

A GEOSPATIAL APPROACH TO MAPPING AND ASSESSMENT OF URBAN ECOSYSTEM SERVICES IN BULGARIA

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Abstract

The mapping of ecosystem services is essential for understanding how ecosystems contribute to human wellbeing. The EU Biodiversity Strategy to 2020 requires the member states to map and assess the state of ecosystems and their services. Urban landscapes provide various services and their mapping necessitates prioritization, integration of data and application of geospatial approaches. In this paper, we focus on the geospatial approach used to assess and quantify the ecosystem services provided by the urban ecosystems and its possibilities for producing maps at multiple scales. The assessment of ecosystem services is based on various indicators, which rely on different data sources with their own origins, scales, and levels of precision. We develop seven GIS-based approaches that comprise different procedures and tools to arrange the available data and produce ES maps.

The assessment is applied to 20 ecosystem services defined as relevant to the urban ecosystems in the country. We produced maps at multiple scales for selected individual services. The results at the national level are summarized for municipalities and districts, while at the local level, they are presented for three selected cities in large-scale maps.

Keywords: *Urban ecosystems, landscape pattern, ecosystem condition, tiered approach, GIS based approaches, MAES*

1. INTRODUCTION

The mapping of ecosystem services (ES) has become an important topic, and the publications in this field have grown exponentially in recent years (Shagner et al. 2013). This information is essential for understanding how ecosystems contribute to human wellbeing, the locations of areas that provide such contributions, and the areas that benefit. The EU Biodiversity Strategy to 2020 provided an important push to this process in Europe by requiring member states to map and assess the state of ecosystems and their services. The working group on Mapping and Assessment of Ecosystems and their Services (MAES), which was established in response to the Strategy, developed a conceptual framework to ensure coherent mapping and assessment across Europe and across scales (Maes et al. 2013). Urban areas are the environment where most of the population lives and performs their everyday activities, and people need an inclusive, healthy, resilient, safe and sustainable living environment (Maes et al. 2016). Cities depend on both natural ecosystem services provided beyond the city area, in a perimeter of 500–1000 times larger than the city area itself (Folke et al. 1997), and those provided from urban ecosystems (Chiesura 2004). The green infrastructure in the cities is of key importance as a source of a range of benefits (Rall et al. 2015) and can contribute to the sustainable development of the cities (Gonzales and De Lazaro, 2013).

During the last decade, several European countries started their own national ecosystem assessments (NEAs), which included also mapping of ecosystems and their services. There is a diversity of approaches and methods applied in NEAs which makes a comparison between them challenging (Schroter et al. 2016). Although those published after the EU Biodiversity Strategy aimed to comply with it, there is a need of “standardization or at least harmonization of data collection, indicators and methods to assess biodiversity and ecosystem services” (Schroter et al. 2016). The MAES conceptual framework provides a basis for such harmonization by the proposed ecosystems typology, the logical sequence of ecosystem mapping, the assessment of ecosystem conditions and services, and the utilization of CICES classification in ES assessment. The MAES process in Bulgaria started in 2014 with a preliminary mapping of ecosystems followed by development of a methodological framework based on the abovementioned basics of the MAES concept. It included nine methodologies corresponding to the main ecosystem types in MAES typology with a uniform structure including third-level ecosystem typology, mapping of ecosystem types, assessment of ecosystem condition, and assessment of ES (Zhiyanski et al. 2017; Nedkov et al. 2017a). All terrestrial and freshwater ecosystems according to the MAES typology (Maes et al. 2013) as well as most marine ecosystems, with the exception of Open Ocean, are present in Bulgaria. The main part of the territory is occupied by cropland (47.9% of the counties’ area) and forest (38.0%) ecosystems, followed by grassland (7.2%) and urban (4.7%). Urban ecosystems in Bulgaria cover 5333.7 km² and they are evenly distributed throughout the territory (Nedkov et al. 2017b).

Different methods and models are used to map specific ES, and the indicators used to quantify them differ remarkably between provisioning, regulating and cultural services (Maes 2017). Geospatial data is a key component to define the spatial extent of the ES and its further

link with assessment ranking ensures easy and fluent generation of maps (Burkhard 2017). Boyd and Banzaf (2007) note that geospatial information system is needed to express the service providing units both numerically and visually. Geospatial approaches are widely used in environmental assessment (e.g. Rahman and Rashed 2007; Krishnan and Emayavaramban 2014), in studies on the status and changes in landscape pattern (Estoque and Murayama 2018) and urban green spaces (Mougiakou and Photis, 2014) because they provide an appropriate basis for the integration of various spatial data sources at various scales with corresponding tools into a common framework that ensures both data storage and generation of maps. In our case, the data sources for different ES indicators had various origin, format, spatial extent and scale (Zhiyanski et al. 2017). Therefore, we needed to employ different tools and techniques to reveal the spatial aspects of the entire range of ES indicators (Nedkov et al. 2017a). We used GIS as a platform to develop an approach that integrated geospatial data for urban ecosystems in the country, tools for spatial analyses and quantification of ES indicators and mapping techniques.

This paper's main objectives are to present the methodological basis for the mapping and assessment of urban ecosystems in Bulgaria, the GIS-based approaches used to assess and quantify the ecosystem services and the possibilities of producing maps at multiple scales.

2. MATERIALS AND METHODS

2.1. Study area

In this study, we map and assess the urban ecosystems in Bulgaria. The main source of data is the database developed under TUNESinURB project (<http://tunesinurb.org/en/>). It covers all the country's territory outside NATURA 2000 zones (Nedkov et al. 2017a). The total area of urban ecosystems in Bulgaria outside NATURA 2000 zones is 4796.3 km², which is approximately 89.9% of all the country's urban areas calculated on the basis of CORINE 2012 land cover data. However, the area of urban ecosystems outside NATURA 2000 calculated from the TUNESinURB project dataset is 5301.7 km², but there is no calculation of areas inside the zones. Because the calculations are made using different sources (CORINE data is much coarser and less precise), calculating the percentage on the basis of the later figures is incorrect, but the results do not differ by much. Therefore, the case study area covers all urban ecosystems in the country outside NATURA 2000 zones, which comprises approximately 90% of all the country's urban areas. On the other hand, the data used to quantify some indicators to assess the ecosystem condition and services are not available at national scale. For this reason, we choose smaller case studies for testing the methodology combining obligatory and optional indicators at a finer scale. Three cities were selected with different size, location, levels of urban development and functional specialization (Figure 1). Varna is the country's third largest city, located on the Black Sea coast; Pleven is a middle-sized city located inside the country on the Danube plain; and Karlovo is a small town located in a valley alongside the Stara Planina and Sredna Gora mountains.

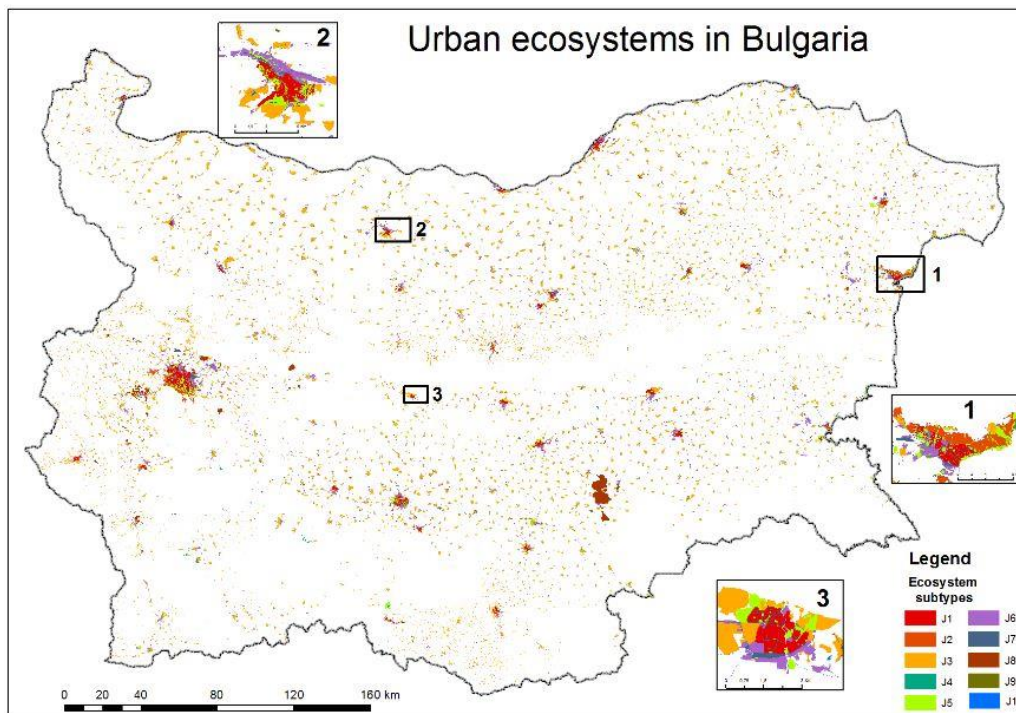


Figure. 1. Urban ecosystems in Bulgaria outside NATURA 2000 and the city case studies (1-Varna; 2-Pleven; 3-Karlovo)

2.2. Methodological framework for mapping of urban ecosystem and their services in Bulgaria

The MAES conceptual framework (Maes et al. 2013) provides a good basis for the harmonization and unification of the mapping and assessment process. This framework was further developed with a detailed workflow scheme that defines particular stages and recommends data sources, methods and approaches (Burkhard et al. 2018). The methodological framework developed and applied here is relevant to urban ecosystems of the entire territory of Bulgaria comprising the full cycle of the assessment and mapping of the capacity of these ecosystems to deliver ecosystem services (Zhiyanski et al. 2017). The ecosystem mapping is based on the typology of ecosystems at the European scale developed by the MAES working group (Maes et al. 2013). For Bulgarian urban ecosystems, the third level (subtypes) was based on the National Concept for Spatial Development for the period 2013–2025 (NCRD 2012). The subtypes were defined also in correspondence with EUNIS habitat classification (Davies et al. 2004) so the final version of the typology included 10 subtypes (Zhiyanski et al. 2017; Nedkov et al. 2017a). Urban ecosystems differed significantly from other ecosystems with their clearly defined boundaries, which were formed because of anthropogenic processes and were usually well documented in the official registers. Therefore, the main data sources for their delineation were administrative, such as cadastral maps, property registers, urban master plans, etc. The delineation of urban ecosystems in Bulgaria in the areas outside NATURA 2000 zones was performed in the frame of the TUNESinURB project. The workflow was conducted in two steps and the delineation of the ecosystems was made using a flexible spatial approach (Nedkov et al. 2016).

The assessment of urban ecosystems condition followed the elaborated methodology (Zhiyanski et al. 2017) and was based on collecting and analyzing data for a set of indicators. Due to the diversity of urban ecosystem types and their specifics, the outlined common indicators (a total number of 37) are grouped into three categories: “key indicators”, which are obligatory and describe the condition of all urban ecosystems; “optional indicators”, which are

not well supported with data at the national level but are desirable for assessment and further monitoring; and “recommended indicators”, which are not supported with data but are recommended for better assessment of condition of urban ecosystems and could be proposed in further procedures by experts (Chipev et al. 2017). Contrary to the national extent, where the indicators are not always supported by appropriate data, for the selected case study areas data are available for each indicator obtained from national databases, field observations and laboratory analyses in accordance with the methodology (Zhiyanski et al. 2017). The assessment of urban ecosystems condition was realized both at regional (in case-study areas) and national scales, and the results were integrated in the spatial database. These results were used to analyze further the capacities of urban ecosystem services. Several ecosystem condition indicators were used in ES assessment including climate deficit of potential humidity, risk to atmospheric drought, potential evapotranspiration, vegetation cover, soil organic matter, air quality, vegetation cover and integrated index of spatial structure. The later incorporates build types and land cover from the Local Climate Zones concept (Stewart and Oke 2012) with urban ecosystem classes based on MAES typology. The index is used to define vegetation cover in urban ecosystems and assess their condition as a part of the assessment framework and reveals the landscape pattern of the urban areas (Nedkov et al. 2017a).

2.3. Geospatial approach for mapping urban ecosystem services

ES maps are the final product of a complex continuous process that includes ES identification, the selection of indicators, collection of data, quantification of ES indicators, ES assessment (evaluation) and the production of ES maps. The process is also related to the mapping of ecosystem types and the assessment of ecosystem condition. Geospatial data is a key component for defining the spatial extent of the ES and its further link with assessment ranking ensures easy and fluent map generation (Burkhard 2017). The access to Spatial Data Infrastructure (SDI) is very important as it provides accessibility to a wealth of quality information as well as interoperability (Otero and Tores 2017). The spatial data sources for ecosystem types and ES indicators for our study had various origins, formats, spatial extents and scales. This variety necessitated the use of different tools and techniques for spatial analyses to produce an appropriate GIS database that was crucial for generating ES maps. The conceptual scheme of our approach is given in Figure 2, and its main components are presented further in this sub-chapter.

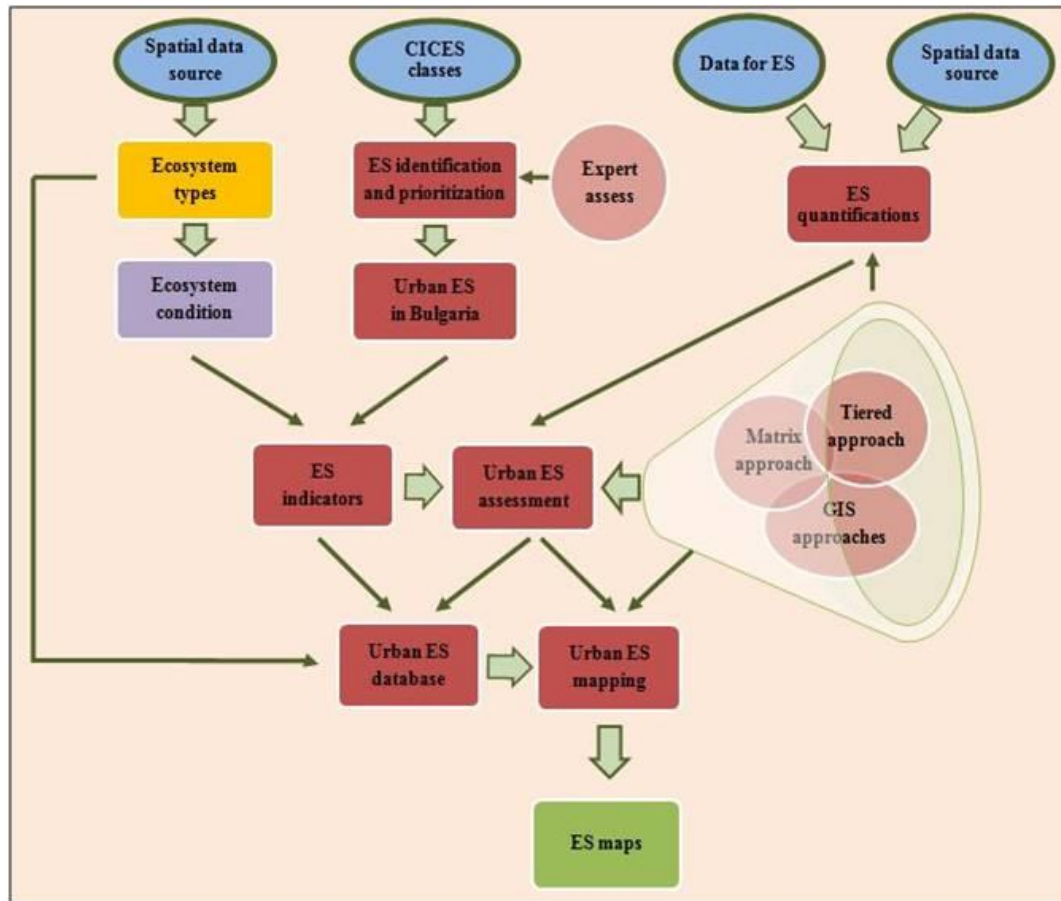


Figure. 2. Conceptual scheme of the geospatial approach

The tiered approach is recommended to make ecosystem services maps comparable across Europe and to support the member states in mapping ecosystem services (Maes et al. 2014). Following this approach, we allocated the services according to the data availability and the level of details into these three tiers. At tier 1 were the services with no uniform data at the national level. The assessment was based on indicators and parameters derived from the ecosystems spatial database and expert judgment. The services at tier 2 were provided with statistical data or biophysical parameters at the national level that could be interpolated using GIS spatial proxy analyses. The services at tier 3 were selected for more detailed analyses by modeling biophysical processes at the local level for case study areas.

To assess ecosystem services provided by urban ecosystems we analyzed all potential sources of data at the national level and the ecosystem parameters that can be represented by each of them. Furthermore, we analyzed the results from the assessment of ecosystem conditions and selected indicators that could be used for ecosystem services assessment. When more than one indicator was available for a particular service we combined them in aggregated indicators. The indicator values are measured in different units, and for the overall assessment, they were normalized using a 1 to 5 relative scale. The value intervals were defined using a particular statistical method for each individual or aggregate indicator. For instance, the carbon storage was calculated in tC/ha. The values varied between 0.2 tC/ha and 213 tC/ha among polygons. The intervals were defined using the natural breaks method with break values at 0.2, 12.59, 32.27, 46.31, 61.68 and 213.42.

2.4. GIS-based approaches for ES assessment

The development of the GIS database is one of the main components in the methodological framework of urban ecosystems in Bulgaria (Zhiyanski et al. 2017). The core of this database is a polygon vector layer that contains all delineated urban ecosystems in the country. The data about ecosystem's condition and services are organized in a relational structure that contains a series of tables, keys, and relations between them. Each table corresponds to a particular stage of the assessment process and stores the results of this procedure. The data in these tables are also used as sources for further assessment procedures (see Figure 2). The assessment of ecosystem services is based on various indicators, and each of them relies on different sources of data with a respective origin, scale, and precision. Therefore, a separate approach must be developed for each service with procedures to achieve appropriate results. On the other hand, they have some similarities that make it possible to group them in more general approaches that ensure some simplification and unification of the work. As a result of analyses of all aspects of the ES assessment process, the procedures were grouped in seven approaches: 1) expert assessment, based on ecosystem subtypes at the national level; 2) expert assessment, based on ecosystem subtypes and additional parameters; 3) quantitative assessment, based on aggregated data at the administrative level (municipality or district); 4) quantitative assessment, based on aggregated data in natural spatial units (soil types, bedrocks, water bodies, etc.); 5) qualitative assessment based on calculation of each individual polygon from the ecosystems database; 6) quantitative assessment, based on calculation of values for each individual polygon from the ecosystems database; and 7) quantitative assessment, based on modeled data available for each polygon from the ecosystems database.

The first approach is the most simple and is applicable for ecosystem services with no reliable data at the national level and where there is no option for further division of the ecosystem subtypes. The scores are given for each ecosystem subtype in general and transferred to all corresponding polygons in the database. For the second approach, we use additional parameters such as the integrated index of spatial structure of urban ecosystems to better reflect the spatial differentiation of the urban ecosystems. Both approaches correspond to tier 1 as defined by Maes et al. (2014). The third approach is applied for indicators with data available at the administrative level (mainly municipality) and the assessment of ecosystem subtypes is based on aggregated data at the corresponding administrative level. The fourth approach is similar to the previous, but instead of administrative units, the indicator data are quantified using data aggregated from natural elements such as soil, bedrock, water, etc. The fifth approach is based on data derived mainly from the assessment ecosystem condition. The scores there are in relative scale (qualitative) and available for each polygon of the dataset. Therefore, the ES assessment could be performed for each polygon using GIS overlay techniques. The sixth approach is based on quantitative data that is available or could be calculated for each polygon of the GIS dataset. For instance, the amount of carbon is calculated for each polygon using a GIS-based approach that incorporates data from the integrated index of spatial structure, vegetation cover, and organic matter in the soils and carbon content in the vegetation (Nedkov et al. 2017a). Approaches three to six correspond to tier 2 because they rely more or less on statistical data used to derive more complex indicators that are combined to estimate ecosystem services (Maes et al. 2014). The seventh approach relies on data from the GIS-based modeling of biophysical processes. It was applied only at local scale because it required more detailed input data that were not available for the whole country and the modeling process necessitated time and resources that were not available for this study. This approach corresponds to tier 3. The level of complexity and precision increased from the first to the seventh approach. For each ecosystem service particular approach and indicators for ES assessment were assigned (Table 1).

Table 1. GIS approaches and indicators for quantification of urban ecosystem services. Appr.—approach, the numbers are given in the text; Indic—types and number of indicators used for an ES; Ag-aggregated indicator (the figure indicates the number of indicators aggregated in it; I-indicator (the figure indicates the number of indicators); and N-number of ecosystem subtypes relevant to the respective service.

Ecosystem services		National level		Local level		Total number indicators	N subtype ecosystems
		Appr.	Indic.	Appr.	Indic.		
Provisional	P1. Cultivated crops	5	Ag 2	7	Ag 3	8	3
	P2. Reared animals, etc.	5	I 3	5	I 3	3	3
	P3. Wild plants, algae, etc.	5	I 3	5	I 3	3	5
	P4. Wild animals and their outputs	5	I 1	5	I 2	2	4
	P5. Groundwater for drinking	4	I 1	4	I 1	1	6
	P6. Surface water for non-drinking	4	Ag 1	4	Ag 1	3	8
	P7. Groundwater for non-drinking	4	I 1	4	I 1	1	6
	P8. Fibers and other materials	2	I 3	2	I 3	3	8
	P9. Genetic materials	6	Ag 1	6	Ag 1	3	10
	P10. Plant and animal resources	3	Ag 1	3	Ag 1	6	10
	P11. Animal mechanical energy	3	I 1	3	I 1	1	3
Regulating	R1. Regulation of pollution	1	I 1	1	I 1	1	8
	R2. Erosion regulation	5	I 3	5	I 3	3	7
	R3. Water flow and flood reg.	6	Ag 1	7	Ag 1	4	10
	R4. Regulation of air flows	5	I 2	5	I 2	2	10
	R5. Pollination and seed dispersal	3	I 1	3	I 1	1	3
	R6. Pest and disease control	5	I 5	5	I 5	5	7
	R7. Regulation of soil formation	5	I 8	5	I 8	8	6
	R8. Global climate regulation	6	Ag 1	6	Ag 1	4	10
	R9. Regional climate regulation	5	Ag 1	5	Ag 1	3	10
Cultural	C1. Recreation	4	Ag 3	4	Ag 3	9	7
	C2. Scientific and Educational	3	I 1	3	I 1	1	10
	C3. Cultural heritage	3	I 6	3	I 6	6	6
	C4. Aesthetic and spiritual	5	I 1	6	I 2	2	9

The results of ES capacities by polygons in the GIS database were aggregated first into municipalities and then into districts using a summary statistics tool. The aggregation was applied by generating mean values of all ES capacity scores per municipality or district. Then, the mean values were assigned to municipality and district GIS layers. The resulting layers contain mean ES capacities of urban ecosystems in each municipality (or districts) based on the assessment of each individual service. Then, the ES capacity for each municipality or district was defined by the statistical analysis of resulting range of mean values. We assume that the highest score per municipality represents the highest ES capacity for the respective ES in the country. The value intervals of the capacity scores were defined using the natural breaks method. The same procedure was also applied at the district level.

The local level maps were designed at scales that corresponded to the area of the respective city, and they varied between 1:5 000 and 1:15 000. In this case, the polygons from the GIS database were used as spatial units, and the assessment scores for each of them were depicted on the map.

3. Results

3.1. Urban ecosystems and their services in Bulgaria

The spatial data of urban ecosystems was stored in a vector polygon layer that includes 71 425 polygons covering an area of 5300.8 km². The largest area was occupied by *residential and public low density areas* (J3) with 3117 km², which was 58.8% of entire urban ecosystems area. The second largest subtype was *industrial* (J6) with 827.6 km² (15.6%) followed by *urban green areas* with 501.1 (9.5%). The latter does not present the area of green infrastructure because all other subtypes also had more or less green spaces, but their area was below the minimum mapping unit; therefore, they were not delineated as separate urban green areas. The *residential and public areas of cities and towns* (J1) occupied 278 km² (5.2%); the *transport network* (J7), 201 km² (4.3%); and the *extractive industrial sites* (J8), 201.3 km² (3.8%). The other four subtypes (J2, J4, J9 and J10) had limited extents; each occupied less than 1% of the entire urban area.

The relevant ecosystem services to urban ecosystem subtypes were identified as a result of prioritization procedure. First, 11 ecosystem service classes from CICES classification were defined as not relevant for urban ecosystems and removed from further prioritization. Then, another eight services were removed due to the lack of available data. Further analyses of the services with partially available data resulted in unification of several services. This procedure resulted in 20 ecosystem services defined as relevant to urban ecosystems and that can be assessed and mapped at national level in Bulgaria (Table 2). The provisioning group contained the highest number of services (11) because they are easily quantifiable and more data were available.

Table 2. Ecosystem services and their relevance to the urban ecosystem subtypes in Bulgaria

Ecosystem services		J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	Area km ²
Provisioning	P1. Cultivated crops	1	1	1								3479.3
	P2. Reared animals, etc.		1	1			1					4028.0
	P3. Wild plants, algae, etc.		1	1	1	1		1				3961.3
	P4. Wild animals and their outputs			1	1	1					1	3663.0
	P5. Groundwater for drinking	1	1	1	1	1	1					4840.5
	P6. Surface water for non-drinking	1	1	1	1	1	1	1			1	5077.9
	P7. Groundwater for non-drinking	1	1	1	1	1	1					4840.5
	P8. Fibers and other materials	1	1	1	1	1	1	1			1	5077.9
	P9. Genetic materials	1	1	1	1	1	1	1	1	1	1	5300.8
	P10. Plant and animal resources	1	1	1	1	1	1	1	1	1	1	5300.8
	P11. Animal mechanical energy		1	1			1					4028.0

Regulating	R1. Regulation of pollution	1	1	1	1	1	1	1		1	5077.9
	R2. Erosion regulation	1	1	1	1	1	1			1	4840.5
	R3. Water flow and flood reg.	1	1	1	1	1	1	1	1	1	5300.8
	R4. Regulation of air flows	1	1	1	1	1	1	1	1	1	5300.5
	R5. Pollination and seed dispersal		1	1		1					3703.1
	R6. Pest and disease control	1	1	1	1	1	1			1	4852.5
	R7. Regulation of soil formation	1	1	1	1	1	1				4840.5
	R8. Global climate regulation	1	1	1	1	1	1	1	1	1	5300.8
	R9. Regional climate regulation	1	1	1	1	1	1	1	1	1	5300.5
Cultural	C1. Recreation	1	1	1	1	1	1			1	4852.5
	C2. Scientific and Educational	1	1	1	1	1	1	1	1	1	5300.8
	C3. Cultural heritage	1	1	1	1	1	1				4840.5
	C4. Aesthetic and spiritual	1	1	1	1	1	1	1		1	4852.5

3.2. Mapping of selected individual ecosystem services

3.2.1. National-level mapping

For this paper, we selected five services to present the results of the ES mapping at the national level: cultivated crops, groundwater for drinking, animal-based mechanical energy, global climate regulation and aesthetic value. They were chosen to be representative for the three main groups of services and to show the application of different GIS-based approaches.

The results showed that urban ecosystems have predominantly relevant-to-medium capacities to provide cultivated crops and groundwater for drinking. The most common values were between 1.2 and 1.7 (Figure 3). The capacity for animal-based mechanical energy was slightly lower with predominance of the relevant capacity class, and only a few municipalities had values higher than 2.5 (Figure 3). The results for aesthetic value had predominant medium capacity with a slight tendency to high capacity. The most common values were between 2 and 2.6. The district-level map for this service showed a quite diverse distribution with all classes being distributed almost evenly between different districts. The results for global climate regulation showed the highest scores among these five services. The predominant supply capacity was medium to high, with the most common values between 2.5 and 3.3.

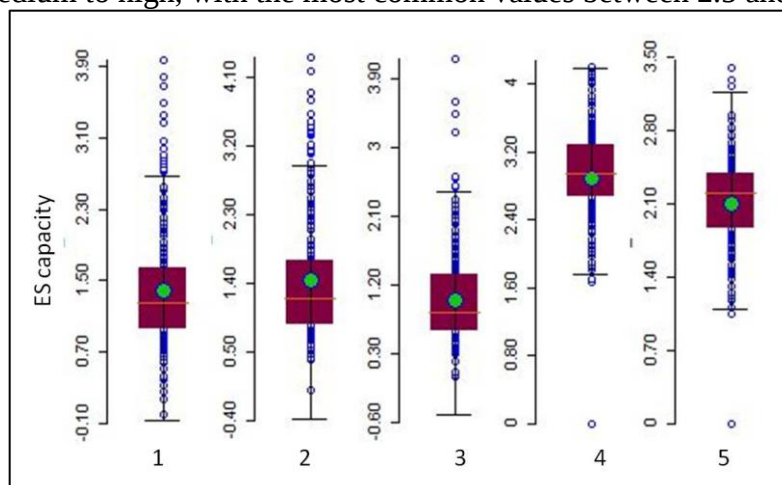


Figure 3. Block-plot diagrams for the selected ecosystem services at the municipality level; 1—cultivated crops; 2—groundwater for drinking; 3—animal mechanical energy; 4—global climate regulation; and 5—aesthetic value

The maps at the municipality level give more detailed information which allows regularities in the spatial distribution to be revealed. The municipalities with high capacities to provide cultivated crops are located in the country's central, southern and western parts (Figure 4) in areas with predominantly mountainous relief. This distribution is mainly due to the high scores of the indicators for environmental conditions (risk to drought and soil organic matter) and ecological state (air quality) of these areas. The lack of data for soil productivity at the national level does not allow this important indicator to be used; therefore, these results should not be considered fully representative. Higher scores for groundwater for drinking were obtained for ecosystems located in river terraces and other accumulative relief forms—lowlands, kettle-plains and mountain foothills. This service was primarily formed by groundwater and, to a limited extent, by karst water. Urban ecosystems could directly influence the sustainability of this service. Municipalities with the highest scores were located mainly in the lowlands in the country's southern part.

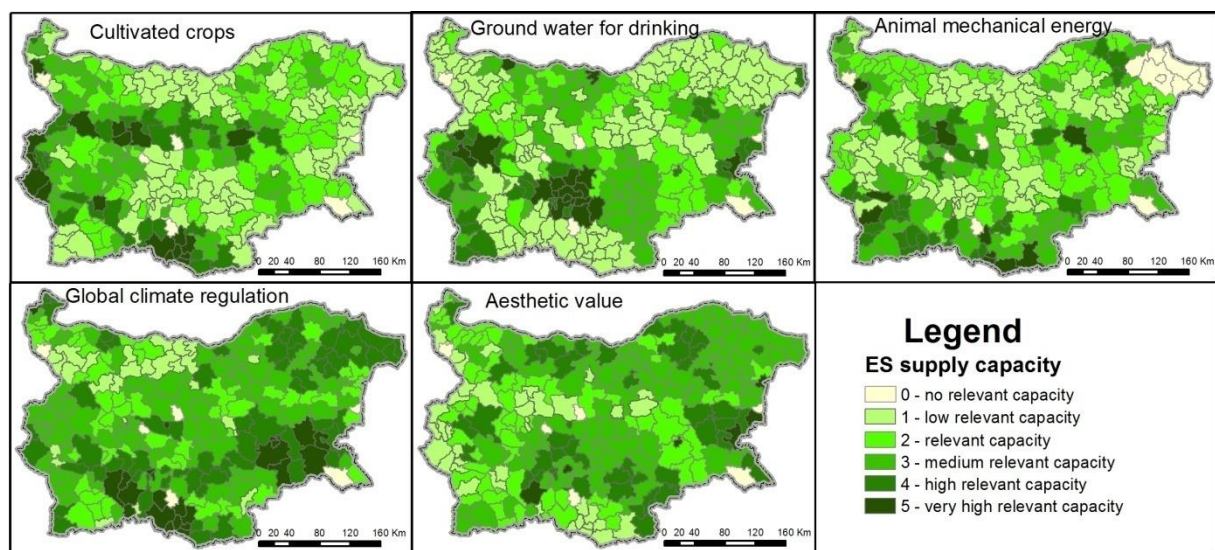


Figure 4. Maps of selected ecosystem services supply capacities at the municipality level

The municipalities with highest scores for animal-based mechanical energy are located in the southern, southwestern and central parts of the country. These areas are predominantly rural and mountainous where the use of animals in agriculture is preserved. The correspondence between municipality and district maps is best for this service because the GIS approach used here is based on data at the municipality level and the information for the polygons within a single municipality is uniform. The map of global climate regulation at the municipality level does not show a specific distribution pattern because the green infrastructure in different settlements depends on administrative measures rather than environmental factors. Some of the municipalities (and districts) in the Rhodope Mountains have high scores that correspond to the higher forest cover in this area. However, the other municipalities with such high scores are located in the country's eastern part, which is predominantly lowland with extensive agricultural areas and rare forest vegetation. The scores of the aesthetic value are higher in the municipalities and districts with big cities, such as Sofia, Plovdiv, Varna, Burgas, Pleven.

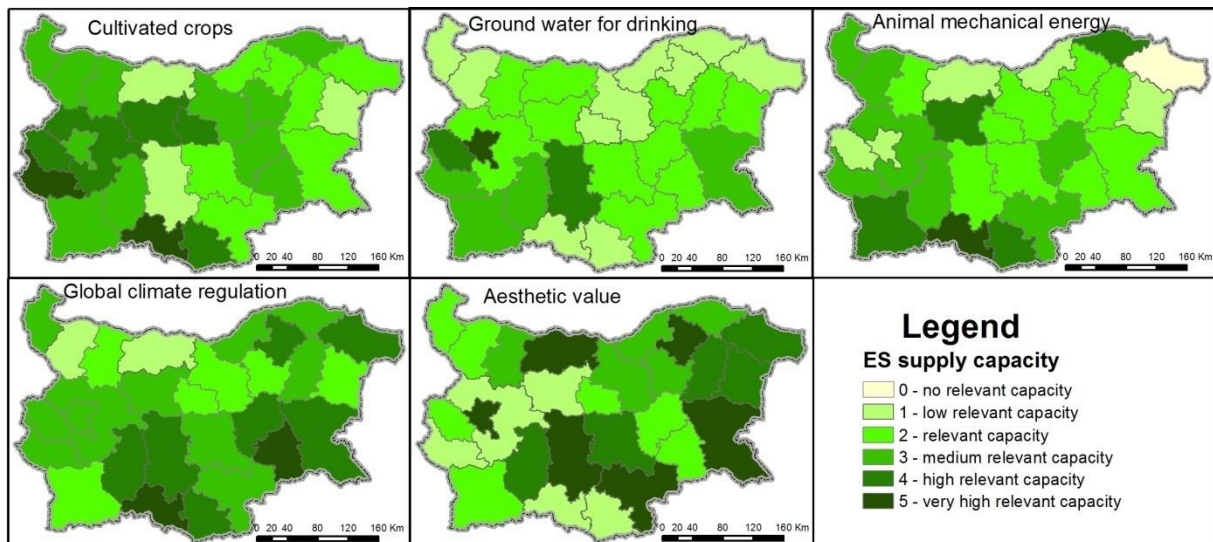


Figure 5. Maps of selected ecosystem services supply capacities at the district level

3.2.2 Case study areas mapping

The urban ecosystems assessment was implemented at large scale, and the resulting GIS database contained detailed data for each settlement in the country. This enabled the preparation of large-scale maps at the city level that could reveal ES supply capacity distribution in more detail. The purpose of this subsection is to demonstrate the flexibility of the approach at multiple scales and through different indicators. Three ecosystem services (cultivated crops, global climate regulation and aesthetic value) were chosen to demonstrate local scale differences of ES supply in the case study cities.

Cultivated crops are not common in urban ecosystems, but urban agriculture is increasingly proposed as an environmentally friendly answer to global challenges (Aerts et al. 2016). For the assessment at the national level, we used two complex indicators: environmental condition and ecological state. Each consisted of individual indicators that represented the environmental condition as factors (such as evapotranspiration and soil organic matter) for crop growth and the environmental condition (such as air quality and NO₂ content) that affected the quality of the crop production. Soil productivity was used as an additional indicator at the local level because it was not available for the whole country. The maps produced for the city of Pleven show that there are particular differences of the results when only the obligatory indicators at national level are used (Figure 6A) and when soil productivity indicator is added (Figure 6B).

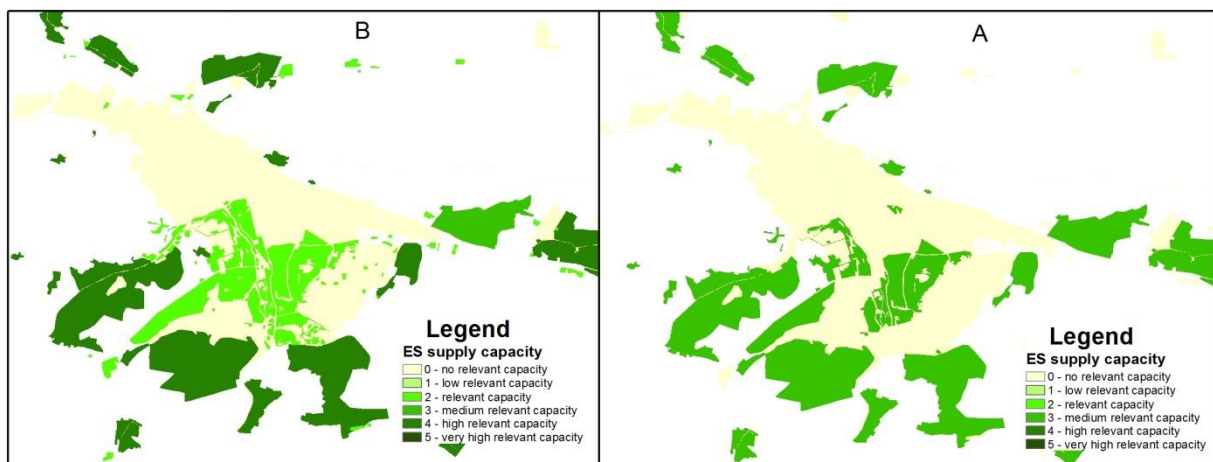


Figure 6. Cultivated crops supply capacity in the Pleven case study: A—using obligatory indicators at the national level and B—using more indicators (obligatory + optional) available at the local level.

The aesthetic value of urban ecosystems was assessed using the photoelicitation method by counting pictures uploaded in a spatially explicit internet platform (Google Earth). For the assessment at the national level, the results of the selected case study areas were summarized, and the scores were assigned to each ecosystem subtype. For instance, the average score in the case studies for J1 was 4; therefore, this figure was assigned for all J1 polygons in the database. The maps presented in Figure 7A show the results of this approach. The maps in Figure 7B were prepared using the initial results by counting the picture polygon by polygon.

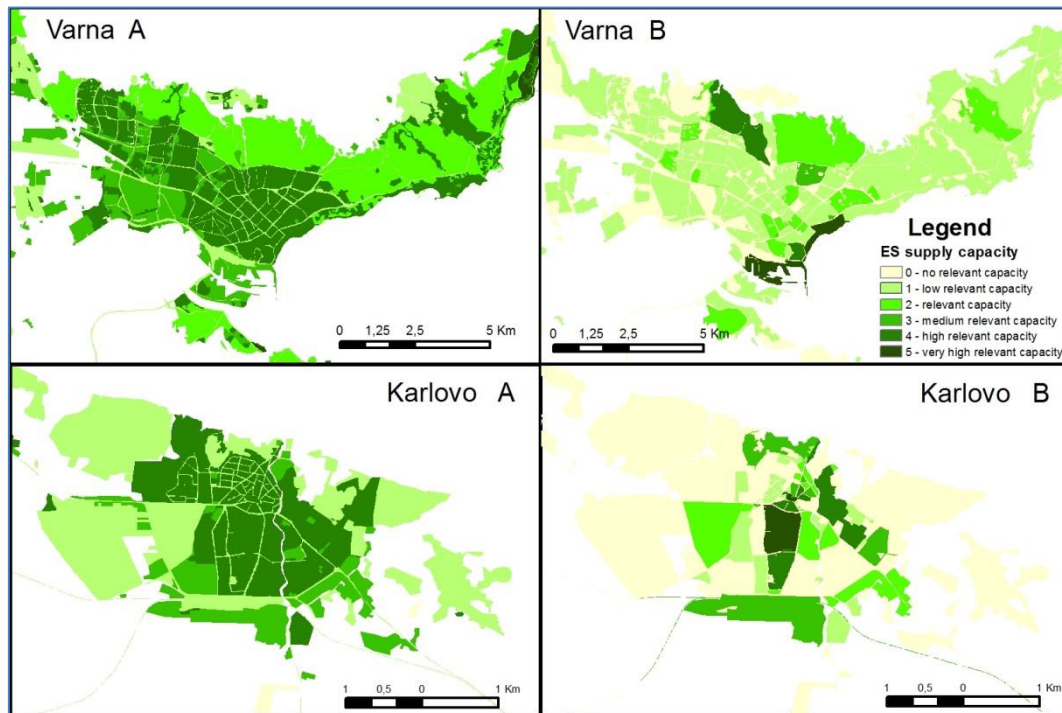


Figure 7. Aesthetic value in of urban ecosystems in Varna and Karlovo using summarized results at the national level (A) and initial results in the case study areas (B)

4. DISCUSSION AND CONCLUSIONS

The GIS-based approaches are organized in seven groups, starting from the simplest form of expert-based ecosystem services assessment and less detailed data in the first to the more complex and comprehensive analysis with detailed results in the last one. They are compliant with the available datasets in Bulgaria that can be used for quantification of different ES indicators. The algorithms are based on widely used GIS tools that can be easily adapted to datasets in other countries. The users can choose the most appropriate approach depending on the data quality and the level of complexity required by particular study objectives.

The main challenges in urban ecosystem services assessment undoubtedly stem from their anthropogenic origin. In this sense, the assessment principles and indicators should be in full compliance with the criteria for a favorable living environment for humans and their everyday lives. The bulk of the data and criteria used to analyze and evaluate ecosystem services derived from environmental monitoring are applicable to natural ecosystems, but in this case, a wider database must be integrated with comprehensive information on anthropogenic factors. Thus, they could function simultaneously as a source of services and as factors modifying the potential for providing urban services. This fact is particularly relevant to the assessment of urban ecosystems' condition. Here, information is utilized on the population number and density, transportation hubs, recreation hotspots, type and density of built environment, as well as characteristics of the ecosystems in the contact area of the urban environment.

This study reflects the results of the first national survey of ecosystem services provided by urban ecosystems in Bulgaria outside NATURA 2000 (approximately 89.9% of all the country's urban areas). It is based on the national methodology for the assessment and mapping of urban ecosystem services (Zhiyanski et al. 2017), which is consistent with the MAES framework (Maes et al. 2013) and CICES classification. A multi-tiered approach is applied for effective integration of a wider range of spatial and non-spatial databases with different quality and utilization of analyses as well as various levels of complexity. The approach allows easy and convenient options for generation of ES maps at multiple scales and with different levels of details and complexity.

The application of the proposed approach allows the assessing and mapping of the supplies of 20 individual ecosystem services at the national level. The results showed that urban ecosystems in Bulgaria have higher overall supply capacities for regulating and cultural services and lower supply capacities for provisioning services. At the municipality level, the areas with high capacities for regulation services have lower capacities for provisioning services and vice versa. The initial data by polygons are appropriate for the preparation of large-scale maps at the local level representing ecosystem services supplies for different urban areas.

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