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MULTICRITERIA APPROACH FOR THE IDENTIFICATION, MAPPING, AND ASSESSMENT OF ECOSYSTEM SERVICES IN FUNCTIONAL URBAN AREAS

ABSTRACT
of a PhD thesis
for awarding the educational and scientific degree “Doctor”
in a professional field 4.4. Earth Sciences
(Physical Geography and Landscape Science)

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Sofia, 2025

The dissertation consists of 173 pages, including 126 pages of main text and 47 pages of titles, references, and appendices. The study includes 40 figures, 24 tables, and 20 appendices. The list of sources used covers 326 titles, of which 78 are from the Internet.

The dissertation was discussed and approved for defense at a meeting of the Department of Landscape Ecology and Environmental Protection at the Faculty of Geology and Geography of Sofia University “St. Kliment Ohridski”, held on September 12, 2025.

CONTENTS

I. INTRODUCTION

The contemporary understanding of landscape is that of a multi-layered system in which natural and social components interact to form a complex structure. This structure determines the functions of the landscape and thus provides a variety of ecosystem services (ES) that are fundamental to human well-being. It is precisely this interrelationship between "structure → functions → services" that guides the landscape-ecological approach, which considers the natural environment alongside human needs. In the contemporary context, ecosystem services are a link between ecological processes and social needs, helping to understand and manage complex socio-ecological systems (Hansen, Pauleit, 2014). This gives rise to the concept of landscape multifunctionality, expressed in their ability to provide multiple ecosystem services simultaneously.

In this context, urban and peri-urban systems are particularly important. The contemporary challenges facing cities, such as urbanization, extreme weather events, etc., are grouped under No.11, "Sustainable cities and communities" of the United Nations Sustainable Development Goals (2015). Urbanization on a global scale includes both the expansion of cities and the increasing densification of existing urbanized areas. This leads to a transformation of the structure and functions of urban ecosystems (Haase, 2021) and, consequently, of the ecosystem services they provide. However, the challenges we face today are significant and multifaceted. Along with temperature anomalies, floods, and droughts associated with climate change, urbanization is a challenge for cities and thus for the geographical concentrations where most of the world's population now lives (UN, 2018). These processes put pressure on the natural elements in the UE—green and blue infrastructure (GI & BI), which are crucial for the health and well-being of the population.

It is green infrastructure and ecosystem services that are being promoted as concepts that have the potential to improve environmental planning in urban areas based on a more comprehensive understanding of the complex relationships and dynamics of socio-ecological systems (Hansen, Pauleit, 2014).

The urban environment is not isolated in space but is connected to its surroundings in a complex socio-ecological system, and therefore urban areas need to be considered in conjunction with their peripheries. Optimizing the connection between urban and peri-urban areas and ensuring and maintaining landscape multifunctionality, including the connectivity of green infrastructure around urbanized areas, is a key condition for ensuring diverse ecosystem services.

Cities or urban areas are increasingly identified as socio-ecological-technological systems (McPhearson et al., 2023). Therefore, a holistic approach that integrates biophysical structure and social function is sorely needed to understand these complex systems (Qian et al., 2020).

The aim of the dissertation is to develop a spatial model for the identification, mapping, and assessment of ESs from Functional Urban Areas (FUAs) that is as applicable as possible for the purposes of urban planning and management and decision-makers. The approach uses the methodology of Multi-Criteria Decision Analysis

(MCDA) at each stage of the study and includes the comprehensive identification of the demand and supply of ecosystem services in a single package (bundle of ecosystem services), which mutually determines and supports their significance in terms of benefits for people without compromising their sustainability over time. The specific practical activities to which the model is applied are the planning of the urban green system and its integration with the regional aspect of the green infrastructure (in the sense of landscape-ecological planning) and general urban planning with optimization of the center-periphery connection.

The study was conducted in response to the recommendations of the Mapping and Assessment of Ecosystems and their Services (MAES) working group for real-life examples and applications of how the conceptual framework for mapping and assessing of ecosystem services can be applied on an urban scale. The study discusses and builds on the MAES methodology for measuring the state of ecosystems and the provision of ecosystem services in urban areas, recommendations for its use in assessing urban green infrastructure (UGI) and nature-based solutions (NBS) and organised in support of policies, testing the methodological approach in a selected Functional Urban Area centred on the urban core of Burgas.

The subject of this study are the ecosystem service bundles provided by the urban ecosystems, and in particular the urban green infrastructure.

The object of the study is the territory of the Functional Urban Area (FUA-Burgas), considered as a single urban ecosystem.

The objectives of the study are as follows:

1. Identification of ecosystem services relevant to the urban ecosystems and in particular the territories of the Functional Urban Area and development of a matrix for prioritizing the ecosystem services.
2. Developing a spatial unit for mapping and assessing the ecosystem services at two spatial levels.
3. Conducting a study to select a case study - FUA in which to apply the model.
4. Application of the model to the selected case study - condition assessment of the ecosystems within the boundaries of the FUA-Burgas.
5. Applying the model to the selected case study - assessing selected ecosystem services within FUA-Burgas.

II. OVERVIEW OF CHANGES AND CHALLENGES IN THE DEVELOPMENT OF MODERN CITIES. FUNCTIONAL URBAN AREAS.

II.1. Characteristics of contemporary urban areas. Impact factors

Urban areas are complex and dynamic systems whose characteristics are constantly changing under the influence of natural and anthropogenic factors. Their distinctive features are considered in several dimensions. In terms of their purpose (centers of human activity and development), cities are constantly growing, leading to progressive overpopulation. They perform a wide range of social and economic functions, increasingly becoming multifunctional spaces. They are characterized by clear spatial specialization—of inner urban areas, of the relationships between the city, the periphery, and satellite centers. The spatial structure of cities is also undergoing significant changes as a result of climate change and its specific manifestations in the urban environment, such as urban heat islands, flood risk, water shortages, etc., as well as the growing demands of society on resources and the living environment. All these processes are leading to a trend towards accelerated dynamics, which requires effective planning and optimal use of urban space.

II.2. Contemporary response to the challenges in the state and development of cities

The contemporary response to the challenges facing urban development is based on new approaches to spatial planning and management. The focus is on the structural elements of urban morphology – green and blue infrastructure – in line with current concepts and international initiatives for sustainable development (EEA, 2017). Contemporary spatial analyses offer a new perspective on the functionality of cities, integrating the topics of natural capital and ecosystem services as key dimensions of the urban environment. In this framework, contemporary environmental management is complemented by ecosystem-based approaches and nature-based solutions, which bring practical benefits and improve the adaptability of cities.

In the 21st century, cities are viewed as socio-ecological-technological systems with embedded social structures, institutions, and driving forces, as well as dynamic feedback loops between their social, ecological, and infrastructural components (McPhearson et al., 2016).

II.3. Essence and characteristics of Functional Urban Areas. FUAs in Bulgaria

A FUA consists of a given city and the surrounding, less densely populated local units that are part of the city's labor market - the “commuting zone” (Dijkstra et al., 2019) or daily commuting. They are a powerful tool for comparing socio-economic and spatial trends in cities and for developing urban development policies. FUA can bring about a change in the way policies are planned and implemented by providing the right scale to address issues that affect both the city and its surrounding commuting zone (Dijkstra et al., 2019).

FUAs, core cities, and their commuting zones, where most European citizens live and work, cover 20% of the European Union territory. The urban population is growing, with regional patterns linked to different stages of economic development (Maes et al., 2020).

Since 2010, the National Statistical Institute of Bulgaria (NSI) has provided information on 18 cities and 17 territorial units comprising 58 municipalities forming their hinterland. For the Republic of Bulgaria, these are the cities of Sofia, Plovdiv, Varna, Burgas, Pleven, Ruse, Vidin, Stara Zagora, Sliven, Dobrich, Shumen, Pernik, Yambol, Haskovo, Pazardzhik, Blagoevgrad, Veliko Tarnovo, and Vratsa and their areas. In this way, changes in the demographic and economic development of cities and their areas can be tracked for the period 2010-2018 and sustainability can be achieved in the production and dissemination of comparable statistical information on cities on a European scale (Kalchev, 2018).

III. CONTEMPORARY LANDSCAPE-ECOLOGICAL CONCEPTS AND APPROACHES IN RESEARCH AND PLANNING OF URBAN AREAS

III.1. Landscape-ecological approach in the exploration of space

This study is based on the concept of urban space as a complex and dynamic landscape mosaic in which the center and the periphery play different but interdependent roles.

Borisova (2013) notes that in natural environment, boundaries are those areas where the most intense exchange processes take place and where substances and energy accumulate. Similar to natural landscapes, in urban systems, boundaries and peripheral zones are key to the stability and sustainability of the core, as they concentrate the exchange of substances and energy. In urban ecosystems, the functioning of the core, which is subject to overload and constant change, is only possible through the effective use of the potential of the periphery. In this context, the landscape-ecological approach emphasizes the “structure-function” relationship and cause-and-effect dependencies. Rapid changes in the structure of cities lead to disruptions, alterations, or loss of ecological functions, which gives rise to new requirements for spatial planning. It is precisely green infrastructure that is one of the main tools for maintaining and restoring ecological functions in the urban environment (Borisova, 2013). It makes it possible to identify and optimize “bundles” of ecosystem services that simultaneously meet the needs of the population and strengthen the sustainability of the urban environment.

III.2. Urban ecosystems

According to Zhiyanski et al. (2017) “Urban ecosystems” are understood as areas where most of the human population lives, as well as ecosystems that significantly influence the development of other types of ecosystems. Maes et al. (2020) defines them as specific socio-ecological systems: almost entirely artificial, but including all other types of ecosystems in varying proportions, strongly influenced by human activity.

According to Zhiyanski et al. (2017), one of the key elements for achieving sustainable urban development and ensuring a high quality of life is the planning and construction of environmentally friendly infrastructure and the protection of the environment that supports it. The concept of green infrastructure provides a suitable platform for integrating these activities into the spatial planning and design of urbanized areas (Zhiyanski et al., 2017).

III.3. Green Infrastructure concept

In this study, green infrastructure is considered a key element of the urban structure, which is the main carrier of ecosystem services in urban ecosystems. "Green infrastructure is an interconnected network of natural areas, including agricultural land, green corridors, wetlands, parks, forest reserves, communities of native plant species, and marine areas that naturally regulate stormwater runoff, temperature, flood risks, and the quality of water, air, and ecosystems" (Green Infrastructure – EC).

III.4. Ecosystem services in urban environments

The study of urban ecosystems (UES), i.e., "Ecosystem services provided by urban ecosystems and their components," is becoming the focus of ecosystem services research (Geneletti et al., 2020) today. In recent years, research on mapping ecosystem services in urban and peri-urban environments has increased significantly, especially in Europe and China (Pereira et al., 2024). Initially, only urban green infrastructure and individual UES were considered separately (Gómez-Baggethun, Barton, 2013, Haase et al., 2014, Baro et al. 2015, etc.), but subsequently the focus has gradually shifted to clusters/bundles of ecosystem services in selected European cities (Baro et al. 2017, Kremer et al. 2016, Shen et al., 2020, etc.). There are also developments at the European level – Kourdounouli and Jönsson (2019) examine the condition of ecosystems and the services they provide within the scope of Larger Urban Zones on a European scale. Maes et al., 2019 present how urban green infrastructure and UES can support urban policy objectives at different stages of the planning process and at different spatial scales. In recent years, we have witnessed innovative concepts integrating urban green infrastructure, urban ecosystem serices, and nature-based solutions for sustainable and flexible urban management (Almenar, 2021; Haase, 2021).

Given the multifunctionality of landscapes, a given set of ecosystem services can respond in a similar way to social and environmental factors to form so-called "ecosystem services bundles". This study adopts the following definition and meaning of the term ecosystem services bundles (according to Berry et al., 2016): "a set of related ecosystem services that are linked to a given landscape and usually occur together repeatedly in time and/or space."

Urban green infrastructure is the main source of ecosystem services in the urban environment and has been the subject of considerable scientific interest in recent years because of its proven public benefits. Urban green infrastructure can be very diverse in nature, including typologies such as parks, gardens, forests, green roofs and walls, and rivers (Naumann et al. 2011; Pauleit et al. 2011; EEA 2012). Each typology, in turn, can differ in key components (e.g., soil cover, tree cover, size, and shape), thus providing different ecosystem services with varying capacities (Bolund and Hunhammar 1999; Chang et al. 2007; de Groot et al. 2010; Bowler et al. 2010).

Through its multifunctionality, urban green infrastructure provides the following regulating/supporting and cultural services, which form the core ecosystem services bundle (as defined by CICES): regulation of water quality and quantity (runoff, rainwater, etc.), regulation of air quality (air purification), moderation of microclimatic conditions, mitigation of the impact of extreme climatic and hydrological phenomena, erosion prevention, bioremediation of waste and pollutants from human activity, noise reduction, provision of habitats, including pollination, maintenance of biodiversity, recreation and aesthetics of the urban and suburban landscape, sense of place, educational and scientific value, etc.

The creation and improvement of urban green infrastructure for regulating the microclimate and combating summer heat is one of the most common measures for ecosystem-based adaptation. Due to their cooling capacity, i.e. the capacity to change temperature, humidity, and wind fields, green infrastructure can contribute to reducing high temperatures in cities and reducing the associated health risks (Lafortezza et al. 2013; Escobedo et al. 2015).

III.5. Nature-based solutions in urban environments

Among the various definitions proposed for nature-based solutions, the International Union for Conservation of Nature (IUCN) (Cohen-Shacham et al. 2016) defines nature-based solutions as "actions to protect, sustainably manage, and restore natural and modified ecosystems that address social challenges effectively and adaptively, while providing human well-being and biodiversity benefits". Nature-based solutions are increasingly taking center stage in efforts to transform cities to adapt to climate change, improve the physical and mental health of residents, and contribute to sustainability, equity, and inclusive human well-being (Kabisch et al. 2017; Frantzeskaki et al. 2019; McPhearson et al. 2022, McPhearson et al., 2023). However, nature-based solutions rely on biodiversity and well-functioning ecosystems to provide ecosystem services such as temperature regulation, coastal protection, rainwater absorption, physical and mental health of people, and many others. Making cities resilient, adaptive, and sustainable in an increasingly uncertain future requires transformations on many scales and types, including greater attention to the management, protection, and restoration of urban ecological infrastructure so that nature-based solutions can meet the needs of adaptation and quality of life in cities (McPhearson et al., 2023).

III.6. New interdisciplinary concepts in urban planning

In the dynamics of contemporary urban development, new interdisciplinary concepts are emerging that integrate approaches from landscape ecology, architecture, spatial planning, social sciences, etc. into the management of sustainable urban areas.

Tactical urbanism, for example, is a concept that is steadily gaining popularity in urban planning - with its emphasis on civic participation and rapid, adaptive interventions, this innovative approach is transforming and revitalizing the urban ecosystems (Urban Design Lab). Another innovative approach is the concept of so-called "biophilic design", created as a framework for a satisfying experience of nature in the built environment in response to the shortcomings of contemporary architecture and landscaping practices (Kellert et al 2008, Kellert 2005, Kellert and Finnegan 2011, Browning et. Al, 2014).

There are a number of different guidelines and rules for planning and providing urban green spaces. The measure or so-called "3-30-300" rule is a new comprehensive guideline for urban forestry. It aims to ensure equal access to trees and green spaces and their benefits by setting thresholds for at least 3 well-planted trees visible from every home, school, and workplace, no less than 30% tree cover in each district, and no more than 300 m distance to the nearest public green space from each home (Konijnendijk, 2023). Cities in Europe, the US, and Canada use the measure formally or informally in their urban development strategies and plans, such as Haarlem in the Netherlands, Malmö in Sweden, Saanich in Canada, and Zurich in Switzerland (Konijnendijk, 2023).

IV. METHODOLOGICAL APPROACH FOR IDENTIFYING, MAPPING, AND ASSESSING ECOSYSTEM SERVICES FROM FUNCTIONAL URBAN AREAS

IV.1. Essence and characteristics of MCDA

MCDA is a structured and transparent methodology and general framework that combines different approaches to assist individuals or groups of stakeholders in examining complex situations while taking into account a set of criteria and often conflicting objectives (Belton and Stewart, 2002; Saarikoski et al., 2016). The main idea behind MCDA methods is to evaluate the results of alternative courses of action in terms of criteria that reflect the key dimensions of the decision-making problem, incorporating human judgment and preferences (Mendoza and Martins 2006, Saarikoski et al., 2016). MCDA is mainly used for priority setting, i.e., ranking alternatives according to the positions of participants and/or decision-makers. The assessment element in MCDA (normalization and weighting) can also be used to raise awareness by enabling citizens/stakeholders to explore their preferences and basic positions (Saarikoski et al., 2016).

MCDA is an established method that is widely used in environmental assessment, management, and/or modeling, including in ecosystem services analysis. For the purposes of ecosystem services assessments, the MCDA approach is considered as: An alternative for economic assessment (Chan et al., 2012); A complementary approach to cost/benefit analysis; A decision-making system that integrates economic and non-economic indicators (Newton et al., 2012) (Saarikoski et al., 2016).

IV 2. Model for identifying, mapping, and assessing ecosystem services from Functional Urban Areas with MCDA

The model presented in this study aims to create an approach for identifying, mapping, and assessing ecosystem services from Functional Urban Areas (Fig. 1). The methodological approach is divided into two main stages: Identification, and Mapping and Assessment of ecosystem services, and combines three main concepts: green infrastructure, ecosystem services, and nature-based solutions (according to Haase, 2021). The steps of the MCDA methodology for ecosystem services analysis according to Langemeyer, et al. (2016) and Gret-Regamey (2017) and according to Durham et al. (2014) have been adopted and can be found in the individual stages of the model: 1) Definition of the problem. 2) Analysis and engagement of stakeholders. 3) Definition of criteria. 4) Selection and weighting of criteria. 5) Definition of alternatives. 6) Prioritization of alternatives. 7) Sensitivity analysis. Multi-criteria analysis is also used in some of the stages.

The definition of the problem to be solved can be broadly defined as identifying areas with high demand and low supply of green infrastructure in an urban environment in order to ensure equal access to ecosystem services for the local population in the context of accelerated economic development and climate change adaptation. The stakeholder engagement stage is one of the key stages in the methodology. The involvement of experts from various professional fields and, above all, local government (municipal representatives) in the work process ensures that the key needs and problems in the area are identified. The criteria and alternatives, including their prioritization (weighting) in the model, are defined by strategic documents presenting the objectives and aspects of the development of the Functional Urban Areas, as well as those reflecting the structure of ecosystems in the Functional Urban Areas, taking into account the spatial heterogeneity in the supply of ecosystem services. They also reflect the views and values of different stakeholder groups, while being based on scientifically supported research and policy in the territory.

Such a scaling approach provides additional information about the nature of the mosaic of green areas and their ecological functions. It should be noted that not all green areas meet the criteria and are managed as elements of green infrastructure. Important criteria for identifying green infrastructure are: multifunctionality (provision of diverse environmental services) and connectivity (protection of ecological networks) of the territory (Liquete et al., 2015). The application of the methodology aims to provide as much information as possible on urban planning in the context of socio-ecological technological urban systems (Qian et al., 2020, McPhearson, 2023) for: structure (given the land cover of the territory with information on the abiotic and biotic elements of the natural environment) and functionality (given the functions of the territory).

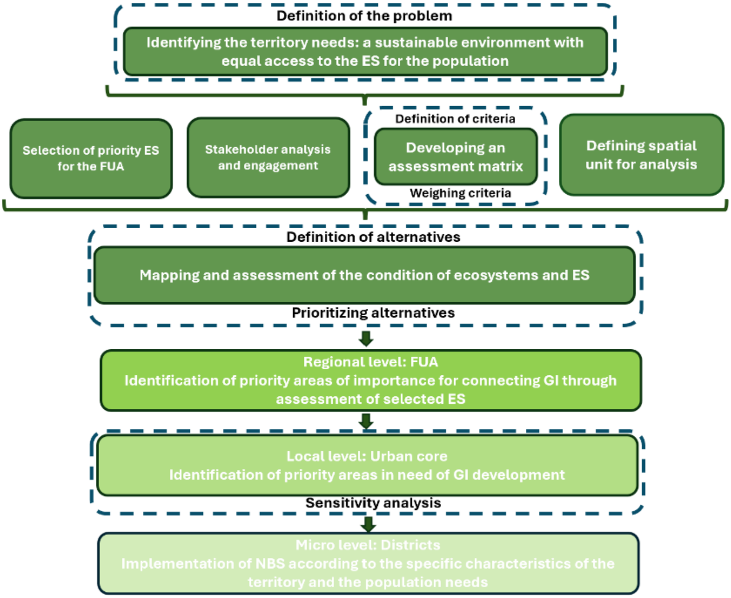

Fig. 1. Graphical diagram of the methodological steps in the study

- **Identification of ecosystem services**

  The ecosystem services identification stage consists of the following main steps:

I. Selection of priority ecosystem services for the Functional Urban Areas.
II. Analysis and stakeholders engagement.
III. Development of an assessment matrix.

I. Selection of priority ecosystem services for the Functional Urban Areas

Prioritization is a key moment in research on ecosystem goods and services. It is necessary to highlight the services that are most important for a given urban environment in terms of human well-being and the provision of a sustainable environment for urban residents. The selection of priority ecosystem services is based on the specific characteristics of the Functional Urban Areas and the important condition of providing services along the "periphery-city" axis, both in terms of need and actual consumption by the population. The selection depends both on the importance of the specific service (identified according to the defined criteria) and on the availability of data for it (the processes of selecting priority services and selecting indicators for service provision were carried out simultaneously).

The current selection is based on previous studies and good practices on the subject. The inclusion of already developed ecosystem services priorities (specifically for urban areas in Bulgaria), in which a large team of experts participated, lends weight and credibility to the results. The following criteria were selected for the selection of priority ecosystem services for the Functional Urban Areas:

- Presence of the service in the prioritization carried out under the project "Towards a better understanding of ecosystem services in urban environments through assessment and mapping (TUNESinURB)" and the "Methodology for assessing and mapping the urban ecosystems condition and their services in Bulgaria" (Zhiyanski et al., 2017);
- Presence of the service in the prioritization carried out under the project "National Methodology for Mapping and Biophysical Assessment of Ecosystem Services for the Purpose of Planning and Informed Management of Green and Blue Infrastructure in the Sofia Municipality", Sofiaplan, 2020.
- Presence of the service in review materials, MAES methodological documents, established as fundamental on the topic of urban ecosystem services, and articles in recent years (Gomez-Baggettun et al., 2013; Haase et al., 2014, Veerkamp et al., 2021, etc.).

As a result of the analysis, 12 ecosystem services were identified as priorities for the scope of the Functional Urban Areas (Table 1):

Table 1. Ecosystem services prioritized for the scope of the Functional Urban Areas

Class	**Ecosystem service (according to CICES V5.1)**
Provisional	Provision of water for drinking purposes (Surface and groundwater bodies, source of drinking water for the population)
	Provision of water for non-drinking purposes (surface and groundwater bodies used for non-drinking purposes)
	Provision of materials (Wood, fibers, and other products from plants, fungi, algae, and bacteria in biotic systems for direct use or processing)
	Provision of food (All cultivated plants in biotic systems grown for food purposes)
Regulating	Climate regulation at regional and local levels (The ability of biotic systems to regulate temperature and humidity, including ventilation and transpiration)
	Hydrological cycle and water flow regulation (The ability of biotic systems to regulate the hydrological cycle and maintain water flows, including flood control and coastal protection)
	Maintaining populations and habitats (The ability of biotic systems to maintain populations, habitats, and biodiversity, including protection of the gene pool)
	Mitigation of harmful anthropogenic impacts (The ability of biotic systems to mitigate noise, odors, and other impacts)
Cultural	Recreation (Characteristics of biotic systems that allow activities promoting health, recovery, or enjoyment through active interactions)
	Scientific and educational value (Characteristics of biotic systems that enable scientific research or education - creation of traditional ecological knowledge)
	Cultural heritage (Characteristics of biotic systems that are relevant to culture or heritage)
	Aesthetic value (Characteristics of biotic systems that enable aesthetic experiences)

II. Analysis and stakeholders engagement

The analysis highlights the importance of early identification and engagement of stakeholders in the process of researching and managing environmental challenges. Involving groups such as local authorities, businesses, NGOs, the general public, and vulnerable groups increases policy effectiveness and reduces the risk of conflict. Engagement facilitates trust building, information exchange, and the adaptation of scientific results to local needs. The ultimate goal is more sustainable management and improved quality of life in the urban ecosystems (Durham et al., 2014).

III. Matrix for identifying needs in the Functional Urban Areas

The process of developing a tabular matrix for identifying the objectives and needs in the Functional Urban Areas and, depending on them, the specific urban ecosystem services (priorities for the Functional Urban Areas in the Bulgarian context) by the stakeholders is a key element in the methodological approach of the study. The aim is to present conceptually the stages in defining certain criteria by which participants (stakeholders) assess the importance of a given service and thus identify a set of services for analysis for a specific territory.

Fig. 2 presents an example model for identifying the leading and distinctive functions of Functional Urban Areas and, specifically, the goals and needs of the population in the urban core. When selecting criteria, the condition for purposefully stimulated multifunctionality and sustainability of the urban ecosystems in an environment of ecological, social, and economic variables was followed. It is necessary to take into account natural (environmental) or culturally conditioned and historically formed socio-economic aspects of the urban environment that are relevant to the well-being of the local population, especially local geographical/localization factors such as urban morphology.

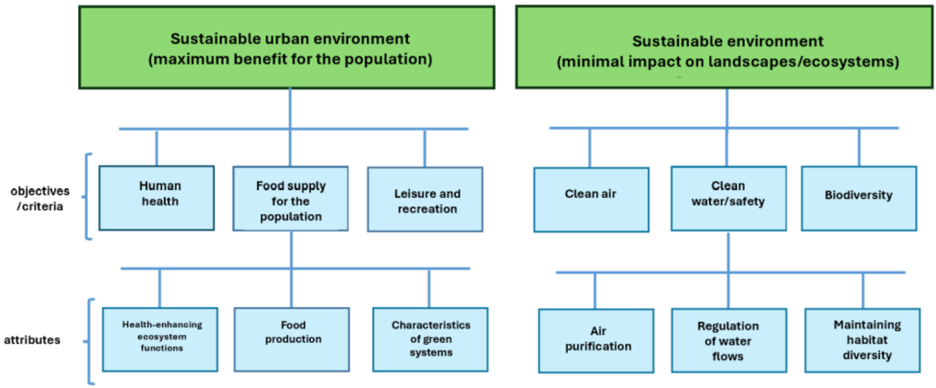

Fig. 2. Example model for identified objectives and needs for the FUA territory

For the specific territory, the objectives and needs are validated through documents and development plans at national and regional level, setting the strategic guidelines for regional connectivity, low-carbon economy, and spatial sustainability.

The need for a sustainable environment and the identification of minimal impact on landscapes assesses the territory's ability to maintain basic landscape and ecological functions, which are so necessary in the context of intensive use of urban and peri-urban areas and a changing climate. The above structure can be used to identify and prioritize ecosystem services in collaboration with stakeholders in each Functional Urban Area based on a set of predefined criteria. The aim is to assess and classify each ecosystem service according to its importance, significance, or contribution to the territory. The final prioritization highlights which services contribute to specific criteria, i.e., are considered most valuable or critical by the community, which helps inform decisions about the future development of the area, resource management policies, etc.

The classification of criteria by degree of importance (ranking by weight) is done from the perspective of the needs of the stakeholder (the criteria have different priorities for different groups). The definition of alternatives is determined according to the already identified priority ecosystem services, as well as the addition of specific services characteristic of the given territory. To prioritize them, methods such as the analytical hierarchy process (AHP), pair-wise comparison, etc. are usually used.

- **Mapping and assessment of ecosystems and services provided in Functional Urban Areas**

According to Zhiyanski et al. (2017), for the effective integration of ecosystem services into activities related to use in urban areas, it is necessary to identify and assess, in spatial terms, the areas that ensure the maintenance of biodiversity, ecosystem functioning, and the provision of ecosystem services. To carry out such an assessment, the most accurate spatial data possible is required.

An important feature is the spatial units that carry ecosystem services, the units of consumption, and the territories connecting them. For mapping purposes, such territories should be considered as a spatial unit. This allows for the application of landscape-scale geographic assessment methods based on landscape units corresponding to the area of influence (Burkhard & Maes, 2017). Syrbe & Walz (2012) emphasize the key importance of the spatial structure of landscapes for understanding the functioning of ecosystem services. They recommend assessing Service Providing Areas (SPAs), Service Benefiting Areas (SBAs), and Service Connecting Areas (SCAs), or the spatial connections that facilitate the flow of matter, energy, or organisms between SPAs and SBAs.

- **Assessment of the ecosystems condition**

The condition of the urban ecosystems is closely linked to the provision of various ecosystem services. In this study, most of the information on the condition and pressure on ecosystems in the Functional Urban Areas is taken from the document

"Mapping and assessment of ecosystems and their services: An EU ecosystem assessment" (Maes et al., 2020), where the assessment was carried out in accordance with the 5th MAES report (Maes et. al 2018) and the proposed typology of state variables for ecosystem reporting and criteria for selecting state variables from SEEA (Czúcz et al. 2019). In addition, several leading indicators of status and pressure were selected to present the current status of the territory in more detail (Table 2). The indicators were selected from the following methodological documents identified with the topic of urban ecosystems, including the latest developments:

- Mapping and assessment of urban ecosystems and their services (Maes et al., 2016).
- Mapping and assessment of ecosystems and their services: An EU ecosystem assessment (Maes et al., 2020).
- Analytical framework for mapping and assessing the condition of ecosystems in the EU, 5th MAES report (Maes et al., 2018).
- SELINA D3.2: Derive a minimum set of key ecosystem condition indicators per ecosystem type (Thomas et al., 2025).

The above-mentioned documents provide basic data for establishing a (legally binding) methodology for mapping and assessing ecosystems and their ability to provide services, as well as for defining the minimum criteria for good urban ecosystems status, as required by the EU Biodiversity Strategy to 2030 (Maes et al., 2020).

Table 2. Condition indicators (structural characteristics of ecosystems and environmental quality) and pressure indicators

	Indicator	**Data used**
Condition	Share (%) of the dominant land cover type	Urban Atlas 2018
	Type of urban structure	Global Human Settlement Layer
	Share (%) of protected areas and zones	EAOS, Register of protected areas and protected zones in Bulgaria
	Bathing water quality	Bathing Water Directive - Status of bathing water, EEA
Pressure	Share (%) of sealed/impervious areas	Copernicus Impervious Built-up 2018
	Land use change	Urban Atlas Land Cover/Land Use Change 2006-2018
	Concentration and emissions of air pollutants	European air quality data (interpolated data) - Series MAPPING AND ASSESSMENT OF ECOSYSTEMS AND THEIR SERVICES: AN EU ECOSYSTEM ASSESSMENT 2020
	Tree cover change	Copernicus Tree Cover Change Mask 2012-2018
	Fragmentation (density)	Landscape fragmentation Effective Mesh Density, EEA

- **Spatial unit for mapping and assessment of ecosystems and services in urban environments**

Cities are directly dependent on surrounding areas for the provision of mainly material, but also significant regulatory and cultural ecosystem services. It is therefore necessary to consider the links and flows of urban ecosystem services on a regional scale or the so-called rural-urban gradient. Leading researchers on the topic of ecosystem services demonstrate this importance (Haase, Nuissl, 2010; Larondelle, Haase, 2013), with the most significant methodological recommendation being that of the fifth MAES report on the study of urban ecosystems within the boundaries of the FUA (Maes et al., 2016).

The approach presented in this study, which allows for the analysis of information at different spatial levels (regional and local) and integrates the structure and functions of the urban ecosystems, reveals the spatial heterogeneity of complex urban socio-economic systems and aims to optimize urban planning and management (according to Qian et al., 2020), (Fig. 3):

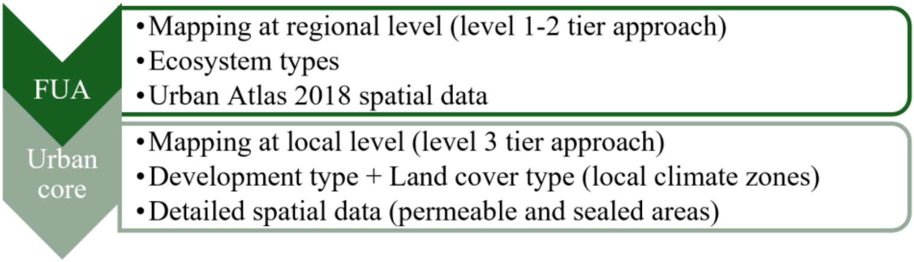

Fig. 3. Approach for assessing ecosystem services at two spatial levels

The analysis of the condition of ecosystems and selected ecosystem services at regional level aims to present an overall picture of the territory, i.e. the boundaries of the Functional Urban Area, while at local level a multi-criteria geospatial analysis has been carried out to identify priority areas for the implementation of the nature-based solutions. The starting point for the study at the local level is that all permeable surfaces in an urban environment are considered to provide ecosystem services, including municipal/state and private properties, i.e., they are a spatial localizing factor for actual provision (SPA), while all impervious/sealed surfaces are limiting factors (according to Grêt-Regamey et al., 2017). The areas where services are used (SBA) cover the built-up areas of cities where the population lives, although the density within the urbanized space varies. This is why, specifically within urban areas, the service connection area or flow path (SCA) is scarce, i.e., there is an almost direct relationship between SPA and SBA, and in the best case, an overlap.

For this reason, the study at the local level focuses on the structure and functions of green infrastructure and the resulting environmental benefits enjoyed by local residents, such as air quality and water flow regulation, cooling effect, leisure and recreation, etc. The final result aims to be a cartographic visualization of the balance between demand and supply of ecosystem services in an urban environment (following the example of Haase, 2012; Baro et al., 2015; Baro et al, 2016; Baro et al., 2017), including the identification of priority areas for the implementation of the nature-based solutions at city and district level. The desired effect of the model is to provide decision-makers with adequate information and an applied effect for planning, namely linking the provision of ecosystem services to their beneficiaries.

- Regional level (the commuting zone, Functional Urban Area)

Why are Functional Urban Areas most suitable for urban ecosystems analysis? Considering Functional Urban Areas as urban ecosystems is a new interpretation of the landscape-ecological approach to addressing the challenges facing cities.

As a result of a detailed study of literature sources, it was established which spatial data and analysis methods are suitable for the above-described structure, and data from Urban Atlas 2018 LULC (recommended by Maes et al. (2016) as the main source for mapping urban ecosystems at European level) by equating ecosystem types to land cover classes following the example of Hristova & Stoycheva (2021), who equate ecosystems at national level according to data from Corine Land Cover 2018. The Urban Atlas database was chosen over Corine Land Cover 2018 because of its more detailed classes in urban areas.

The spatial units from Urban Atlas that fully match the ecosystem types are equated to Level 3, and those that do not are at Level 2. For the purposes of this assessment at regional level, there is no need to unify the ecosystem levels, and the urban ecosystems are presented in detail at Level 3, as they are the main subject of the study, while the other ecosystem types represented in the commuting zone (Functional Urban Area) area are visualized at Level 2 in order to preserve their homogeneity/integrity from the point of view of the existing landscape unit.

- Local level (Local climate zones (LCZ) in part of the urban core)

For the purposes of the integrated multi-criteria geospatial analysis of the urban area, this study chooses to use the climate classification methodology for urban areas developed by Oke and Stewart (2012). LCZs serve as a unified working framework for conducting territorial assessments for the demand and supply of ecosystem services by the urban green infrastructure for the following reasons (NUCGRT, 2024 – Burgas Report):

- LCZs reflect urban morphology in specific spatial combinations between types of built-up areas and adjacent land cover (Oke and Stewart, 2012).
- LCZs determine important characteristics of the urban climate (temperature regime, including the urban heat island effect, and surface air circulation), air quality, and conditions for dust and pollutant retention (Dimitrov et al., 2023, Aslam and Rana, 2022).

- The universality, simplicity, and objectivity of the LCZ framework make it a promising tool for a wide range of future applications, especially in the field of climate-responsive urban planning and design (Han et al., 2024).
- LCZs has been used as the main information unit in determining the typology of urban ecosystems in the Methodology for assessing and mapping the urban ecosystems condition and their services in Bulgaria (Zhiyanski et al., 2017) (NUCGRT, 2024 – Burgas Report).

The structured methodological approach of the study is consistent with the conceptual framework of MAES for mapping and assessing urban ecosystem services. The model aims to integrate the benefits of urban green infrastructure into local policy. The study seeks answers to the challenges identified by Maes et al. (2016) on the topic, namely the development of indicators at different scales and resolutions that meet the needs of different levels of government, public and private interests, awareness raising, priority setting, etc.:

- The inclusion of indicators reflecting both the structure and functions of urban green infrastructure is important due to the existing discrepancy between scientific research, which focuses on the functional role and regulating and maintaining ecosystem services, and urban planning practices, which focus mainly on the structural aspect of green spaces and still partially apply the concept of ecosystem services.
- Grouping the key ecosystem services provided by urban green infrastructure into a common bundle, rather than considering them individually according to the CICES classification system, aims to identify the real multifunctionality of urban ecosystems facilitate the perception of the benefits of urban ecosystem services by local authorities and the application of the concept of common policy objectives in various areas such as health, security, urban microclimate (reduction of heat islands), air quality, social well-being, and energy consumption/efficiency.
- The methodological approach coincides with some of the key thematic areas of the EU strategic initiative "ESPON 2030", which aims to provide territorial data, analysis and evidence to support policymakers and public institutions, namely: resilience to crises (economic, social, environmental), achieving carbon neutrality by 2050, reducing social and spatial inequalities, and addressing growing interdependencies and cross-border interactions. These objectives are achieved through a strategic approach based on two main pillars: collecting data and analyses on socio-economic and environmental processes and thematic and comparative studies at European level, and transforming scientific results into practical tools for policymakers (ESPON 2030, EU).

IV. 3. Selection of a case study Functional Urban Area

A multi-criteria analysis was applied to select the test Functional Urban Area, for which a matrix was created to assess the list of Functional Urban Areas at national level according to selected criteria (Appendix 1). The process of determining these criteria is the result of an extensive literature review of the geographical analysis of Bulgarian Functional Urban Areas, strategic documents, and good practices.

The purpose of the selected criteria, summarized in three groups, is to cover all aspects related to the topic of Functional Urban Areas:

1. Distinctive characteristics of Functional Urban Areas.
2. Technical feasibility of the study.
3. Role of the ecosystem services topic in the planning and management of Functional Urban Areas,

and are ranked (at expert level) in order of importance, following the logic: In which Functional Urban Areas is the ecological status deteriorating? → Who is affected by these problems? → Has there been any previous experience in solving the problem?

The first step aims to identify which Functional Urban Areas in Bulgaria are experiencing significant environmental problems. This also includes the potential for natural heritage, expressed in the naturalness and diversity of the natural environment. The second step involves two different aspects: on the one hand, it is necessary to identify who is affected by these environmental problems – how many people; on the other hand, it is clear that the quality of the environment in cities is a result of the economic functions of the settlement – the largest cities in terms of area and population logically have more profound and complex environmental problems to solve. The final step aims to take into account the basis, i.e., whether the local government is familiar with and has previous experience not only with the topic of ecosystem services but also with sustainable management of the natural environment (Genelletti et al., 2020), and last but not least, the availability of spatial data.

Each group includes several criteria, represented by parameters with indicators, on the basis of which the test Functional Urban Area was selected. For some indicators, European-level data (such as EUROSTAT and COPERNICUS) were used, which ensures comparability of results, while for others, national databases were used for greater detail.

As a result of the study conducted at national level according to the listed criteria, the Functional Urban Areas of Sofia scored the highest in the analysis, Burgas came second, and Varna and Plovdiv came third with the same number of points. The final decision to choose Functional Urban Area of Burgas (FUA-Burgas) as a test area was made taking into account the smaller and more compact area of the urbanized space, even though it ranks second in the country in terms of area after the capital city, as well as the prospects for detailed spatial data through projects with the Municipality of Burgas.

V. APPLICATION OF THE MODEL FOR IDENTIFICATION, MAPPING, AND ASSESSMENT OF ECOSYSTEM SERVICES – ON THE EXAMPLE OF A FUNCTIONAL URBAN AREA – BURGAS

V.1. Description of the case study area. General characteristics of the city of Burgas and the FUA. Spatial unit for mapping and assessing the condition and services in the FUA-Burgas.

The FUA-Burgas comprises five municipalities and ranks second in the country in terms of size and fourth in terms of population (NSI 2016). The center of the urban core—Burgas—is the second largest in the country and is characterized by a complex urban morphology, including compactly built residential, industrial, and public areas in the central urban core and a fragmented structure on the periphery due to the location of the system of coastal lakes, wetlands, and Burgas Bay. This complex geography of the municipality of Burgas is an important factor for the infrastructure provision in the territory, as it has largely determined the development and configuration of the settlement network and the model of its socio-economic development. On the other hand, the municipality's geographical position within the national territory, its direct contact with the Black Sea through Burgas Bay, and its location in relation to the main communication transport corridors and urban centres, is a major comparative advantage of the municipality, which is of decisive importance for its spatial and functional-economic development (Spatial Development Plan of Burgas Municipality 2021-2027).

The administrative boundaries of the FUA-Burgas include the physical-geographical units of the Burgas Lowland and the Hisar-Bakadzhik Threshold, with the area characterized by low and hilly terrain, estuarine lakes and lagoons along the coast, a low and indented coastline, and contemporary processes of subsidence, accumulation, and abrasion (Geography of Bulgaria, Volume I, 1966).

The area falls within the zone of influence of the Black Sea climatic sub-region of the Continental-Mediterranean climatic region. The prolonged heat waves during the summer months in recent years are directly related to the formation of the urban heat island effect (Dimitrov et al., 2023) and the conditions for increasing concentrations of pollutants in the surface air (NUCGRT 2024 - Burgas Report). Climate change trends in temperature regimes show clear prerequisites for maintaining higher average annual temperatures, which raises the question of discussing the expansion of green infrastructure in urban environments to increase the cooling effect and help reduce pollutants in the atmosphere (NUCGRT 2024 - Burgas Report). According to long-term climate scenarios (Dimitrov et al., 2015), under the influence of the Mediterranean climate, the urban area is expected to be exposed to a greater risk of persistent droughts, fires, and floods.

The green system of Burgas includes several larger parks and gardens, with the Sea Garden as its leading core, playing a distinctive role in the functioning of the urban green infrastructure. The municipality participates in national and European projects for green infrastructure, sustainable mobility, and adaptation to climate change, establishing itself as a model for a smart and sustainable city (Burgas Municipality – Plans and Strategies).

As described in Chapter IV, the current model follows the ecosystem services assessment at two spatial levels: regional (in the area of the FUA's commuting zone) and local (in the area of the urban core).

- Regional level

Table 3 presents the results of the alignment of the land cover/land use classes of Urban Atlas 2018 with the ecosystem types at the national level (levels 2 and 3) in the FUA-Burgas:

Table 3. Matching of the land cover/land use classes of Urban Atlas 2018 to the ecosystem types at national level (levels 2 and 3) in the FUA-Burgas

Land use/land cover classes according to Urban Atlas 2018	**Ecosystems (levels 2 and 3)**
Airports	Level 3: J7. Transport networks and other built-up areas with hard surfaces
Cultivated land (annual crops)	Level 3: Annual crops (mainly cereals)
Construction sites	Level 3: J6. Industrial sites (including commercial sites)
Continuous urban fabric (sealing > 80%)	Level 3: J1. Residential and public areas in cities and villages
Discontinuous dense urban fabric (sealing 50% - 80%)	Level 3: J1. Residential and public areas in cities and villages
Discontinuous urban fabric with low density (sealing 10% - 30%)	Level 3: J3. Low-density residential and public areas
Discontinuous urban fabric with medium density (sealing 30% - 50%)	Level 3: J3. Low-density residential and public areas
Discontinuous urban fabric with very low density (sealing < 10%)	Level 3: J3. Low-density residential and public areas
Fast transit routes and associated land	Level 3: J7. Transport networks and other built-up areas with hard surfaces
Forests	Level 2: Forests
Urban green areas	Level 3: J5. Urban green areas (including sports and recreational facilities)
Grassland communities	Level 2: Low vegetation
Industrial, commercial, public, military, and private units	Level 3: J6. Industrial sites (including commercial sites)
Isolated structures	Level 3: J6. Industrial sites (including commercial sites)
Land without current use	Level 2: Pastures
Mining and waste disposal sites	Level 3: J8. Extractive industrial sites
Open spaces with little or no vegetation	Level 2: Areas with sparse vegetation
Other roads and associated land	Level 3: J7. Transport networks and other built-up areas with hard surfaces

Pastures	Level 2: Pastures
Permanent crops	Level 3: Perennial crops (orchards and vineyards)
Ports	Level 3: J6. Industrial sites (including commercial sites)
Railways and associated land	Level 3: J7. Transport networks and other built-up areas with hard surfaces
Sports and leisure facilities	Level 3: J4. Recreational areas outside towns and villages
Water	Level 2: Rivers and lakes
Wetlands	Level 2: Wetlands

- Local level

This study for the territory of Burgas follows the methodological steps in the development for Sofia and Burgas (according to Popov et al., 2019, NUCGRT 2024, Burgas Report): in a GIS environment, the territory is divided into territorial units of equal size and shape – a uniform network of square cells (grid), thus achieving uniformity in the scope of the individual units, which in turn makes the application of geostatistical and spatial interpolation methods more reliable and justified (Popov et al., 2019). In 2024, for the purposes of preparing the "Report on the selection of sites/objects in which to carry out interventions to reduce secondary dust dispersion through greening measures in the urban environment in the Municipality of Burgas" (NUCGRT 2024), 14 types of LCZ were identified within the urban area of the city of Burgas (Table 4), (Fig. 4). They are organized into grid cells of equal size and shape with sides of 100 m x 100 m and an area of 1 ha, numbering 3468. It is this spatial unit that is used for the purposes of the dissertation. The cells were defined using data from aerial photography of the territory with an unmanned aerial system (UAS) from 2022. The leading criterion is the predominant percentage of the type of development in each cell and its distinctive combination with the type of land cover (NUCGIT 2024, Burgas Report).

Table 4. Local climate zones in the city of Burgas

LCZ	**Number of cells**	**Area %**
LCZ_3 Compact low-rise buildings	2	1
LCZ_4 Open high-rise buildings	49	1
LCZ_5 Open mid-rise buildings	814	23
LCZ_6 Open low-rise buildings	180	5
LCZ_8 Large low-rise buildings	871	25
LCZ_9 Sparsely built	114	3
LCZ_10 Heavy industry	5	1
LCZ_A Dense trees	21	1
LCZ_B Scattered trees	246	7
LCZ_C Bush, scrub	63	2
LCZ_D Low plants	427	12
LCZ_E Bare rock or paved	199	6

LCZ_F Bare soil or sand	5	2
LCZ_G Water	348	10
Total	**3468**	**10**

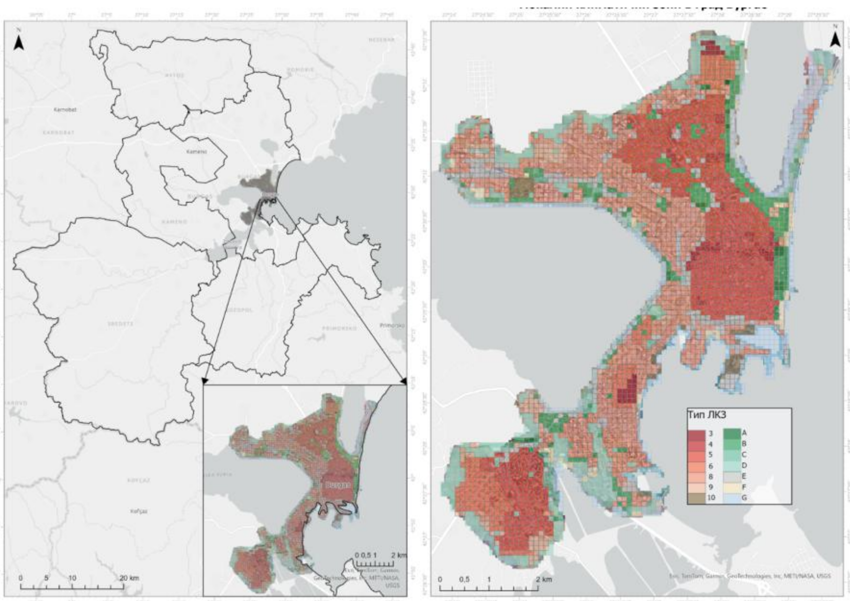

Fig. 4. Municipalities falling within the scope of FUA-Burgas and types of LCZ in the city of Burgas

V.2. Identification of ecosystem services in FUA-Burgas

The definition of criteria for prioritizing and evaluating ecosystem services in FUA-Burgas is a leading process in the current methodology. The steps for their determination are the result of a geographical analysis of the territory of FUA-Burgas, strategic documents at regional level, and good practices (projects of the Municipality of Burgas). The vision for the development of Burgas 2021-2027 aims to transform the city into an attractive and sustainable place to live and do business by preserving the natural environment and identity, promoting innovation and economic growth, and improving urban spaces and connectivity. The sub-objectives and measures set out in Priority 4 of the urban development plan of Burgas "Sustainable use of natural resource potential and adaptation to climate change", include measures to preserve natural capital, raising awareness and capacity for climate measures, a legal framework for adaptation, and the development of green and blue urban infrastructure (Integrated Urban Development Plan 2021-2027, Municipality of Burgas).

In this study, the results of a survey conducted among citizens in the municipality in 2020 in connection with the development of the urban plan 2021-2027, containing questions about the problems identified in the municipality, citizens' opinions on significant projects to be implemented during the next planning period to improve the overall appearance of the city and the municipality, etc. 50% of respondents indicate the need for the reconstruction of green areas as the most urgent need for their living space. (Integrated Urban Development Plan 2021-2027, Municipality of Burgas).

A short questionnaire was created for the purpose of identifying priority ecosystem services for the region. The survey was directed at a target group of stakeholders—governing bodies and experts from the Municipality of Burgas involved in issues related to ecology and the environment, spatial planning and management, etc. In preparing the questionnaire, a pairwise comparison and AHP approach was followed to identify the leading and secondary services for development in the region. The questionnaire included 12 ecosystem services (described in Chapter IV – priority ecosystem services for the urban environment) – 4 from each category of services – provisioning, regulating, and cultural. It was provided to municipal employees so that the ecosystem services could be expertly evaluated against each other in terms of their importance for the current and future functioning of the urban ecosystems. The ArcGIS Survey 123 platform (ArcGIS Online, ESRI) was used for easy and quick completion. The survey was completed by 12 experts from the Municipality of Burgas. Table 5 presents the summary results of the respondents – a list of prioritized ecosystem services in descending order. The participants emphasise services that combine the basic needs of the population and the quality of the urban environment, while services related to materials and some regulatory functions with a more indirect impact on everyday life remain secondary.

Table 5. Summary results from the questionnaire on identified priority ecosystem services

Class	Ecosystem service
Provisioning	Provision of water for drinking needs (Surface and underground water bodies, source of drinking water for the population)
	Provision of food (All cultivated plants in biotic systems grown for food purposes)
	Provision of water for non-drinking purposes (Surface and groundwater bodies used for non-drinking purposes)
	Provision of materials (Wood, fibers, and other products from plants, fungi, algae, and bacteria in biotic systems for direct use or processing)
Regulating	Climate regulation at regional and local levels (The ability of biotic systems to regulate temperature and humidity, including ventilation and transpiration)
	Hydrological cycle and water flow regulation (The ability of biotic systems to regulate the hydrological cycle and maintain water flows, including flood control and coastal protection)
	Maintaining populations and habitats (The ability of biotic systems to maintain populations, habitats, and biodiversity, including protection of the gene pool)
	Mitigation of harmful anthropogenic impacts (The ability of biotic systems to mitigate noise, odors, and other impacts)
Cultural	Recreation (Characteristics of biotic systems that allow activities promoting health, recovery, or enjoyment through active interactions)
	Scientific and educational value (Characteristics of biotic systems that enable scientific research or education - creation of traditional ecological knowledge)

	Cultural heritage (Characteristics of biotic systems that are relevant to culture or heritage)
	Aesthetic value (Characteristics of biotic systems that enable aesthetic experiences)

Based on the above criteria (objectives and needs of the FUA-Burgas territory) for prioritizing ecosystem services for mapping and assessment, and given the specific nature of the urban ecosystem services (the predominance of regulating services over provisioning and cultural services, spatial relationships, etc.), the connection with the green infrastructure concept and, above all, the availability of mapping data, the following ecosystem services were selected (Fig. 5):

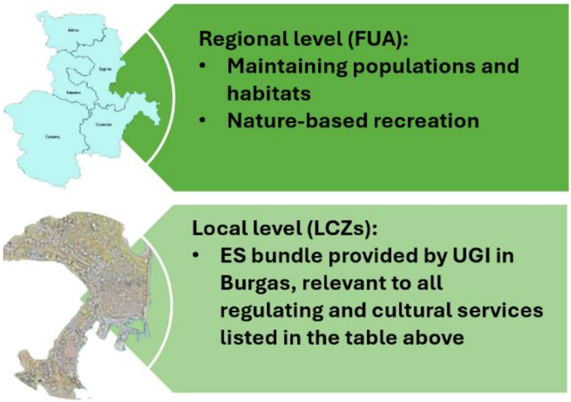

Fig. 5. Prioritized ecosystem services for mapping and assessment in FUA-Burgas

V.3. ASSESSMENT OF THE CONDITION AND PRESSURE ON ECOSYSTEMS IN FUA-BURGAS

This section presents the results of the literature review, visualization, and analysis of spatial data for assessing the condition and pressure on ecosystems within the boundaries of the FUA-Burgas according to the indicators described in Table 2 of Chapter IV, Section III. The first part of the assessment covers a literature review by Maes et al. 2020, and after summarizing the results of the assessments of the status and pressure of the urban ecosystems in the FUA-Burgas compared to the EU-28 averages for short-term and long-term trends in various indicators, the following conclusions can be drawn:

- ➢ The long-term trends in the assessments of the urban ecosystems in the FUA-Burgas are below the EU average for most indicators (worse indicators).
- ➢ Short-term trends in assessments are more neutral or slightly improving, especially in the area of green infrastructure and urban densification.
- ➢ Air quality in the FUA-Burgas is under serious pressure, with most pollutants (especially PM_{10} and $PM_{2.5}$) consistently high and above EU averages.

- The expansion of urban areas contributes to the continued loss of land and fragmentation of habitats, with no significant improvements in reducing soil sealing.
- Slight improvements in the structure and stability of vegetation cover have been observed.

The following key characteristics for the territory stand out from the additional analyzed indicators for condition (structural characteristics of ecosystems and environmental quality) and pressure:

- In the FUA-Burgas, land cover is balanced between agricultural, urbanised and semi-natural areas, with pastures dominating (23.5%), followed by arable land, dense urban structures (11.1%) and industrial sites (10.5%), reflecting the flat terrain and intensive urban development.
- Spatial analysis of the type of urban structure shows a concentration of dense and continuous built-up areas in the urban core of Burgas, which gradually decrease towards the periphery and boundaries of the FUA.
- 43% of the territory of the FUA-Burgas is covered by protected areas and zones, united under the name "Burgas Wetlands", part of the Via Pontica bird migration route.
- There are 15 bathing locations in the FUA-Burgas with high and stable water quality, with the highest results shown by "Burgas - Central Beach", "V.S. Duni", and "Sozopol - Central Beach".
- Sealed areas in the FUA-Burgas account for 1.39%, with the urban core having the largest relative share.
- In the period 2006–2018 (according to Copernicus Urban Atlas 2018 data), less than 1% of the territory of the FUA-Burgas has been changed, mainly through the replacement of arable land and pastures with urban areas, especially in the urban core and the periphery.
- The highest levels of air pollutant concentrations and emissions ($PM_{2.5}$) in 2024 are observed in the urban core of the FUA-Burgas, with values increasing towards the center in proportion to the degree of urbanization.
- In the period 2012–2018 (according to Copernicus Tree Cover change mask data), the tree cover in the FUA-Burgas remains stable, with minimal losses and local changes.
- The highest fragmentation is observed in the urban core of Burgas and the coastal tourist areas, while the northern and southern parts of the FUA remain largely unfragmented.

According to the analysis conducted to assess the condition of ecosystems based on the indicators used, it can be concluded that the landscapes/ecosystems in the FUA-Burgas are characterized by ecological pressure, which stems mainly from the degree of urbanization (increase in sealed areas) and persistent air pollution, leading to degradation and fragmentation of the territory. Positive assets include the high percentage of protected areas and zones, which is a distinctive feature of the region, the excellent quality of bathing water, and the stable areas with tree cover with minimal losses. As a result, the territory of the FUA-Burgas reflects a mixed picture in terms of ecosystem condition and pressure indicators, with opportunities for sustainable spatial planning, despite some of the identified pressure elements.

V.4. Mapping and assessment of ecosystem services at regional level

The ecosystem services selected for mapping and assessment at regional level are in line with the availability of data and their application for integrating and linking the green infrastructure within the FUA-Burgas.

Natural landscapes and their biodiversity are usually associated with protected areas that are incompatible with direct anthropogenic impact. Are there similar natural sites that support biodiversity in an urban environment? What is the role of peri-urban areas in ensuring species richness, as well as recreation and leisure, and is their potential being used appropriately? These are topical issues that deserve the attention of decision-makers, as people's need for an environment closer to nature in cities is more pronounced than at any other time in history. The elements of green and blue infrastructure that are part of the larger urban ecosystem provide significant and proven benefits to urban residents. Appendix 2 presents the potential of ecosystems in the FUA-Burgas to provide the ecosystem service "maintaining populations and their habitats, including protection of the gene pool". The assessment is applied within the spatial units of the Urban Atlas 2018 LULC. The focus here is only on those units in the nomenclature that have the attributes of green infrastructure. The assessment of the composite index indicators (with the corresponding assessment parameters) is quantitative and influenced by the guidelines and methodology provided in the Singapore Index on Cities Biodiversity (Chan et al., 2021) (Table 6). The results show the highest values expected for coastal/lake areas, which fall within the periphery of protected areas and zones and are characterized by the highest degree of naturalness of the environment, and the lowest values in the most built-up areas around urban centers. The most widespread areas are those assessed as having medium and lower potential, followed by areas with low and very low potential. The smallest percentage of the FUA territory is covered by areas with higher and high potential. A limitation of the approach is that it does not take into account other factors that influence the maintenance of habitats and their biological diversity, such as certain natural (climatic conditions – temperature changes, frequent extreme weather events, etc.) and anthropogenic (transport infrastructure and other facilities, illegal hunting, etc.). The lack of comprehensive data on biological species as evidence of the existing biological diversity in the urban area can also be noted as a limitation and difficulty in conducting the study.

Table 6. Assessment of the urban ecosystems in FUA-Burgas for the provision of biodiversity and habitats - indicators and parameters of the composite index

Indicator	Parameter (calculated for each spatial unit from Urban Atlas 2018)
Hemeroby index	Rating (1-6)
Share of protected areas and representativeness of natural heritage elements	Overlap (presence/absence) of protected areas and zones
Distance of natural heritage elements from the urban core	Distance of 2, 10, or more km from the urban core
Presence of water bodies	Presence/absence of water bodies
Share of key biological species	Presence/absence of key biological species

Appendix 3 presents the potential of natural heritage sites within the boundaries of the FUA-Burgas to provide the ecosystem service "nature-based recreation". Recreation in nature is one of the most significant ecosystem services provided by green infrastructure, which has an impact on people's physical and mental well-being. Providing adequate green infrastructure for nature-based recreation is one of the main objectives of urban planning (Cortinovis et al., 2018). The aim of this regional analysis is to continue the analysis at national level presented in sub-section IV.3. The study complements the national-level results from the identification and assessment of natural heritage as a source of leisure and recreation services (Ihtimanski et al., 2020). Methodologically, the study is conducted in three stages: identification, mapping, and assessment. Natural heritage sites are identified and mapped according to three criteria: 1) Established standards of international importance; 2) Established standards of European and national importance; 3) New elements of natural and cultural heritage sites of national and regional importance. A multi-criteria spatial analysis combining natural, cultural, and social criteria was used to assess the presence of natural heritage sites. For the assessment at national level for all Functional Urban Areas in Bulgaria, a common assessment of 4 indicators with different weighting of the criteria was used. Here, at regional level, a detailed assessment was carried out with an additional 4 indicators using a modified version of the ESTIMAP model (Zulian et al. 2013, Paracchini et al. 2014) for the FUA-Burgas. ESTIMAP is a collection of models (for recreation, pollination) for spatial assessment of ecosystem services, initially developed to support European policies across the EU, but increasingly applied on a smaller scale to assess the potential for nature-based recreation (Zulian et al. 2018). The model measures the recreational potential of the territory for outdoor recreation and leisure in nature. It consists of two main parts:

1. Recreation potential, which maps the potential capacity of ecosystems to support nature-based recreational activities.

2. A map of the recreation opportunity spectrum, which combines an indicator of proximity/distance and the availability of infrastructure with recreation potential and provides a map with nine categories of recreational opportunities.

The areas identified with the highest scores from the two ecosystem service assessments are key in terms of biodiversity conservation and landscape identity and can be used to identify priority areas for conservation, restoration, and strategic planning of green infrastructure at the regional level. The areas can also serve as proposals for projects to build a unified network of green infrastructure/ecological infrastructure, connecting the natural heritage of the FUA territory—the urban cores with the surrounding area, which will benefit:

- Supporting urban planning to address the problems of urban areas and improve the quality of life of the population by improving and maintaining the ecosystem services.
- Engaging the local community on the issue.
- Promoting nature-based solutions, especially in areas that provide the least ecosystem services, and improving the attractiveness of territories, the health and quality of life of the population, and the creation of green jobs (Raymond et al., 2017).

V.5. Mapping and assessment of ecosystem services at the local level

In this analysis at local level, the mapping and assessment of ecosystem services were carried out jointly. The current situation of the actual balance of supply and consumption with/of the bundle of ecosystem services provided by the urban green infrastructure within the city of Burgas was analysed. The study was conducted through a multi-criteria geospatial analysis of mapping and assessment of the territory to optimize the components of the green infrastructure that would increase the available potential for providing ecosystem services.

The study follows the methodological framework for selecting sites/objects in which to carry out interventions to reduce secondary dust dispersion through greening measures in the urban environment in the Municipality of Burgas by Borisova et al., 2024.

The indicators have been selected to focus on the main functions and condition of green areas in the city. The parameters applied have identified those green areas that play the role of green infrastructure elements (meeting the requirements for connectivity and sufficiency), as the main focus is on the area and connectivity of green elements to provide regulating and cultural ecosystem services – in terms of increasing biodiversity (Shanahan et al., 2011, Beninde et al., 2015, Leveau et al., 2019), cooling effect (Jiang et al., 2021), human health (Nguyen et al., 2021), etc.

Mapping and assessment were performed by creating a composite index (*Creating composite index* - ESRI ArcGIS Pro 3.3.0), which contains a selection of variables, their preliminary processing, combination, and subsequent finalization of the index (according to Borisova et al., 2024, Buie et al., 2024), (Fig. 6). A total of 7 indicators (Table 7 and Table 8) were identified to assess the demand for and supply of green infrastructure in the specific conditions of the urban morphology of Burgas.

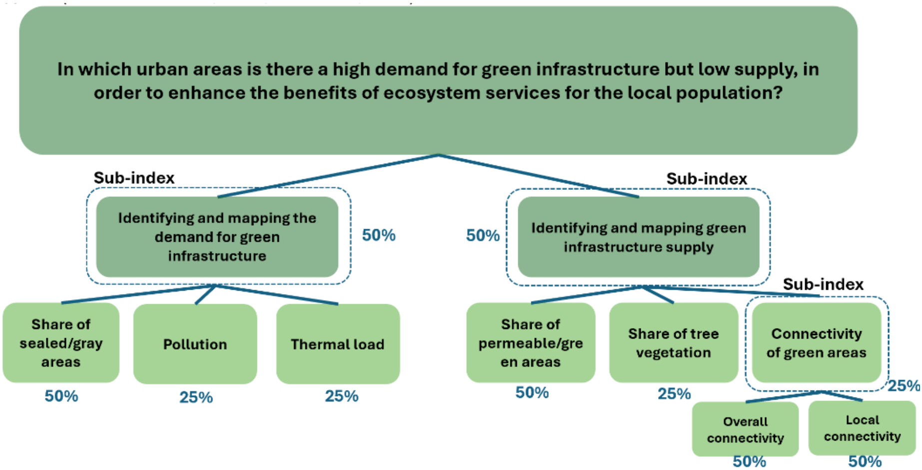

Fig. 6. Scheme of the composite index (according to Buie et al., 2024)

Table 7. Indicators of the demand for green infrastructure, parameters, scale, and data sources for the composite index (according to Borisova et al., 2024)

Indicator	Parameter (calculated for each LCZ)	Scale	Data used and source	Tools used in ESRI ArcGIS Pro 3.3.0
1. Gray coefficient	% of sealed/impervious gray areas	0-9% 10-19% 20-29% 30-39% 40-49% 50-59% 60-69% 70-79% 80-89% 90-100%	Spatial layer of sealed areas for the city of Burgas for 2022 (Geographica Ltd.)	*Analysis tools – Summarize within*
2. Pollution with PM10	Average annual concentrations of PM10 (µg/m3) from all sources located in the territory of Burgas Municipality (for 2019)	Up to 2 µg/m3 Up to 5 µg/m3 Up to 8 µg/m3 Up to 10 µg/m3 Up to 15 µg/m3 Up to 20 µg/m3 Up to 25 µg/m3 Up to 30 µg/m3	PROGRAMME FOR IMPROVING THE QUALITY OF ATMOSPHERIC AIR IN THE MUNICIPALITY OF BURGAS FOR THE PERIOD 2021-2027	Georeferencing Digitization *Select by location*
3. Land surface temperature	Average ground surface temperature (°C)	From 24 to 39 °C	Landsat 8 Satellite image 30.07.2022 (NUCGRT- Report of Burgas, 2024)	*Zonal statistics* *Select by attributes*

Table 8. Indicators of the supply of existing green infrastructure, parameters, scale, and data sources for the composite index (according to Borisova et al., 2024)

Indicator	Parameter (calculated for each LCZ)	Scale	Data used and source	Tools used in ESRI ArcGIS Pro 3.3.0
1. Green/blue ratio	% of unsealed/permeable green and blue areas	0-10% 11-20% 21-30% 31-40% 41-50% 51-60% 61-70% 71-80% 81-90% 91-100%	Spatial layer of green areas for the city of Burgas for 2022 (Geographica Ltd.)	*Analysis tools – Summarize within*
2. Share of tree vegetation in the composition of existing green areas	% of tree canopy cover	0-100 %	Point layer with trees in Burgas for 2022 (Source – Geographica Ltd.)	*Analysis tools – Buffer* *Analysis tools – Summarize within*
3. Overall connectivity/fragmentation of green areas	100 m distance between green areas, Average daily intensity of motor vehicles on main transport arteries in Burgas	1 – No 100 m distance between green areas, which are fragmented by transport arteries 2 – There is connectivity of 100 m between green areas larger than 1 ha, but they are fragmented by the busiest transport arteries (more than 10,000 vehicles per 24 hours) 3 – There is a 100 m connection between green areas larger than 1 ha (core areas), but they are fragmented by less busy roads (less than 10,000 vehicles per 24 hours)	Spatial layer of green areas for the city of Burgas for 2022 (Geographica Ltd.) Strategic detectors for monitoring transport traffic, Burgas Municipality (NUCGRT – Report of Burgas, 2024)	*Analysis tools – Buffer* *Select by location*
4. Local connectivity of green areas	Connectivity (in directions) of green areas between LCZs	0-8	Spatial layer of green areas for the city of Burgas for 2022 (Geographica Ltd.)	*Analysis tools – Polygon Neighbors*

- **Indicators for the demand of green infrastructure:**

For the indicator “PM_{10} pollution”, data for 2019 from the Burgas Municipality Air Quality Programme (2021-2027) was used. The main sources of pollution are domestic heating and transport.

The “Land surface temperature” indicator uses data from Landsat 8 (July 30, 2022) for the average midday temperature, which has a direct impact on the dynamics of the surface air (NUCGRT, 2024).

- **Indicators for supply with green infrastructure:**

The idea of creating a grey and green/blue coefficient is borrowed from the Singapore Index on Cities Biodiversity (Chan et al., 2021), Jiang & Menz (2025) and the so-called "blue-green factor" (UnaLab), and represents the ratio of green and gray areas. The indicator is applied in the sense of permeable and impermeable (sealed) surfaces. The green-blue coefficient group includes predominantly green areas (grass and tree vegetation), but there are also a small number of LCZs with predominantly water areas or areas without vegetation such as sandy strips and other sandy areas (most often border LCZs). The gray coefficient group includes all sealed surfaces, including buildings. The spatial data used to create the gray and green/blue coefficient layers has been supplemented and updated with a classified layer of surfaces from photogrammetric photos from UAS from 2023 (provided by Geographica Ltd.). The current indicator is the most important one, with the greatest weight in the assessment of the variables for the composite index, as it represents the actual flow (in this case, areas) of need and provision of ecosystem services.

The calculation of the indicator for % tree canopy cover is related to the creation of the above-mentioned comprehensive layer of green areas in the city through buffers.

The overall connectivity indicator is borrowed from the Singapore Index on Cities Biodiversity, applying an average value of up to 100 m between green elements (Chan et al., 2021). For this purpose, the total layer of green areas is divided into patches, the area of which is calculated, and then areas larger than 1 ha are marked. To check whether green areas larger than 1 ha are connected, a 50 m buffer zone was created between them. The size of 1 ha was chosen because of the function of green areas as cores and their sufficiency as a medium/habitat for species.

The local connectivity of green areas is in line with the concept of defragmentation, which involves the creation of green roads or corridors to connect fragmented landscapes. This indicator distinguishes the connections of each LCZ possessing a certain green area with the neighbouring green areas (according to Jiang & Menz, 2025). The "connectivity" factor increases the effectiveness of green elements on the regulation of microclimatic conditions and the improvement of air quality. As a result of this indicator, it can be concluded that the city of Burgas has very good connectivity of green areas, forming a continuous green system throughout the city, with only the central urban area remaining with isolated green spaces.

As a next step in creating the composite index, the indicators were pre-analyzed using a correlation matrix (*Scatter plot matrix,* ESRI ArcGIS Pro 3.3.0) (Fig. 6), representing the relationships between all indicators/variables used in the model. Pearson's correlation coefficient, ranging from -1 to +1, shows the strength and direction of the linear relationship between two variables.

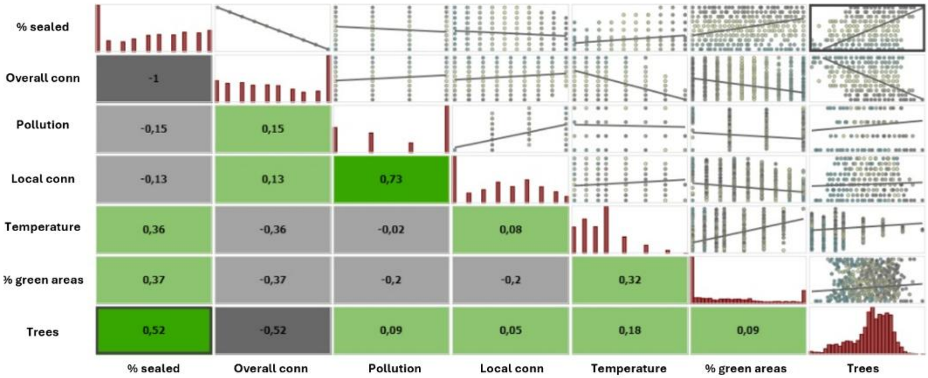

Fig. 6. Correlation matrix of all indicators/variables in the model

As can be seen from the graph, one of the strongest positive correlations is found between the indicators "Overall connectivity" and "Local connectivity", which is entirely expected, as they measure similar characteristics. "% tree cover" and "grey coefficient" have a moderate to high positive correlation, which is logically explained by the fact that as sealed areas increase, grassy areas decrease and trees remain as representatives of green areas. Conversely, with a weak to moderate positive correlation, there is no clear increase in % tree cover with the increase in green areas. A negative correlation is observed between connectivity and "land surface temperature" and "green-blue coefficient", which suggests that better connectivity of green areas is associated with lower temperatures and more green space. The remaining relationships between the indicators have values close to 0, which indicates a weak or absent linear relationship. In addition, the indicators are analyzed in more detail in separate correlation matrices by need and provision groups.

The composite index tool was run several times, using different processing and combination options to test how each combination of indicators affects the final index. The z-score classification method was chosen to structure the data in the model, as the data presented show clear asymmetry. Methods that standardize using z-score shift the distribution so that it is positioned around the mean, thereby reducing the impact of asymmetry but not eliminating it completely (Buie et al., 2024).

The first run of the tool is with all 7 indicators/variables in order to initially load it with the variable data. The next launch of the tool is with the grouping of two sub-indices of the variables for demand and supply before finalizing the final index. The advantage of sub-indices is the thematic grouping of variables for each dimension (Buie et al., 2024).

Sub-index "Identification/mapping of actual supply with green infrastructure": As a preliminary step, a sub-index "Connectivity of green areas" has been created here, as it is clear from the matrix above that the two connectivity indicators have a very high correlation coefficient, which means that in the initial version they have the greatest weight in the formation of the provision sub-index. The final result of the created connectivity sub-index focuses with the highest scores on green areas larger than 1 ha that are connected to each other, i.e. on the most important components of green infrastructure, the so-called "cores". After the initial test, greater weight was given to % green areas (0.50) compared to % trees and connectivity (0.25 each), which led to results identifying LCZs with the highest scores with over 70% green areas.

Sub-index "Identification/mapping of the demand for green infrastructure": Assigning a higher weight to % sealed areas (0.50) than to temperature and pollution (0.25 each) raised the threshold for the highest need from 50% to 60-70% sealed areas in the LCZs (Fig. 7):

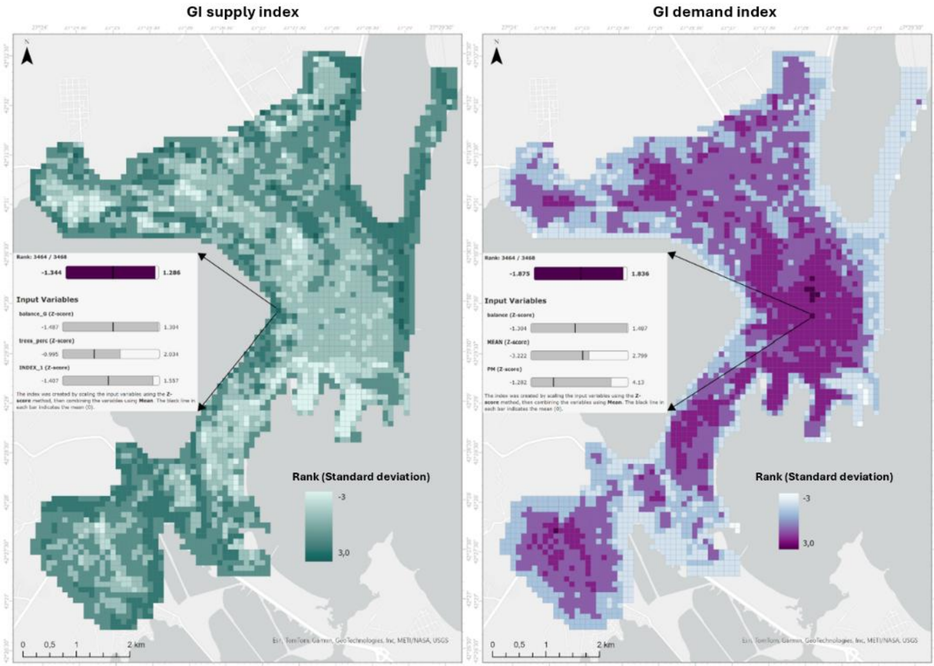

Fig. 7. Index of supply and demand for green infrastructure

➢ **Final composite index and thematic summary of results**

The final composite index is the result of combining the two sub-indices by their average value. The values of the supply sub-index are reversed to obtain the combination of the lowest supply with the highest demand. The result of this model is the identification of LCZs with high values of "demand for green infrastructure" but low "supply of green infrastructure" – areas with a deficit in terms of regulatory mechanisms in the urban ecosystems with a need to build green infrastructure elements (Appendix 4).

➢ **Identification of clusters with "hot and cold spots"**

The final assessment is completed with a study of the spatial grouping of the index results, as recommended by Buie et al., 2024 for model refinement. The result of this stage is the statistical identification of clusters of LCZs with high demand for green infrastructure" and high "supply with green infrastructure" (Fig. 8). For this purpose, the *Hot Spot Analysis* tool *(Getis-Ord Gi*,* ESRI ArcGIS Pro 3.3.0) was used, which calculates the Getis-Ord Gi* statistic for each object in the dataset. The resulting z- and p-values show where objects with high or low values are spatially grouped, with each object considered in the context of neighboring objects (Modeling spatial relationships, ESRI ArcGIS Pro).

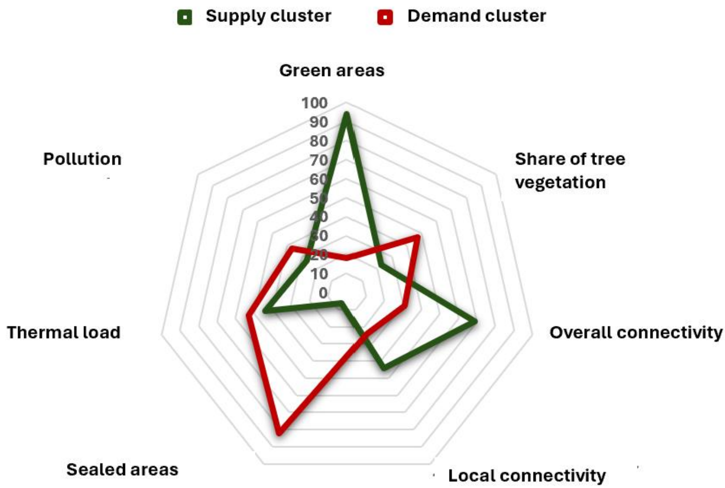

Fig. 8. Clusters with the highest demand and supply (visualized average values of the indicators for all cells in the clusters)

The results reveal clear spatial contrasts in the balance between demand and supply of ecosystem services provided by urban green infrastructure in the city. The central urban areas, the central zone of Meden Rudnik district, and the northern and southwestern industrial zones have been identified as hot spots with high demand and low supply, reflecting increased average surface temperatures, PM pollution, and extensive sealed areas. In contrast, areas with the highest provision of green and blue infrastructure, such as the Sea Garden and lakeside areas, form key supply clusters that reflect local climate regulation, air purification, biodiversity maintenance, and leisure and recreation benefits. The identified clusters highlight the deficits and synergies of the territory - densely built-up urban centers need interventions in green infrastructure, while peripheral green-blue multifunctional systems serve as a source of ecosystem services.

The analysis establishes the pattern that sealed areas are associated with the negative effects of increased surface temperature and pollution, and conversely, in the presence of green areas, the above-mentioned parameters decrease, which coincides with the conclusions of Dimitrov et al., 2023. It can also be summarized that the connectivity of green areas affects the negative effects by enhancing the cooling effect, as it is clearly observed that better connected green areas have lower temperatures.

- **Sensitivity analysis**

The sensitivity analysis aims to justify the significance of the chosen method and, accordingly, its impact on the results obtained. To create the final composite index, two different options for processing and combining the variables were tested:

Option 1 – Composite index with a combination of the average values of the two sub-indices (demand + supply).

Option 2 – Composite index combining the average values of 5 indicators: 1. Tree vegetation coverage; 2. Connectivity of green areas; 3. Gray/green ratio; 4. Land surface temperature; 5. PM_{10} pollution.

As a result of the values obtained for the final composite index, Option 1 was selected, as the sub-indices adjust for the different number of variables, achieving a balanced contribution to each dimension. For the spatial grouping of the results (Option 1), the following were tested: Multivariate Clustering, Cluster and Outlier Analysis, and Hot Spot Analysis (ESRI ArcGIS Pro 3.3.0). They identify areas with statistically significant clusters of high values as well as deviations.

Conclusions from the analysis:

- The z-score pre-processing method is most effective in ensuring equal dispersion (Buie et al., 2024).
- When testing the two variants and the three methods for clusters/hot spots, there is almost 90% overlap – the results are consistent.
- The correlation matrix test proves the significance of the sub-indices.
- The model is more accurate for the central parts of the city and shows deviations in the periphery, which proves its dependence on very accurate spatial data.

- **Assessment and analysis at the level of districts/territorial units in the city of Burgas**

For the application of the results in spatial planning, the identified areas were analyzed at the level of city districts, including additional indicators (Borisova et al., 2024) (Table 9). The data obtained from the assessment of the "demand/supply" balance in relation to the green urban infrastructure were subjected to secondary analysis by introducing information on the presence and spatial concentration of residential and public facilities and population (Borisova et al., 2024). As a result, statistical data were obtained for each territorial unit with information on population, % concentration of residential buildings and social facilities, % green area, % of residential buildings with access within 300 m to public green space over 1 ha, % of the district with areas of demand, and % of the district with areas of supply.

Table 9. Indicators for prioritization, parameters, and data sources for the purposes of analysis at the district/territorial unit level in the city

Indicator	**Parameter (calculated for each district/territorial unit)**	**Data used and source**	**Tools used in ESRI ArcGIS Pro**
1. Spatial concentration of residential buildings	Number and % of the total for the district/territorial unit	Agency for Geodesy, Cartography and Cadastre, KAIS – portal for electronic services, open data – buildings – Burgas	*Summarize within*
2. Spatial concentration of public facilities	Number and % of the total for the city	Burgas Municipality	*Summarize within*
3. Population	Number and % of the total for the city	Burgas Municipality	-

The indicators have been selected to emphasize the requirement for sufficient green space for the local population, leading to so-called "green equity". The current 3 + 30 + 300 methodological approach (Konijnendijk, 2023) has been applied for the assessment, which provides a good analysis of local green space requirements:

- 300 m access to green areas: identification was carried out by selecting residential buildings and urban and extra-urban parks + municipal areas designated for greening over 1 ha from the data on land properties for the city of Burgas (Agency for Geodesy, Cartography and Cadastre). A buffer of 300 m was applied to the latter.
- 30% coverage of districts/territorial units with green areas: To identify areas with more than and less than 30% coverage of green areas, the summary layer of green areas (tree and grass vegetation) was used, applied in the analysis to identify the balance between the demand and the supply of the territory.
- Visibility of 3 trees from each residential building: The current final step of the 3 + 30 + 300 indicator has been tested for a selected unit of the city by selecting trees up to 50 m away from each residential building and applying the *Generate origin – destination links* analysis tool (ArcGIS Pro 3.3.0) (Appendix 5).

As a result of the comprehensive analysis, it was found that the central and densely populated districts/territorial units have the greatest imbalance in the demand for and supply of ecosystem services from urban green infrastructure as a result of the limited availability of green spaces, while the peripheral districts/territorial units are characterised by a better, even positive balance in terms of supply and demand, as well as overall ecological and recreational potential. The districts with the largest population and concentration of residential and social facilities and, at the same time, with the lowest percentage of green areas and, as a result, with the highest share of areas in need are Vazrazhdane and Central City Area and the central parts of Meden Rudnik district (Appendix 6).

➢ **Planning nature-based solutions**

This sub-section aims to present examples of nature-based solutions for application in the territory to ensure equal provision of ecosystem services at local and regional level within the boundaries of the FUA-Burgas. The specific proposals support the achievement of a balance in the quantitative dimensions of ecosystem services provision and consumption. Table 10, borrowed from Maes et al. (2020), presents integrated proposals for possible nature-based solutions, classified according to their suitability for local or regional level in order to achieve the greatest impact on the target tasks. The current proposals aim to stimulate the balanced distribution of ecosystem services across the territory to achieve green/environmental justice. Such interventions lead to difficult synergies between different environmental and socio-economic objectives.

Table 10. Integrated proposals for nature-based solutions in the territory of FUA-Burgas for strategic planning of green ifrastructure (according to Maes et al., 2020)

NATURE-BASED SOLUTIONS AND MEASURES			**APPLICATION**	
Type	**Subtype**	**Examples**	**Local level**	**Regional level**
Design and management of new ecosystems	Intensive management of urban green spaces	1. Greening of roadside areas along busy streets/boulevards (flower beds and trees) 2. Green roofs 3. Green wall systems 4. Pocket parks	LCZ 3, 4, 5, etc.	-
	Urban water management	Sustainable drainage systems	✓	-
	Ecological restoration of degraded terrestrial ecosystems	1. Restoration of soil and vegetation on slopes 2. Planting trees/hedges/perennial grasses to stop surface runoff	✓	✓
	Restoration and creation of semi-natural water bodies and hydrographic networks	1. Restoration of vegetation on river banks 2. Construction of wetlands and water management facilities		✓
Better use of protected/ natural ecosystems	Strategies for protection and conservation in terrestrial and marine protected areas (e.g., Natura 2000 sites)	1. Restricting or preventing specific types of activities and practices 2. Ensuring the continuity of the ecological network 3. Protecting forests from deforestation and degradation resulting from logging, fires, and unsustainable levels of non-timber resource extraction		✓

NBS for sustainability and multifunctionality of managed ecosystems	Management of agricultural and forest landscapes	1. Agri-environmental practices 2. Agri-environmental network structure 3. Forest patches 4. Living hedges and fences 5.Flower strips	✓	✓
	Management of extensive urban green areas	1. Ensuring the continuity of the ecological network 2. Tools for planning and controlling urban sprawl 3. Historical structure of the urban green network 4. Plant selection 5. Heritage parks 6. Urban nature reserves 7. Use of native plant species 8. Vegetation diversity 9. Green corridors and belts 10. Planning tools for biodiversity, green infrastructure, and ecosystem services	✓	✓

VI. CONCLUSION

Numerous studies on the subject prove that it is difficult and scientifically challenging to examine and present the complex dynamics of large-scale socio-ecological urban spaces through a given model or to derive universal generalised trends given the specific geographical conditions of each urban area. In the context of increasing climate risks and the pursuit of sustainable and intelligent management, there is a growing need for detailed studies of cities and their surrounding areas that assess and present evidence of changes in urban ecosystems in the context of national and European levels to support decision-makers.

Developments at European level on the state of urban ecosystems and the services they provide identify future challenges in the scientific field, as well as some gaps in research (Maes et al, 2020): lack of consistency at EU level in the collection of detailed spatial data and reporting units needed to analyze the pressure and condition of urban ecosystems, such as pollutant concentrations in the air, the capacity of vegetation to remove pollutants, monitoring of protected areas and areas within the boundaries of the Functional Urban Area, urban biodiversity, monitoring of green systems in cities, etc.

The format of the MCDA methodological approach used in the study helps identify the most relevant ecosystem services for local priorities, making it a useful tool for spatial planning and stakeholder engagement.

The model matrix for identifying objectives and needs in the Functional Urban Area for justified prioritization of ecosystem services combines the EU's strategic guidelines for climate-neutral and sustainable cities with the national priorities set out in key documents and programs. The approach ensures a systematic consideration of environmental, social, and economic criteria in the development of urban areas from the perspective of modern socio-environmental-technological systems.

Identifying the needs of stakeholders (with target groups being the active population and local government) leads to a transparent process in the research steps and, accordingly, contributes to better awareness, sustainable use of the ecosystem services, as well as more effective solutions to key environmental and social problems in the area.

Despite the increasingly evident acquisition of the characteristics of major cities in view of the increased pace of urbanization at the global level, the commuting zones in the Functional Urban Areas remain a key resource for providing the necessary ecosystem services. In this sense, the model study of the urban area of the city of Burgas in a regional context helps to view the peri-urban system as a buffer zone in terms of maintaining the optimal condition of the urban ecosystems and as a resource for sustainable use of the territory, given the observed imbalance between sealed and permeable areas in the urban core and the better characteristics in this respect in the periphery. According to the data used to assess the condition and pressure in the FUA-Burgas, no lasting negative trends are observed for the territory (with the exception of air pollutant concentrations, which is a current problem for the whole country), On the contrary, positive aspects are noted, such as the small losses of vegetation cover in the area against the backdrop of the negative trend of more intensive vegetation loss in the commuting zones than in the main cities at EU level.

Assessments are presented of the potential of the FUA-Burgas territory to provide the ecosystem services habitat and biodiversity maintenance and recreation in relation to the connection of green infrastructure at regional level.

On a smaller scale, within the urban area of Burgas, areas with high demand and low supply with green infrastructure have been identified using a composite index with indicators detailing the characteristics and structural elements of green spaces. As a result of the data used in the model at the local level, a need has been identified for the construction and upgrading of green infrastructure elements in the central urban area and industrial zones to the north and southwest, while the peripheral and coastal areas function as "cores" of green infrastructure with high efficiency in regulating the microclimate and maintaining the sustainability of the urban environment in the city. Again, based on the data used, the following spatial dependencies are derived: the temperature of the land surface is most strongly influenced by the amount of sealed areas (which increase it) and connected green spaces (which decrease it); the share of tree vegetation in the composition of existing green areas has opposite dependencies on connectivity and sealed areas, which reflects the pattern of dense development and smaller green areas in the central urban area. After the sensitivity analysis, it was found that the model is stable with different methods of statistical processing of the results, but proves its dependence on accurate spatial data.

The summary analysis of the results shows that the city of Burgas and the region have a good supply of multifunctional green spaces, providing numerous ecosystem services that benefit people and nature. Therefore, the green system designed in this way fulfills the necessary functions in terms of building, maintaining, and expanding a unified green infrastructure. It is recommended to strategically improve the connectivity and coverage of the green infrastructure through nature-based solutions to restore and maintain the balance and ecological capacity in the urban environment in order to ensure fairer access to regulating, supporting, and cultural environmental services in the urban core of the Burgas urban area. The results prove the correlation that larger and closer/connected green areas have higher ratings, therefore, planning should focus on their maintenance in the future, as well as on connecting the remaining green spaces (especially in the central urban area of Burgas) with green corridors to reduce fragmentation and isolation. The results obtained are also important in terms of drawing attention to equal access to green spaces for vulnerable population groups (children and the elderly), seasonal disparities in population concentration (overcrowding in the summer during the tourist season), and identifying social inequalities.

The results of the study underscore the finding by Cortinovis and Geneletti (2018) on the need for a strategic approach that is neglected in current planning documents and the inclusion of explicit EU-related objectives in urban plans.

The presentation of the analyzed information on the demand for and supply of a bundle of ecosystem services in a form suitable for management structures demonstrates the advantages of the approach used through the spatial unit of the LCZs, allowing flexibility in decision-making related to the optimization of the urban environment. The geoinformation database developed to assess the structure and condition of green areas in the city and region to perform the functions of green infrastructure can be useful to the responsible institutions as a starting point for creating a plan for the maintenance, expansion, and sustainable management of green infrastructure. More detailed studies are needed, such as structuring the typology of green infrastructure and studying its morphological characteristics, as well as collecting detailed geospatial data (type, structure, and condition of vegetation) will be needed to derive quantitative parameters for the real benefits of the multifunctionality of the green infrastructure, i.e., the valuation of the ecosystem services. A detailed analysis of the impact of current (characteristic of the current state of the Functional Urban Area) and priority ecosystem services bundles (necessary for the future in view of the ongoing changes), i.e. drawing conclusions about the limits within which these services can be used to maintain the natural and social system in optimal condition, would provide valuable guidelines for spatial and temporal planning of the territory.

The two-level spatial model presented in the study can be applied to the territory of any Functional Urban Area, as these units are provided with freely accessible databases, and the universal spatial units used allow for comparison of results at European level.

The study concludes that the MAES pilot framework for urban ecosystems is relevant for application at different spatial levels by integrating environmental and social indicators and parameters that take into account the specific conditions of urban ecosystems and using high-resolution spatial data. It is essential for mapping and assessing the urban ecosystem services in order to respond to public challenges in cities.

CONTRIBUTIONS OF THE SCIENTIFIC RESEARCH

1. Development and testing of a model for analyzing ecosystem services from Functional Urban Areas through the application of a multi-criteria geospatial approach in all phases of the model—in the identification, mapping, and assessment of services.
2. Provision of information for urban planning and management of the Functional Urban Area of Burgas – analytical data on the structure and functions of urban ecosystems at different spatial levels.
3. Comprehensive assessment of a bundle of ecosystem services from the Functional Urban Area of Burgas – results from the integrated use of software products, tools, and applications. A spatial and statistical analysis of the green infrastructure has been performed. The information in the passports for each local climate zone has been supplemented and updated with data on the structural characteristics of green areas in their capacity as elements of green infrastructure.

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Urban Design Lab

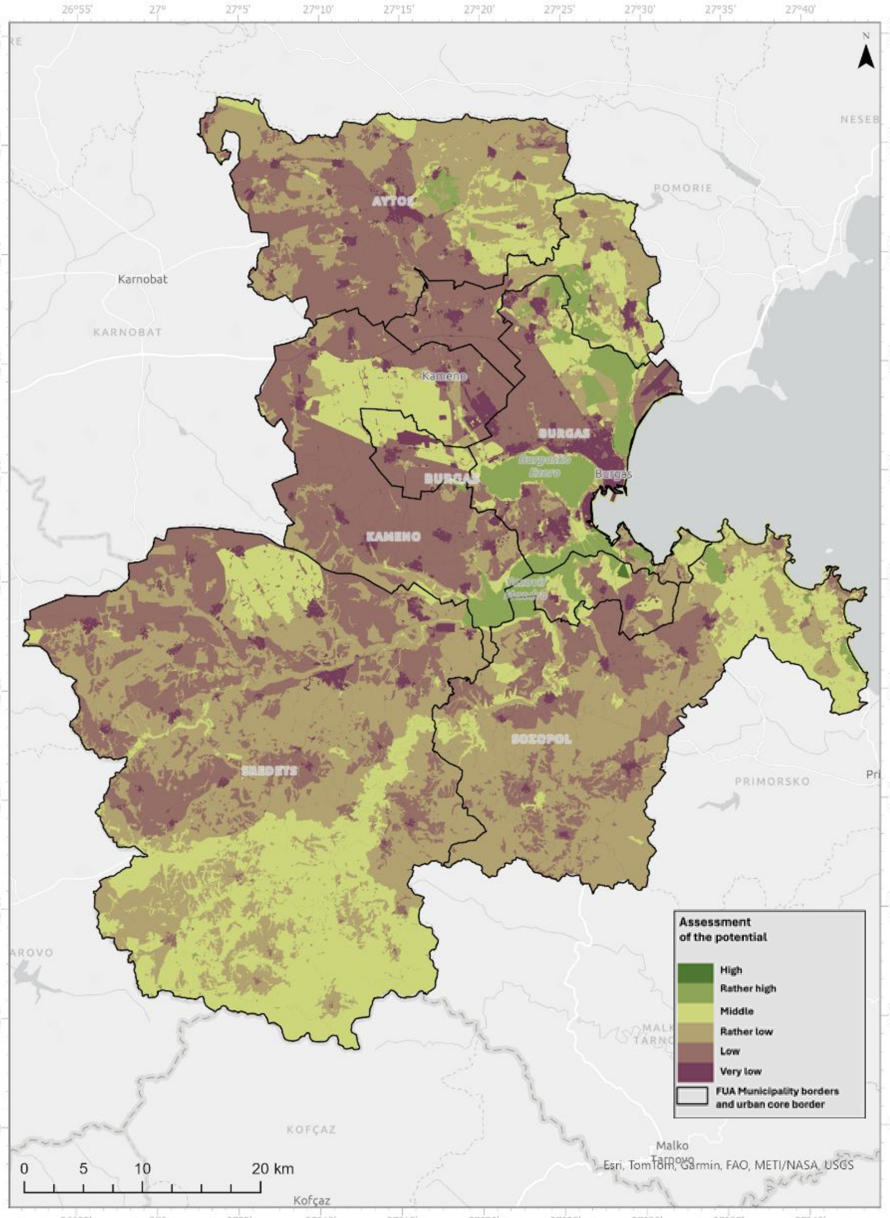
UnaLab – Use of blue-green factors

APPENDIXES

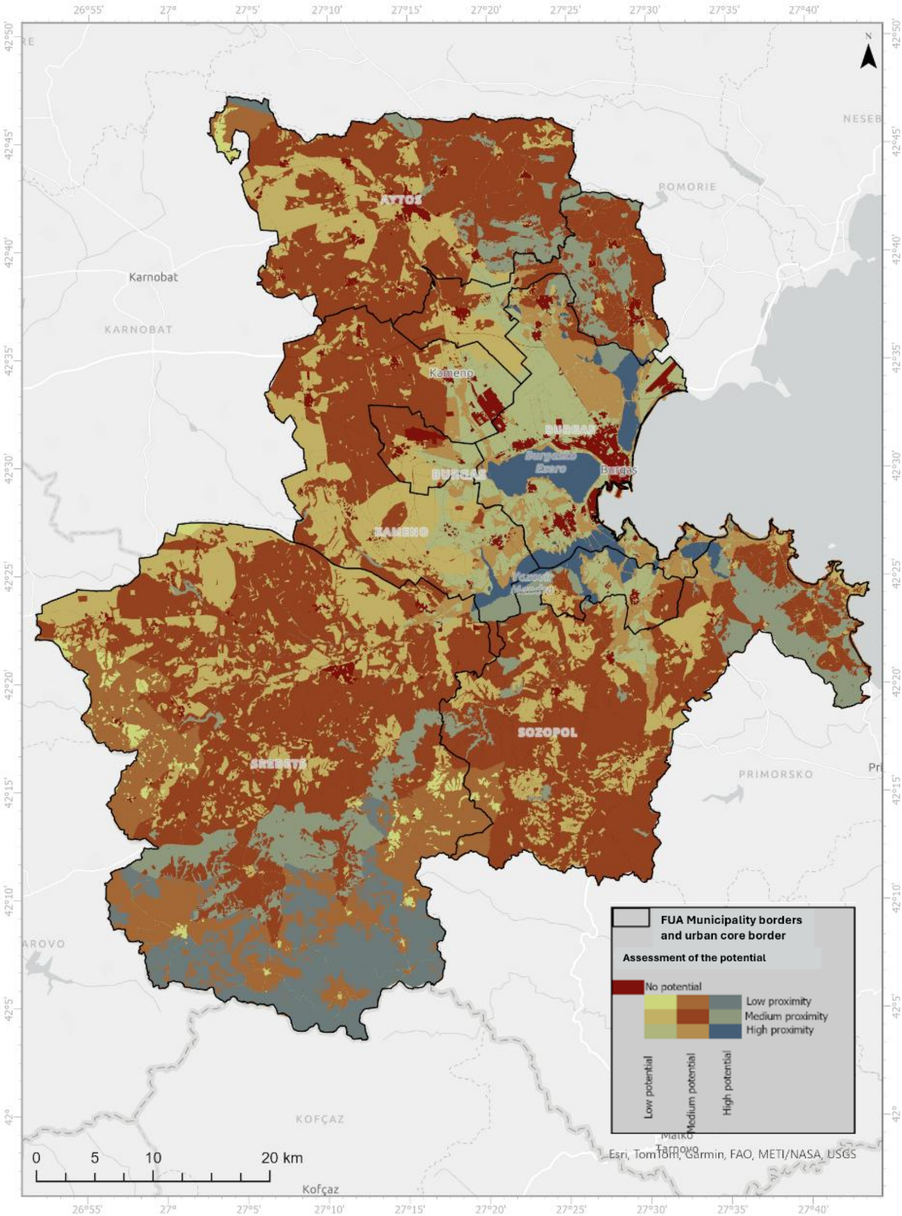
Appendix 1. Multi-criteria matrix for assessment of FUAs in Bulgaria

Criteria	Parameter	Indicator	Data	Alternatives																
				Blagoevgrad	Burgas	Varna	Veliko Tarnovo	Vidin	Vratza	Dobrich	Pazardzhik	Pleven	Plovdiv	Ruse	Sliven	Sofia	Stara Zagora	Haskovo	Shumen	Yambol
ECOLOGICAL SIGNIFICANCE AND VULNERABILITY	Quality of the environment	Air quality	EEA	✓	✓			✓				✓	✓	✓		✓		✓		
	Vulnerability to climate change	Increase in air temperature; Risk of flooding; Risk of drought	Ministry of environment and waters, National Institute of Meteorology and Hidrology	✓	✓✓	✓✓	✓	✓✓		✓✓	✓✓✓	✓✓	✓✓✓	✓	✓	✓	✓	✓✓	✓	✓✓✓
	Naturalness of the environment	Hemeroby index	Hermes et al., 2018 Urban Atlas (2018)	✓		✓	✓								✓	✓				
	Natural heritage	Representativeness and quality of natural heritage	Composite indicator	✓	✓	✓	✓						✓			✓				
GEOGRAPHICAL STRUCTURAL PREREQUISITES	Attitude towards "territories with special characteristics"	Coastal, mountainous, border areas	Ministry of regional development	✓✓	✓✓	✓		✓✓				✓✓	✓	✓✓		✓✓				
POPULATION	Number	over 150,000 inhabitants	Eurostat		✓	✓						✓	✓	✓		✓	✓			
	Economically active population aged 20-64	over 100,000 inhabitants	Eurostat		✓	✓							✓			✓				
FUNCTIONS	GDP	Eurostat - metropolitan regions	Eurostat		✓	✓							✓			✓				
	Hierarchical structure and prospects of cities	Cities from level 1-2 of the NCSD + possibility of funding	Ministry of regional development	✓	✓	✓	✓	✓				✓	✓	✓		✓	✓			
Technical feasibility of the study																				
AVAILABILITY OF DATA FOR SPATIAL ANALYSIS AND TECHNICAL GIS TOOLS	Urban Atlas data 2006-2018		Copernicus		✓	✓		✓				✓	✓	✓		✓	✓			
Role of the ecosystem service theme in the planning and management of the FUA																				
GOOD PRACTICES, INNOVATIONS, PROJECTS, INITIATIVES	Presence of the Es theme in leading strategic planning and management documents		Internet search		✓											✓				
	Number of projects related to the Es		Internet search	✓✓	✓✓	✓	✓✓	✓	✓✓✓	✓	✓	✓✓	✓	✓		✓	✓✓✓	✓✓	✓	✓✓

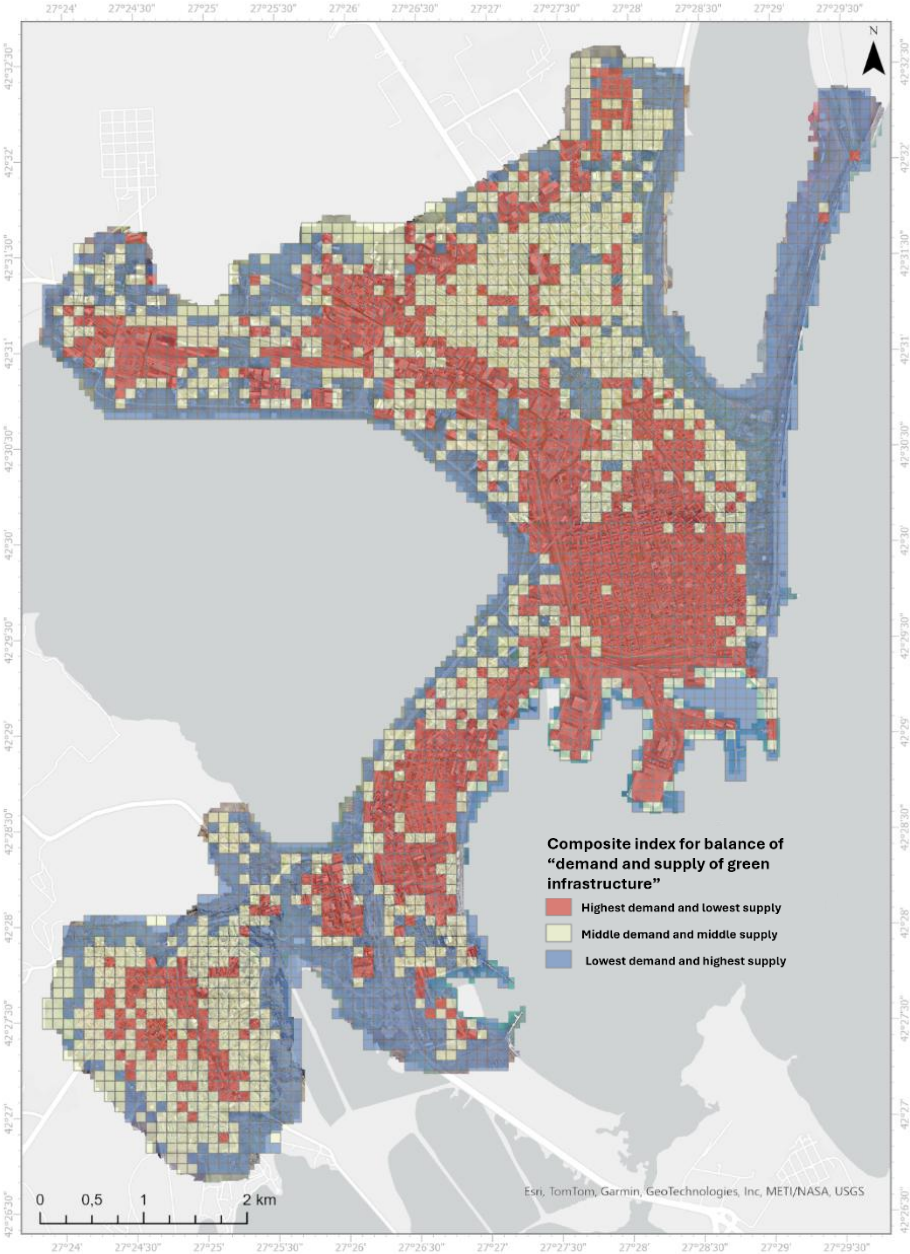
Appendix 2. Potential of ecosystems in FUA-Burgas to provide the ecosystem service "maintaining populations and their habitats"



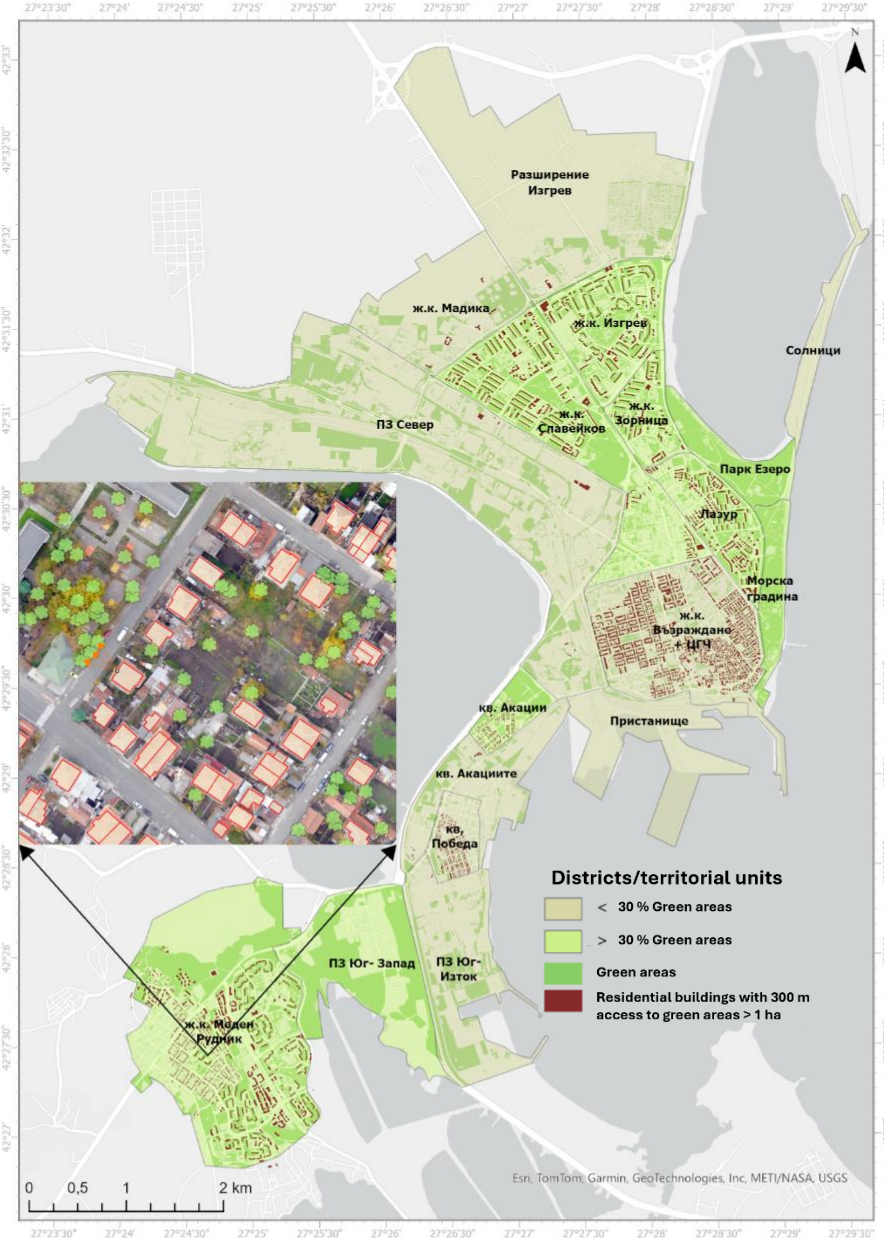
Appendix 3. Potential of ecosystems in FUA-Burgas to provide the ecosystem service "nature-based recreation"



Appendix 4. Final composite index



Appendix 5. 3+30+300 indicator applied in the city of Burgas



Appendix 6. Statistical analysis on a district level in the city of Burgas