single-channel algorithm was used, developed by Jimenez-Munoz et al. (2009), which gives a Root Mean Square Error of 1 °C compared to field survey data. The necessary parameter values and the description of individual steps were taken from the publications (Sobrino et al., 2004; Weng et al., 2004; Wang et al., 2015; Avdan and Jovanovska, 2016), as well as from the USGS website (https: // www. .usgs.gov / landsat-missions / using-usgs-landsat-level-1-data-product) and GISCrack (https://giscrack.com/how-to-calculate-land-surface-temperature-with-landsat- 8-images /). LST calculations were carried out in ArcGIS software mainly using the raster calculator function, after clipping all layers to the administrative boundaries of Warsaw.

Based on the analysis of the histogram and spatial variability of the land surface temperature in Warsaw, the value of 22.8 °C was taken as reference. It is the minimum land surface temperature at the time of measurement in Warsaw, excluding water areas with lower temperatures, including in particular the Vistula River and Wilanów Lake. The temperature in the range of 22.8-23.5 °C was recorded in most areas covered with vegetation, including forests and open areas (the cores of larger areas reached the temperature in the range of 22.8-23.0 °C). It was assumed that the surface temperature in the Warsaw Basin at the time of measurement would be around 23 °C, if not for the anthropogenic land transformation and the related urban heat island effect. The final value of the indicator, i.e. the difference (excess) of the temperature from the reference temperature 22.8 °C for city districts, MSI subdistrict areas and particular land uses was obtained using the *Zonal Statistics as Table* tool in ArcGIS 10.2.

The obtained indicator values (unmet demand) ranges from 10.4 °C in the Szamoty subdistrict (former tractor factory) to 0.8 in the Kabaty Forest (Fig. 6). At the district level, Wawer and Wesoła are characterised by the weakest urban heat island effect (below 4 °C), while Ursus is the only district with an average temperature excess above 7 °C (7.4 °C). When it comes to particular land use, definitely the strongest urban heat island effect occurs in large shopping centres (10.5 °C) and in public transport facilities (9.3 °C). The lowest demand for temperature reduction is found in surface waters (0.5 °C) and forests (2.1 °C), as well as undeveloped greenery with predominance of trees (2.9 °C) and surface waters in parks (3.3 °C). Such low values indicate that the above-mentioned areas not so much add to the heat island effect, but actually contribute to reducing this effect in the neighbouring built-up areas.

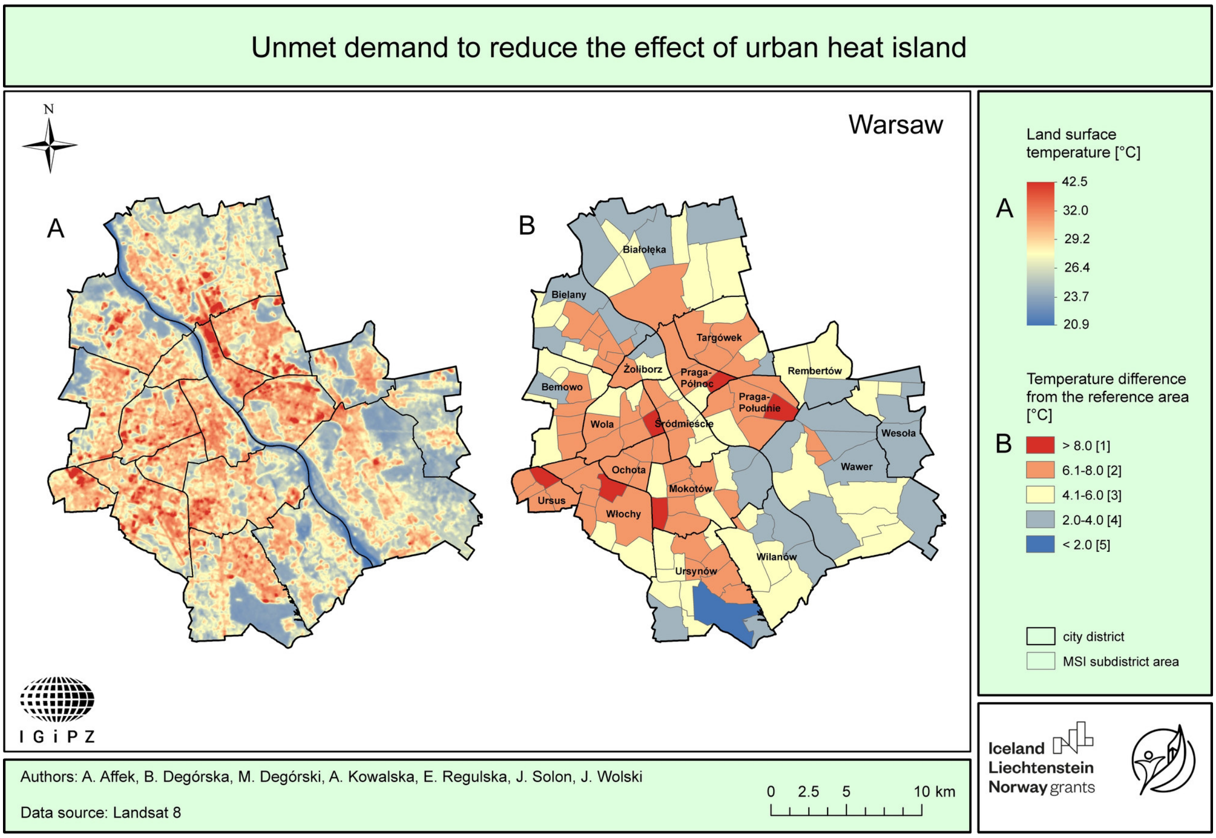

Figure 6. The unmet demand to reduce the effect of urban heat island

3. CULTURAL SERVICES

3.1. Recreation in nature

In CICES V5.1, the service belongs to the *Cultural* section, *Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting* division. It is based on physical and experiential interactions with the natural environment, which lead to improved health, regeneration and entertainment. Four indicators have been developed for this service: two based on expert assessment, one of which concerns the unmet demand for recreation in nature, and the second the use of blue-green infrastructure (BGI) for cycling recreation, and two indicators based on social assessment (participatory method), one of which concerns the potential and the other the actual use of BGI for recreation.

3.1.1. Unmet demand of the city residents for recreation and recuperation in nature

Recreation and recuperation in nature is of great importance for physical and mental well-being of urban residents (Geary et al., 2021; Weinbrenner et al., 2021). It is ensured by green urban spaces, which are more and more valued (increasing the attractiveness of the place of residence) and protected, but often lose out in the competition for land as the share of the population living in urban areas continues to rise. Not only the area of green spaces is important, but also their spatial distribution in the city, which makes them accessible to all residents (Nielsen and Hansen, 2007). The distance from the place of residence to public urban open green spaces in conjunction with their recreational and aesthetic values seems to be of decisive importance (Grahn and Stigsdotter, 2003; Kothencz et al., 2017).

The unmet demand of the city residents for recreation in nature was estimated through the proportion of the population living beyond the 300/1000 m buffer from spaces dedicated to recreation in nature in the subdistricts. After a detailed analysis of the database with the city's functional structure, provided by the Architecture and Spatial Planning Office of the Warsaw City Hall, seven land use classes were selected (forests, arranged green urban areas, unmanaged green urban areas dominated by trees, other green urban areas, waters, waters in parks, sports and leisure facilities) as those providing good conditions for direct, in-situ and outdoor interactions with living systems in city and offering the possibility of recreation and recuperation in nature. Accessibility to green spaces dedicated to recreation in nature was determined on two scales: local and supralocal. For the local scale, a distance of 300 m was adopted, measured in a straight line from the green spaces, corresponding to 5-6 min walk and a minimum area of 1 ha ; for a supralocal scale, a distance of 1000 m and a minimum area of 2 ha (see Zwierzchowska and Mizgajski, 2019; Studium uwarunkowań …, 2020). The demand for recreational services was determined based on the size of the population living in each subdistrict. This data is based on telemetry measurements taken in 2015 that shows the actual number of people staying overnight from Monday to Friday in a given subdistrict. The distribution of residents according to the type of residential area was obtained by combining the distribution of residents from the 2018 Urban Atlas database with the map of residential areas from the Warsaw City Hall. The obtained number of residents was weighed so that the sum for Warsaw was consistent with the total number of residents from the telemetry data. After separating the residential areas within the buffers 300 and 1000 m from the green areas, the proportion of residents living beyond 300/1000 m the buffer from the areas dedicated to recreation in subdistricts was calculated. Due to the scope of the spatial data used, the area of analysis was limited to the city boundaries – green areas outside Warsaw were not taken into account.

The proportion of residents living beyond the 300 m buffer from green spaces dedicated to recreation in nature ranges from 0% to 94 % in subdistricts. High values of this indicator show a high level of unmet demand for recreation in nature, i.e., low share of green spaces in subdistricts and their low availability at a distance of 300 m from the place of residence. All values greater than 0 mean an unfavourable state, as they indicate unmet demand of even a small group of residents. In the city scale, 26% of residents (in 114 out of 143 subdistricts) do not have access to green areas dedicated to recreation, 300 m away from their place of residence. Better availability of green areas in subdistricts was reported at the supralocal scale (1000 m buffer). The indicator value greater than 0 was recorded in only eight subdistricts (Fig. 7).

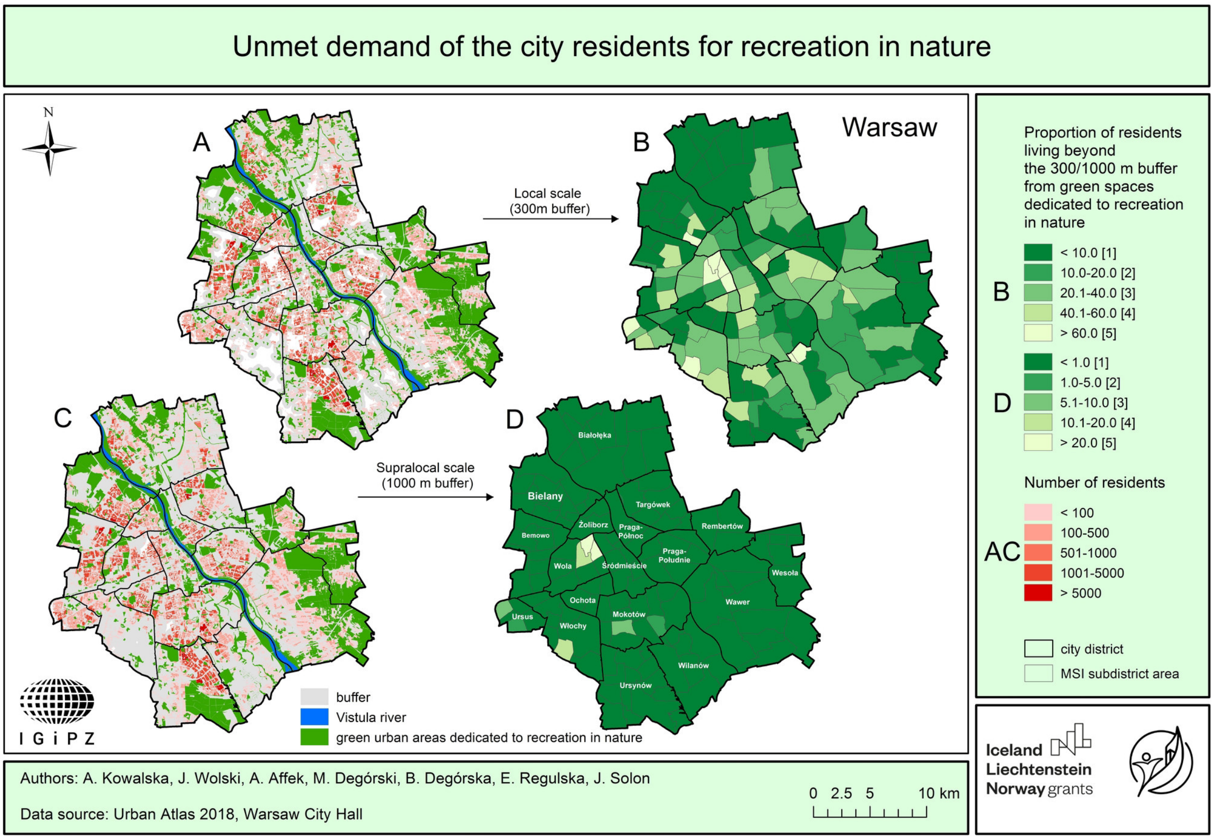

Figure 7. Unmet demand of Warsaw residents for recreation in nature

3.1.2. The use of blue-green infrastructure (BGI) for bicycle recreation

Many people choose the bicycle as a healthy, cheap and environmentally friendly form of transport. Such actions on a local scale are also important on a global scale, as the benefits of cycling emerge in areas such as efficient transport, environmental policy, industrial policy, tourism, public health and social affairs (Pucher and Buehler, 2012; ECF, 2018). An invaluable advantage of urban cycling is also the possibility of direct contact with nature and the multisensory perception of its values. To promote cycling in cities, it is important to identify the reasons why people cycle (Hull and O'Holleran, 2014; Mertens et al., 2014) and factors influencing route selection. In general, urban greenery positively influences increased physical activity (Hartig et al., 2014; James et al., 2015), however, the influence of BGI on attractiveness for cycling is poorly recognized in the scientific literature. Few studies show that cyclists prefer routes in the vicinity of trees (Ghekiere et al., 2015; Mertens et al., 2016), as well as with a significant share of urban greenery and its varied forms (Nawrath et al., 2019), while avoiding the main routes roads and intersections (Winters et al., 2010; Krenn et al., 2014). This shows the relationship between urban green planning and an environmentally friendly mobility policy and encourages the recognition of green streets as multifunctional elements of BGI.

Two information resources obtained from the Architecture and Spatial Planning Office of the Warsaw City Hall were used to demonstrate the use of BGI for bicycle recreation: (1) vector map of Warsaw cycling routes (supplemented with data from OpenStreetMap) and (2) vector map of the city's functional structure, from which eight priority classes have been identified: forests, developed urban green areas, undeveloped urban green areas dominated by trees, other urban green areas (including agricultural and post-agricultural), water, water in parks, areas with sports and recreational facilities. A buffer analysis was used to calculate the density and share of bicycle routes running in the vicinity of the BGI. The following assumptions were made: (1) width of the double-sided (Left and Right) buffer designated along all bicycle routes - 50/50 m, (2) unit measurement sections - 10 m in length.

More than a third of the 922 km bicycle routes in Warsaw are sections predestined for recreation in nature, including L + R - 150 km (16.3%) and L / R - 193 km (21%). The vast majority of routes in the vicinity of the BGI are cycleways, pedestrian and bicycle routes and the so-called other roads. The most blue-green districts from the cyclists' point of view are: in terms of the density of routes running in the vicinity of the BGI - Praga Północ (1.54 km/km^2), and in terms of their share in the length of the entire network - Wesoła (70.8%). On the other hand, Włochy district is the lowest in all aspects (0.1 km/km^2 and 10%, respectively). The division of Warsaw into MSI subdistrict areas (Fig. 8) makes it possible to distinguish a clear corridor conducive to cycling recreation in nature, created by the Vistula river and adjacent areas. On the right bank of the river, the density of routes running in the vicinity of the BGI is 0.74 km/km^2 (47% share in the network), and on the left bank - 0.66 km/km^2 (27%), while the situation is the opposite for the total network density (1.4 and 2.2 km/km^2, respectively).

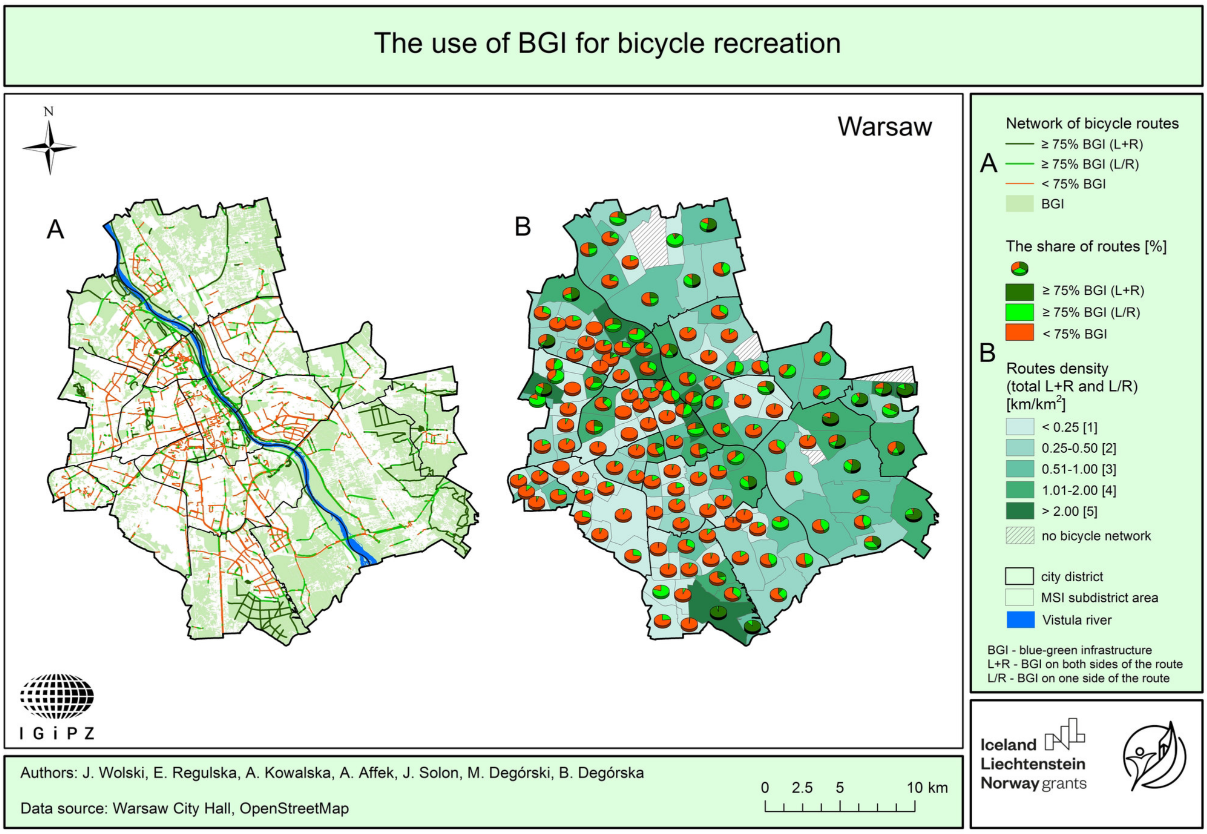

Figure 8. The use of BGI for bicycle recreation

3.1.3. Use/potential of blue-green infrastructure (BGI) for recreation

The subject of measurement is the potential and use of blue-green infrastructure for recreation, and the indicators: 1) review score of BGI on Google Maps and 2) number of reviews of BGI on Google Maps. In Google Maps, each logged in user can evaluate and express his/her opinion on any object located in space, as well as enter a new object. Assessment is made by assigning points (stars) on a scale of 1-5. It is also possible to leave a comment/opinion and attach photos.

In order to calculate the values of indicators for Warsaw, a detailed analysis of the content of Google Maps was carried out within the city's administrative borders in terms of the Outdoor & Recreation category, marked by default in Google Maps with the green tree. This category includes, among others, subcategories such as Park, Hiking area, Garden, Historical landmark, Museum, Tourist attraction, Lake. Only those sites with at least 50 reviews of individual users (representativeness) were taken into account, and these opinions had to be mostly related to recreational value resulting from the presence of blue or green infrastructure (relevance). The vast majority of facilities in the Outdoor & Recreation category were assessed in this respect, although there were exceptions (e.g. outdoor museums, playgrounds, so-called Jordan gardens, gardens of lights, etc.). It should be noted that the database of objects in Google Maps is mostly created by ordinary users, so the categories of objects or their names are not always used consistently. There are also some objects that have different functions, are inherently complex and fit into more than one category. These types of objects required more attention. It was only on the basis of the review of opinions and the recognition of supplementary materials (including orthophotomap, Wikipedia) that the decision was made whether the object in question was part of the BGI and whether the majority of opinions were related to recreation in nature. It was also assumed that the analysis would only take into account facilities with unlimited access (unfenced parks, lawns, boulevards, city forests, walking areas, etc.) and those with time-limited access and often paid entry (e.g. parks closed at night, botanical and zoological gardens). Areas inaccessible to the general public were rejected, including allotment gardens and closed private green areas. Neither were cemeteries considered, which, although often considered as BGI, were in the vast majority assessed in Google Maps from an angle other than their suitability for recreation in nature.

From the 207 selected objects meeting the above criteria, a spatial database was created in the shapefile (shp) point format. Then, the number of reviews, average score, and subcategory for each BGI element were entered into the attribute table. The indicator of both potential (average review score) and utilization (number of reviews) relates to a particular BGI element, but has also been generalized to the city district level. At the district level, the aggregate BGI score is the simple average of all individual user scores assigned to eligible BGI elements. The number of reviews is the simple sum of all of these reviews.

The indicator of using BGI for recreation in Warsaw, showing the number of reviews in Google Maps, ranges from 50 (a predetermined threshold value) to nearly 65,000 (Łazienki Królewskie Park) (Fig. 9). The next positions in terms of use are taken by the Municipal Zoological Garden (36,000) and the Saxon Garden (23,000). At the level of Warsaw districts, blue-green infrastructure enjoys the greatest use in Śródmieście (almost 142,000 reviews) and in Praga-Północ (42,000), and the lowest in Wesoła (650) and Rembertów (52).

The indicator of BGI potential for recreation in Warsaw, showing the users average review score on Google Maps, ranges from 3.8 (including the Slovenian Square in Mokotów) to 4.9 (University Library Garden, Royal Castle Gardens and Capricorn Park in the district of Włochy). At the level of Warsaw districts, BGI has the greatest potential for recreation again in Śródmieście (average score 4.73) and in Wilanów (4.7), and the lowest in Ursus (4.47) and Rembertów (4.4).

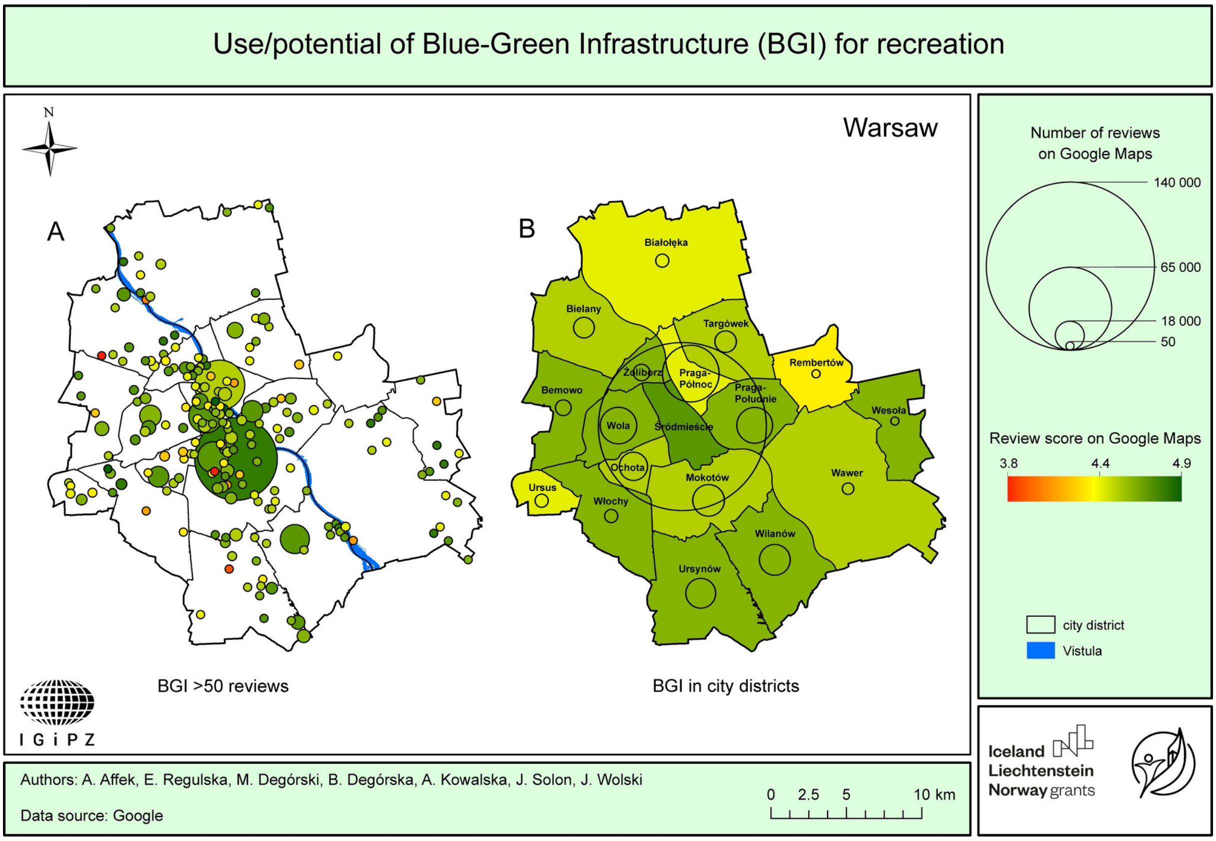

Figure 9. Use/potential of blue-green infrastructure (BGI) for recreation

3.2. Environmental education in nature

Environmental education covers all forms of activities directed to the society, with particular emphasis on children and young people, which are aimed at increasing environmental awareness, promoting specific behaviour beneficial for the natural environment, and disseminating knowledge about nature. These activities are carried out by various educational institutions, including schools and kindergartens as a part of the formal education. Many studies to date have shown that the awareness of ecological processes and benefits of nature increases with the frequency of direct interactions with the natural environment, therefore environmental education in nature is of particular importance for promoting the principles of sustainable development in the society (Affek and Kowalska, 2017; Hutcheson et al., 2018; Torkar and Krašovec, 2019). Taking into account the results of Wolsink's research (2016), showing strong relationships between the number of school excursions and the distance to urban green areas, the potential for environmental education in nature was estimated through the proportion of educational institutions within the 300 m buffer from green spaces dedicated to education in nature in subdistricts.

After a detailed analysis of the database with the city's functional structure, provided by the Architecture and Spatial Planning Office of the Warsaw City Hall, six land use classes were selected (forests, arranged green urban areas, unmanaged green urban areas dominated by trees, other green urban areas, waters, waters in parks) as those providing good conditions for direct, in-situ and outdoor interactions with living systems in city and offering the possibility of environmental education in nature. Areas with an area of ≥2 ha were selected. Accessibility to green spaces offering the possibility of education in nature was studied by distinguishing educational institutions (located on the basis of a database with the functional structure of the city) located within the buffer range of 300 m measured in a straight line from the green spaces. The adopted distance corresponds to a walk of 5-6 minutes, which was considered the maximum time that could be spent on walking during a typical 45-minute lesson. The proportion of educational institutions within the 300 m buffer from spaces dedicated to education in nature in subdistricts was than calculated. Due to the scope of the spatial data used, the area of analysis was limited to the city boundaries – green areas outside Warsaw were not taken into account.

The indicator ranges from 0% to 100%. There are no educational facilities in 19 out of 143 subdistricts. The lowest values (<20%) were recorded in eight subdistricts in the districts of: Wola, Mokotów, Wilanów, Włochy, Białołęka and Wawer, while the highest (> 80%) in 62, located mainly in peripheral and adjacent to the Vistula valley districts (Fig. 10).

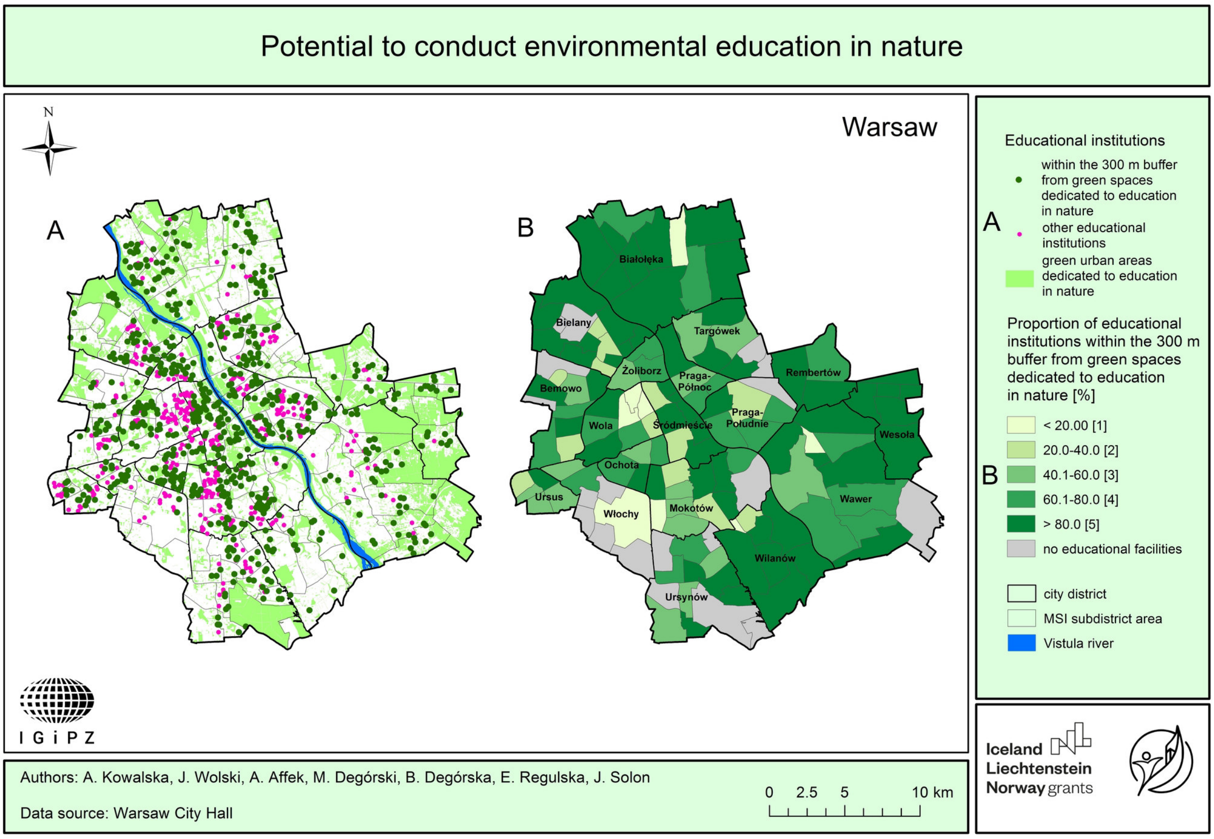

Figure 10. Potential to conduct environmental education of children and young people in nature in the city of Warsaw

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