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URBAN ECOSYSTEM SERVICES – ASSESSMENT OF POTENTIAL AT THE DIFFERENT SPATIAL SCALE: AN EXAMPLE OF POZNAŃ

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ABSTRACT: The aim of the article is the mapping and assessment of ES potential in the scale of the city and identification of site-specific elements that support or reduce the ES potential at the site scale. For this purpose, a multi-criteria spatial analysis, mapping and field vision were conducted. The results showed urban areas with the lowest ES potential that are also characterized by the highest population density. At the site scale, land cover and land-use types with other anthropogenic elements that affect the ES potential and flow were identified. The results can be used to support the transformation process of the city toward nature-based solutions.

KEY WORDS: nature-based solution, multicriteria analysis, Poznań

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Introduction

Cities are manmade areas, where buildings and grey infrastructures with accompanying green and blue spaces create a mosaic of land use and land cover that reflects ecosystems' potential to provide ecosystem services (ES). In this respect, green and blue spaces that should be strategically planned, designed and managed to create green infrastructure (GI) that delivers a wide range of ecosystem services play a particular role in urban areas. In light of contemporary challenges such as climate change (Mizgajski, Zwierzchowska, 2015), demographic aging (Kaczmarek, Łodyga, 2012) and natural resources depletion (Hasse et al., 2014), the ability of GI to provide ES is of significant importance, especially in urban areas where 54% of the total global population lives (UN, 2014). The recognizable ES provided by GI in urban areas include: air filtration, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, recreational and cultural values (Bolund, Hunhammar, 1991; Baró et al., 2015; Sarkki et al., 2016; Kremer et al., 2016; Gómez-Baghettum, Barton, 2013), carbon storage and the provision of habitat for flora and fauna (Holt et al., 2015). Even though ES are increasingly recognized as beneficial for human quality of life, at the background of the developed ES research, studies that assess urban ES are less common. This includes the under-studied relation between the potential supply and demand that offers a useful tool for urban planning at all spatial scales (Kremer et al., 2016). Even fewer studies focus on urban areas of low ES potential that should be regarded as places to be improved. What is more, implementation of study findings into practice is still challenging (Stępniewska, 2016) and has rarely been observed in a land-use policy (Hasse et al., 2014).

Taking the above into account, the study proposes indicator-based assessment and multicriteria analysis of selected urban ecosystem services' potential to recognize its diversity and spatial distribution at the city scale. With this background, the study identifies urban structural units of residential character with the highest mismatches between potential ES supply and demand. In selected residential quarters, the study focuses on the identification of site-specific elements that enhance or reduce ES potential and flow.

The proposed method allows for a fast identification of problem areas with the lowest ES potential and the highest ES demand that should be further investigated as potential hot spots for transition. Recognition which site-specific elements support or reduce ES is a crucial point towards urban improvements and implementation of nature-based solutions. The proposed multi-scale approach can contribute to more efficient and multifunctional space development that will improve the quality of life and may help to reduce the depopulation of less favorable built-up areas.

Study area

Poznań is the fifth biggest city in Poland in terms of the number of inhabitants (Central Statistical Office of Poland, 2015) with a surface area of 261 $km^{2.}$ It is an interesting case study for multiscale assessment of ES because of three reasons. First of all, the city's land-use structure is diverse with a clearly visible environmental structure in the form of green wedges that are formed along the river Warta with its tributaries Cybina and Bogdanka. The green structure is complemented by the southwestern wedge along the Junikowski stream and the eastern wedge along Głuszynka and Michałówka. The green wedges are recognized as an important factor contributing to inhabitants' quality of life and the city's attractiveness. Their importance is highlighted under the present spatial planning policy reflected in the "Study of conditions and directions of spatial development".

Secondly, various forms of residential areas that originate from different periods of time are characterized by specific elements of urban structure that form very diverse conditions for potential supply and demand of ES.

Thirdly, in Poznań the outflow of residents to neighboring municipalities is currently observed. The areas that are most strongly affected by this process are mainly densely built-up, poor in green spaces districts of downtown (Old Town, Łazarz, Wilda) where a decrease in the population number has exceeded 10% over two decades (Centrum Badań Metropolitalnych, 2012). Beim and Tölle (2008) showed that, although environmental aspects such as traffic, noise, pollution, lack of access to recreation and playgrounds are not the main reasons for moving out from the city, they are taken into account when making this decision.

Research methods

The frame of multi-scale assessment of ES is inspired by Wurster's and Artmann's concept that use Urban Structural Units, Unit Specific Sites and Site Specific Elements as linkages among the scales (Wurster, Artmann, 2014). However, the method is simplified and adjusted to focus on residential units for site analysis (Figure 1).

The potential of the city to supply ES was mapped based on data from The European Urban Atlas, which provides land-use maps with a high resolution of 1: 10000 (European Union, 2011). The structural approach applied in Urban Atlas land-use classification allows for treating every patch of land use as an Urban Structural Unit, characterized by sealing degree and the presence of vegetation.

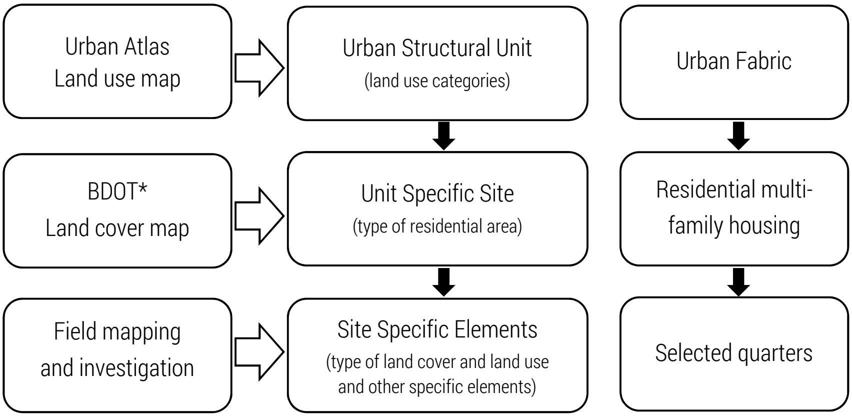

Figure 1. Multilevel approach to ES assessment
* Database of topographical objects

At the city scale, the potential to supply ES was assessed with the use of indicators, based on which a value was assigned to individual types of land use.

According to Gómez-Baggethun and Barton (2013), the relevance of ES in each city varies greatly depending on the environmental and socio-economic characteristics of each site. Therefore, the choice of ES that were assessed was determined not only on data availability and usefulness in planning, management and decision-making but also on recognized importance. Selected ES include the cooling effect, the ability to capture rainwater and physical use for recreation.

The potential for cooling effect was assessed based on the spatial distribution of radiation temperature for Poznań, captured by the Landsat TM satellite on 17 June 2010, at. 9:33 and the literature (Majkowska et al., 2016). Image overlaying with a map of land use allows for determining the differences between the various types of land use and their impact on the radiation temperature (Mizgajski et al., 2015, unpublished material). The potential for rainwater capture was assessed based on studies (Czerwieniec, Lewińska, 1996; Januchta-Szostak, 2012; Gibbons, James, 1996) that show a significant role of the proportion between sealed and unsealed surfaces.

The potential of land for physical use for recreation was assessed based on the findings of Paracchini et al. (2014) who showed that forests are generally considered attractive sites and water is a specific attraction. Overall, more natural sites appear to be more attractive for recreation than areas of higher anthropic influence.

Based on the evidence above, the potential to supply ES has been assigned to different types of land use and presented at 4 levels: priority, significant, insignificant and no-relevance (table 1).

Table 1. Level of ES assigned to particular land-use types

Land use type	Rainwater capture	Cooling effect	Physical use for recreation
Continuous Urban Fabric (S.L. > 80%)	No relevance	No relevance	No relevance
Discontinuous Dense Urban Fabric (S.L.: 50–80%)	Insignificant	No relevance	No relevance
Discontinuous Medium Density Urban Fabric (S.L.: 30–50%)	Significant	Significant	No relevance
Discontinuous Low Density Urban Fabric (S.L.: 10–30%)	Significant	Significant	No relevance
Discontinuous Very Low Density Urban Fabric (S.L. < 10%)	Priority	Priority	No relevance
Isolated Structures	Priority	Significant	No relevance
Industrial, commercial, public, military and private units	No relevance	No relevance	No relevance
Fast transit roads and associated land	No relevance	No relevance	No relevance
Other roads and associated land	No relevance	No relevance	No relevance
Railways and associated land	No relevance	No relevance	No relevance
Airports	Significant	No relevance	No relevance
Mineral extraction and dump sites	Significant	Insignificant	No relevance
Construction sites	Insignificant	No relevance	No relevance
Land without current use	Insignificant	No relevance	No relevance
Green urban areas	Priority	Significant	Significant
Sports and leisure facilities	Significant	Insignificant	Priority
Agricultural + Semi-natural areas + Wetlands	Priority	Significant	Significant
Forests	Priority	Priority	Priority
Water bodies	Priority	Priority	Priority

In the next step, multi-criteria evaluation, which is recognized as a useful methodology to analyze ES synergies (Hasse et al., 2014), and a decision support tool (Langemeyer et al., 2016) was applied to calculate the overall ES potential. The data were rasterized to a resolution of 50m. The analysis assumes that ES are of equal weight and synergy may occur among them at the same Urban Structural Unit. To calculate the overall potential of ES, the contents of the ES potential grids were overlaid.

The demand for ES was assessed taking into account population density in areas of urban fabric with a predominantly residential type of land use, understood as a density of beneficiaries. Data about the number of inhabitants at the district level and at the site scale (address points) were acquired from the Poznań Municipal Office.

The raster of overall ES potential was overlaid with a population density layer. This allowed for selection of residential areas of the highest mismatches between the ES potential and demand. Among them, multifamily residential areas were selected based on the BDOT database as Unit Specific Sites. Finally, three quarters located in districts of Piątkowo, Wilda and Łazarz that are characterized by various sets of site-specific elements (e.g. buildings, pavements, green spaces), which determine the ES potential has been selected for further analysis at the site scale.

Ortophotomaps available as a WMS service, elaborated data from the land and building records database were used as a reference frame for site investigation. Field investigations were used to illustrate the site-specific elements that support or reduce ES potential and flow.

Results of the research

Spatial distribution of ES potential

The spatial distribution of the ES potential is a reflection of the environmental structure of the city of Poznań. The areas with the highest ES potential are primarily forests and surface waters forming urban green wedges. The areas with the lowest potential are, in turn, represented by industrial, commercial, public, military and private units, roads and associated land, railways and continuous urban fabric with ratio of sealed surface exceeding 80%. Spatial distribution of the ES potential is presented in figure 2.

The spatial distribution of the potential demand for ecosystem services

The study focuses on identification of residential areas where mismatches between the ES potential and demand may occur. Therefore, the demand for ES has been assessed on the basis of population density in residential areas at the level of the city's districts. Districts of Poznań where the number of inhabitants per residential area is the highest are Piątkowo, Łazarz, Winiary, Rataje, Chartowo, Żegrze, Jeżyce, Stare Miasto, Górczyn, Wilda and Śródka. Districts with the lowest population density are mainly extensively built-up areas including the peripheral zones of Poznań such as: Wielkie, Głuszyna II, Ławica II, Karolin and Psarskie.

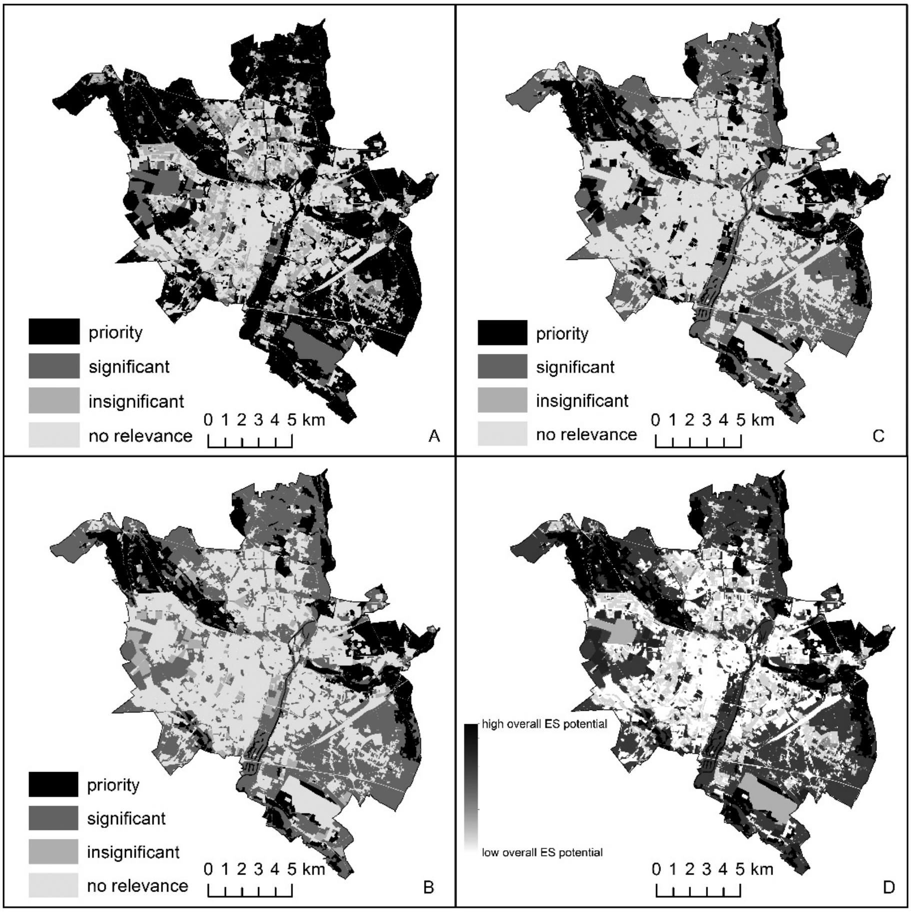

Figure 2. Spatial distribution of ES potential (based on Urban Atlas): A – potential for rainwater capture, B – cooling effect potential C – potential for physical use for recreation D – overall ES potential

The areas with the lowest ES potential and the largest potential demand for ES in the scale of the city

The areas with the lowest overall ES potential encompass 24% of the city. Those that predominantly constitute built-up areas with the highest population density represent 15% of them. This comprises 4% of the total city area. Those areas are located mostly in downtown districts of Stare Miasto, Łazarz, Wilda, Jeżyce, Ostrów Tumski, Śródka, Zawady and Komandoria, and outside downtown in the districts of Górczyn, Winiary, Rataje and Piątkowo. These are the areas where the space for service providing units is limited and the potential demand for ES is relatively high. Spatial distribution of predominantly residential areas with the lowest ES potential is presented in figure 3.

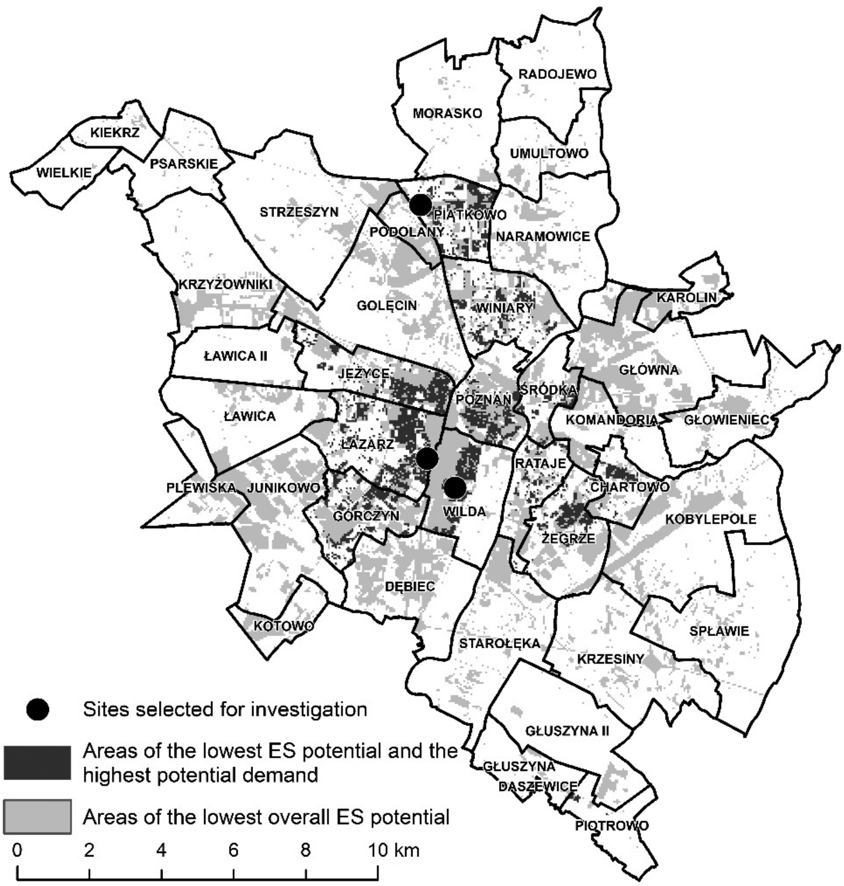

Figure 3. Areas selected for site investigation at the background of areas with the lowest ES potential

Ecosystem services at the site scale

Identification of site-specific elements that shape the ES potential and flow was carried out in three selected quarters of multifamily housing, whose characteristics are presented in table 2. The analysis pays particular attention to the ES potential resulting from existing land cover, land use and elements supporting ES potential and flow at the scale of 1:1000. These areas were examined for:

- the presence of sealed and unsealed surface, including green spaces,
- existence of recreational infrastructure,
- accessibility.

Table 2. Characteristics of investigated sites

Location of the investigated site	Type of residential buildings	Area [m²]	Number of inhabitants*
Wilda	tenement housing built in the early twentieth century	13263	412
Łazarz	tenement housing built in the early twentieth century	25311	491
Os. Hulewiczów	four-story building built in the early twenty-first century	18838	257

* Registered as permanent residents

Quarter on Wilda

The location of buildings creates an inner courtyard, divided into four separated spaces that are appurtenant to each tenement (figure 4).

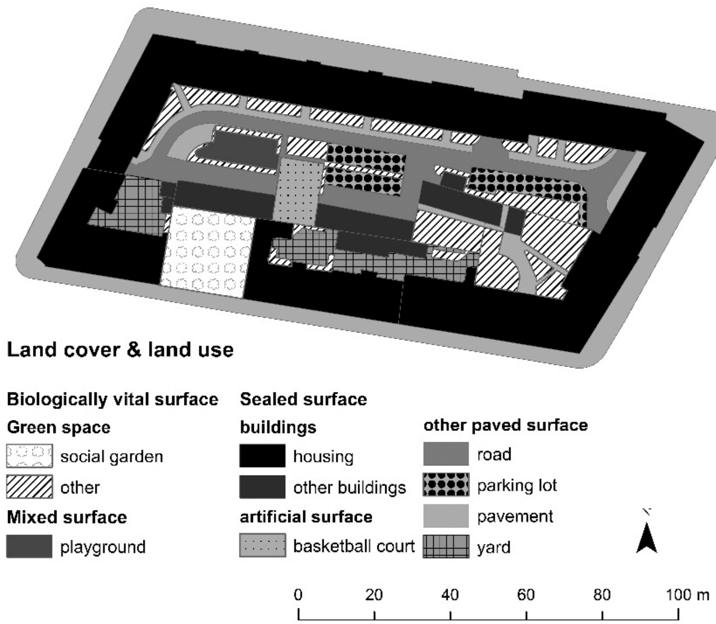

Figure 4. Distribution of green spaces at the background of other site-specific elements in the Wilda quarter

Distribution of site-specific elements such as green spaces and recreational facilities is very diverse among individual yards and the maintenance level is very different (figure 5).

Figure 5.
Wilda quarter – from the left: courtyard's green space, courtyard's sealed surface and social garden

In one of the courtyards, there is a basketball court and a playground complemented with benches and associated green spaces. Green space of an ornamental character is located in front of the buildings and along the fence. Additional narrow strips of biologically vital surface with trees are located between the parking lots. There are also creepers growing on a shelter for waste containers and the sportsground fence.

The surface of the second courtyard is in contrast almost totally sealed off by concrete paving. Only a narrow strip of the surface around the building is not sealed and planted with decorative vegetation (mostly flowers, small shrubs and creeper), enriched by pots of flowers. In the courtyard, there is also a table with chairs for a place to rest and meetings.

In the third courtyard, the ground surface is covered mainly by lawn, spontaneously-growing shrubby vegetation and trees located at the rear of the yard. The location of the shelter for waste containers determines the distribution of the pavement sealed surface in the yard. The yard is not equipped with furniture or any other elements facilitating the use of this area for recreation.

A part of the quarter is taken by a social garden established in a place of a non-existent tenant house. This is an example of regeneration of neglected land, which improved the ES potential. The garden with open access is equipped with benches, a water garden and a flowerbed enriched with pots of flowers and herbs. The potential of this area to provide ES is, however, reduced by acts of devastation and negligence (damage to benches, weedy water garden, partially withered flowerbeds and plants in pots).

Quarter on Łazarz

In the residential quarter of Łazarz (figure 6), there are also areas devoted to economic and educational activities that are fenced off from residential areas. These areas were not investigated due to access restrictions. The courtyards of tenant houses in this quarter have both closed and open access.

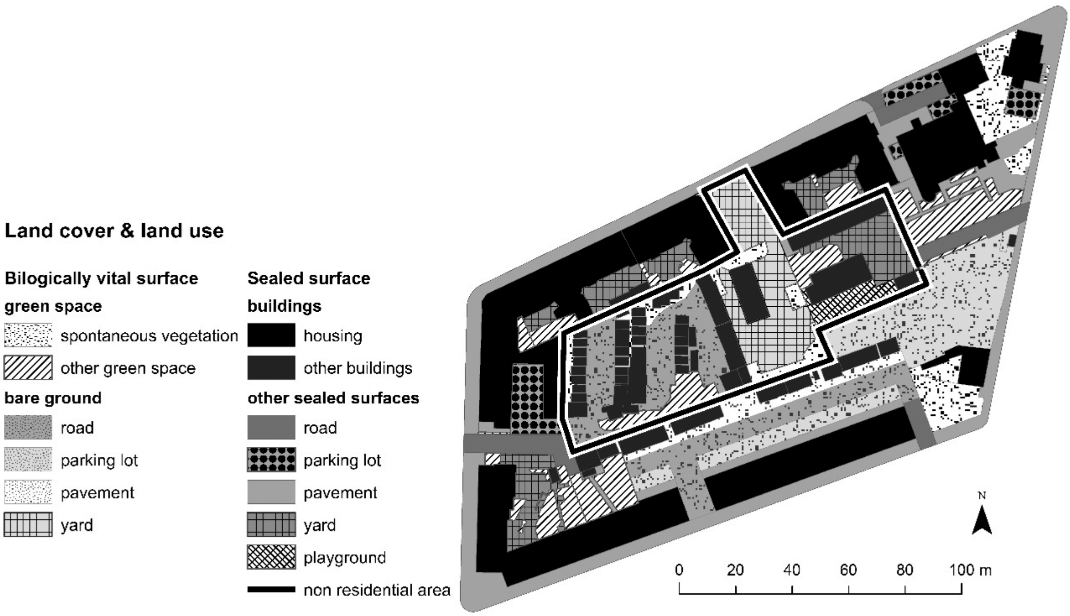

Figure 6. Distribution of green spaces at the background of other site-specific elements in the Łazarz quarter

One of the backyards of a tenement house is totally covered with bare ground almost completely devoid of vegetation. It is used as a road and a parking lot. On the other hand, there are also backyards with typical gardens forming a mosaic of sealed and green spaces. In this quarter, there is also the highest number of yards with spontaneous vegetation that have the lowest level of maintenance clearly visible in the landscape. This quarter is characterized by the highest amount of neglected spaces, spontaneously vegetated. This diversity is presented in figure 7.

Figure 7.
Łazarz quarter – from the left: bare ground used as a parking lot, the garden in the yard, spontaneous vegetation

Hulewiczów Quarter

Quarter of the Hulewiczów estate has the highest rate of green spaces among the investigated areas (figure 8).

Spatial distribution of buildings makes that a significant part of green areas, is located on the northwestern outskirts of the quarter. This side of the estate adjacent to the agricultural land, wasteland and a parking lot is fenced.

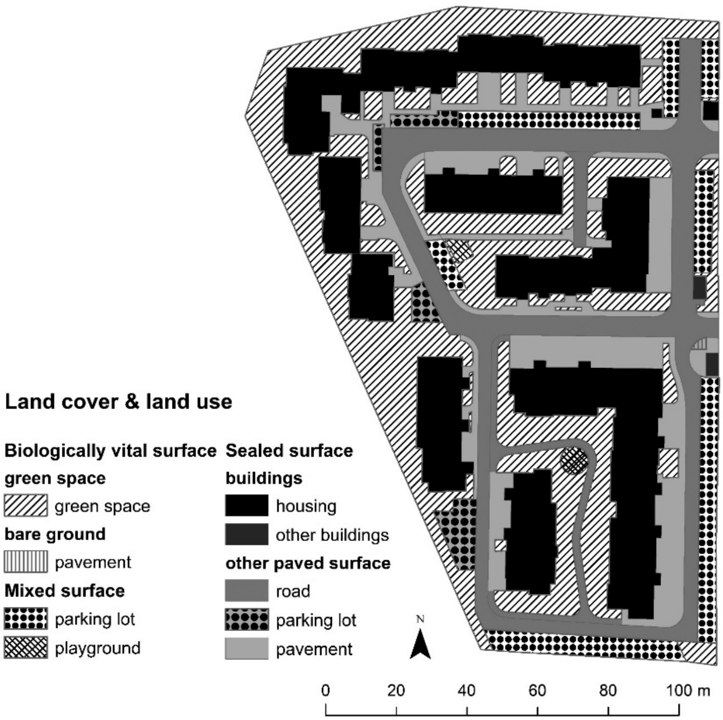

Figure 8. Distribution of green spaces at the background of other site-specific elements in Hulewiczów quarter

The access to particular parts of the green space belonging to housing communities is limited due to partial or complete fencing.

Green areas located "on the back" of buildings are maintained to a lesser extent. Existing plants develop spontaneously and lawns are not mowed regularly. Green areas inside the estate can be divided into two types: green areas in front of buildings and green areas between the buildings (figure 9). The first have a decorative character, not providing recreational use, while green spaces between buildings are more suited for recreational purposes. The green spaces between the buildings consist mainly of lawns with ornamental shrubs and single trees. In these areas, however, equipment for recreation is rather poor. There are two small playgrounds, whose main feature is a sandpit and accompanying single benches. In the whole area, there are no places that would encourage social integration of the adult population.

Figure 9.
Hulewiczów quarter – from the left: green areas at the back of buildings, in front of buildings, between buildings

To provide a wide range of ES, green spaces must be appropriately designed and managed. This is particularly clearly visible at the site scale. The set of characteristics and elements identified in the selected quarters influencing ES potential and the flow is shown in table 3.

The conducted site investigation showed that the green space design and structure influence the emergence of ES synergies to a high extent. A good example is decorative green spaces in front of the buildings, which do not provide possibilities for recreational use, and due to the limited volume of plant's foliage may have a lower cooling effect. On the other hand, the study identified the existing nature-based solution, such as creepers planted to mitigate the visual impact of less esthetic objects, which at the same time support the supply of regulatory ES.

An important issue affecting the potential of ES is maintenance of green spaces. A neglected green space and insufficient or destroyed infrastructure are still present in residential areas in the downtown districts.

Table 3. Characteristics and elements identified in the investigated quarters according to its role in shaping the ES potential and flow

Feature	Wilda	Łazarz	Os. Hulewiczów
Green ratio [%]	17	16	31
Building ratio [%]	43	35	28
Other sealed surface ratio [%]	40	25	33
Recreational infrastructure	Benches, garden or street furniture, playground (sandpit, swing), basketball court	-	Sandpit, swing, benches
Vertical green	Creeper at the shelter for waste containers and sportsground fence	Creeper at the building wall, at shelter for waste containers and fences	Creeper at the shelter for waste containers, at energy pole
Other elements supporting ES potential	Water garden	-	Openwork panels at the parking lot
Elements reducing ES potential	Surface sealing with impervious surface Devastation of street furniture	Surface sealing with impervious surface	Surface sealing with impervious surface
Restrictions	Dogs walking and ball playing	-	Dogs walking and playing with a ball

It should also be noted that at the analyzed areas, access to green spaces is usually partially or totally restricted by fences and lack of access to specific passages. In some cases, it limits the ES benefit zone and a number of beneficiaries while in others creates ES disadvantage zones.

Discussion

The multicriteria analysis of ES potential based on land-use assessment and an indicator approach allowed one to identify areas of the lowest ES potential at the city scale. However, it has to be highlighted that the selection of ES as criteria for inclusion in investigation can vary and should be adjusted to study aims and city characteristics. Advancing spatially-explicit tools in combination with multicriteria analysis is recognized as a priority in the assessment and valuation of urban ES (Haase et al., 2014)

This study supports planning and decision-making by targeting densely populated urban areas of the lowest ES potential, where improvement or creation of a new green space can bring high societal benefits with the introduction of relatively small changes. Among the areas with the lowest ES potential, multifamily residential areas, including tenement houses, have been identified. They represent areas with a rate of 16–31% green spaces, which, to a high extent, determine the ability to supply ES at the local scale. Of course, it has to be borne in mind that exact numbers are affected by the designation of the area's borders. Nonetheless, in this case Unit Specific Sites are spatially explicit.

The investigation on how the proportion between sealed and biologically vital areas may influence the environmental processes at site level was conducted by Szulczewska et al. (2014) Their results have shown that, to assure environmental performance in a neighborhood, the ratio of biologically vital areas should be secured at the level of 40–50% of the plot area. The investigated quarters do not meet this threshold. Moreover, Szulczewska et al. (2014) point out that, although the ratio of a biologically vital area that is based on the quantitative approach is easy to implement in the planning, it does not contain information about the structure or the quality of a green space. This study confirmed that not only the rate of the green space but also the design, structure and maintenance affect the overall ES potential and, to a high extent, influence the ES synergy occurrence. Borowski, Pstrągowska (2015) have recommended to strive to achieve a maximally large surface and mass of plant's foliage to increase the positive impact of the plant on the environment. However, it should be noticed that a large number of bushes limits the space for recreation.

The study showed that urban multifamily residential quarters vary in spatial structure of land cover and land use as well as other site-specific elements, their accessibility, design and management. The chance to improve ES potential and ES flow can be clearly seen not only in surface unsealing or changing the sealed surface cover into a permeable one but also in a small scale nature-based solution such as water gardens. However, as Kabish et al. (2016) point out, there are still plenty of knowledge gaps with regard to the effectiveness of this kind of solution.

The site scale analysis has identified several non-ecosystem based anthropogenic elements such as infrastructure that support the flow of recreational ES. This shows that the supply of ES does not only depend on ES potentials but also on additional input (Burkhard et al., 2014). Not only physical infrastructure and technology, but also social practices and the cultural context mediate ES (Kremer et al., 2016), and this aspect should also be developed in the future.

Conclusions

In a situation of high competition for space, planning and development of multifunctional green spaces with high ES potential become an important solution for spatial problems. Mapping and assessment of ES potential to set priority areas for improvements proved to be a useful tool that can support decision-making conducted under limited resources.

The advantage of the presented method is the ability to use different indicators to assess ES potential as well as the choice of ES included in the analysis can be adjusted to a particular city. Thus, the approach can be further developed. It is also important to notice that applied data allows for a comparison study since Urban Atlas is available for 305 large urban zones, including 27 in Poland. Although BDOT is a database adopted in Poland, many cities worldwide have similar data resources.

Site investigation identifies the importance of land use and the land cover structure that together with recreational infrastructure contribute to the ES potential, flow and ES synergy emergence. The results also reveal existing small-scale nature-based solution. They can act as alternative solutions where multi-ES spaces are not provided or the level of their potential is not sufficient to meet inhabitant's needs. However, to use nature-based solution as a good practices further development of knowledge about their effectiveness is needed.

The results of the study can be used as a support for urban transformation towards the implementation of nature-based solutions and the transition of densely, built-up residential areas toward multi-ES spaces. Such an approach fits in the Poznań municipal policy toward urban regeneration reflected in a program entitled "Friendly yard", in which residential communities from downtown may receive a grant from the city budget for yard development projects.

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