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Mapping of carbon storage in urban ecosystems: a Case study of Pleven District, Bulgaria

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Abstract: Urban landscapes are the environment where most of the population live and perform their usual everyday activities. The continuous urban sprawl and the increasing demand on resources and energy provoke serious discussion on ensuring better human well-being in the settlements while preventing increasing loss of biodiversity. However, urban landscapes also provide a number of benefits for the human society through their ecosystem services. Mapping of ecosystem services has broad application potential since it is an extremely valuable method for visual representation of qualitative and quantitative spatial data. In this paper an approach to assess and map ecosystem services in urban areas at national scale in Bulgaria is presented. It includes identification of urban ecosystem's subtypes according to the classification of National concept for spatial development (for the period 2013 – 2025) and based on MAES (Mapping and Assessment of Ecosystem and their Services) guidelines and EUNIS habitat classification, choice of indicators for ecosystem services, parameterization of these indicators, normalization of the parameters and elaboration of maps in GIS. The ecosystem services indicators set for the study were elaborated on the base of the EEA CISES classification by prioritization of the relevant services in urban ecosystems. The data for the parameters were stored in GIS database and their spatial distribution was analyzed using GIS tools. The approach is tested in the case study area of Pleven region. The results are presented in form of spatial analyses and maps for one of the most important ecosystem services for urban areas: climate regulation indicated with carbon storage in green infrastructure. The application of this approach in spatial planning and regional development could contribute for a significant improvement of the urban environment and better human welfare.

Key words: Ecosystem services, carbon storage, urban ecosystems, GIS

1. Introduction

Urban landscapes are the environment where most of the population live and perform their usual everyday activities. The continuous urban sprawl and the increasing demand on resources and energy provoke serious discussion on ensuring better human well-being in the settlements while preventing the increasing loss of biodiversity. However, urban landscapes also provide a number of benefits for the human society through their ecosystem services. The EU Biodiversity strategy to 2020 aims to halt the loss of biodiversity and ecosystem services in the EU and helps to stop global biodiversity loss. The action 5 of the strategy calls member states to map and assess the state of ecosystems and their services in their national territory. A Working Group on Mapping and Assessment on Ecosystems and their Services (MAES) was set up to underpin the effective delivery of the strategy with objective to support the implementation of Action 5 by the EU and its Member States. The results of its activities have been summarized in three reports that issued since 2013. The reports provide methodological framework for mapping and assessment of ecosystems and their services at European and national scales. Section 4 of the first report proposes a coherent typology to be used for the different types of broad ecosystems to be considered in the assessment to ensure consistency across Member States (Maes et al. 2013).

Mapping of ecosystems and their services has been mentioned as one of the main challenges for the ecosystem service concept's implementation into decision making (Daily and Matson, 2008). It has achieved rapid progress in the recent years and this corresponds to advances in computing power, modeling and Geographical Information Systems (GIS). They provide different tools and techniques for spatial analyses and database development, which can be used to investigate the relationships and influence of the different spatial units, delineation of ecosystems and assessment of ecosystem services. The analyses should be directed to landscape pattern analyses, incorporation of land cover data and possibilities for spatial statistics and landscape change detection (Nedkov, 2010). In the context of MAES process the application of GIS technologies includes mapping of ecosystem types, spatial analyses of data for indicators of ecosystem's state, implementation of tools and models for assessment of ecosystem services and generation of maps.

An important part of implementation of this process is mapping and assessment of urban ecosystems. The urban population grows rapidly and it is expected to reach 70% of all population to the middle of this age. Cities depended on both the nature ecosystem services provided beyond the city area, in a perimeter of 500-1000 times larger than the city area itself (Folke et al. 1997), and these which are provided from the urban ecosystems. The green infrastructure in the cities is of key importance as a source of range of benefits like air filtration, city climate regulation and carbon storage, connectivity between natural systems, biodiversity, community cohesion etc. Green infrastructure is understood as a strategic approach to develop "an interconnected network of green space that conserves natural ecosystem values and functions, and that provides associated benefits to human populations" (Benedict and McMahon, 2002). Different elements of green infrastructure in urban areas provide different set of ecosystem services (Braquinho et al. 2015).

Ecosystems store and sequester greenhouse gases, remove carbon dioxide from the atmosphere, improve the capacity of ecosystems to adapt to the effects of climate change (Maes et al. 2013). Trees and other vegetation absorb CO_2 from the atmosphere during photosynthesis. Much of it is released by respiration, but the rest of the carbon is distributed to the biomass of leaves, roots, seeds, stems and branches and stored there. In this context the elements of urban green infrastructure are main reservoirs of carbon in urban environment. The large urban forest parks contribute at a highest degree to the regulation of the global climate by storing and sequestering greenhouse gases, but other elements of urban green spaces as tree alleys and street trees, house, zoological and botanical gardens, neighborhood green spaces play also an important role. The first national assessment on carbon stored in trees from urban environment informed about accumulation between 350 and 750 million tons of carbon (Nowak, 1993). The data showed that the mean storage of carbon in aboveground biomass of urban forest parks in USA is 25.1 $tCha^{-1}$ compared with 53.5 $tCha^{-1}$ in natural forest stands in 2001 (Nowak, Crane, 2002). Recent studies have shown that land-cover types have major effects on aboveground organic carbon storage in urban vegetation — for example trees accounted for 97% of citywide total in the city of Leicester (Davies et al., 2011). In this study domestic gardens contained only 0.8 $kgOCm^{-2}$ in above-ground vegetation whereas urban trees and woodland stored 28.9 $kgOCm^{-2}$ on non-domestic land (Davies et al., 2011).

National studies on carbon storage in different compartments of urban and peri-urban forest parks confirmed their capacity to store carbon underlying the role of management activities in improving the carbon sequestration (Zhiyanski et al., 2015). Mapping the capacity of carbon storage in all sub-types of urban ecosystems including different elements of urban green spaces areas is essential for defining the appropriate management approaches in urban planning considering supply of regulating ecosystem services by the whole urban ecosystem as integrity. Within the project TUNESinURB (FM of EEA 2009-2014) we aimed at creating a national system for urban areas and their ecosystem services through the application of set of indicators for assessment and mapping with a view to better understanding and implementation of sectoral policies.

The objective of this work is to present an approach for mapping the capacity of carbon storage in all sub-types of urban ecosystems including different elements of urban green spaces areas for defining the appropriate management approaches in urban planning considering supply of climate regulation by the whole urban ecosystem as integrity. This approach could be applied in mapping and assessment of urban ecosystems and their services at national scale in Bulgaria. The approach is tested in a case study of Pleven district and the results of carbon storage ecosystem service are presented.

2. Materials and methods

2.1 Case study area

Pleven district (oblast) is located in North Bulgaria with an area of 4653,3 km². To the north it reaches the Danube which as a natural border with Romania and to the south, east and west borders with the districts Lovech, Vratsa and Veliko Tarnovo. The highest elevation in Pleven district is 300m southwards and 100m northwards. The highest peak is Sredniya (Middle) Peak (316,9m). The Pleven province has a humid continental climate. Summers are warm with average high temperatures of 22–25 °C and lows of 12–14°C. Winters are cool with average high temperatures of 3°C and lows of −2 to 0°C. The annual precipitation is 550 mm. Snowfall mainly occurs from December through March. The rivers in the study area flow in south-north direction and they emptie into the Danube. Theirs freshet is in the late spring, because of the melting snow in Balkan Mountains. Rivers flowing through Pleven district are Iskar, Vit and Osam. The main soil types in the area are Chernozems, Gray Luvisols and Fluvisols. The natural vegetation is almost entirely destroyed and replaced by crops. Steppe vegetation and broadleaf forests of *Quercus cerris, Quercus frainetto*, *Quercus robur*, *Quercus virgiliana*, *Carpinus betulus* and *Tilia* are preserved in some patches. The population of the district is 269 752 inhabitants according to the 2011 Bulgarian Census. There are 123 setlements in the districts including 114 villages and 9 towns. The district’s capital Pleven is the biggest settlement with 122149 inhabitants.

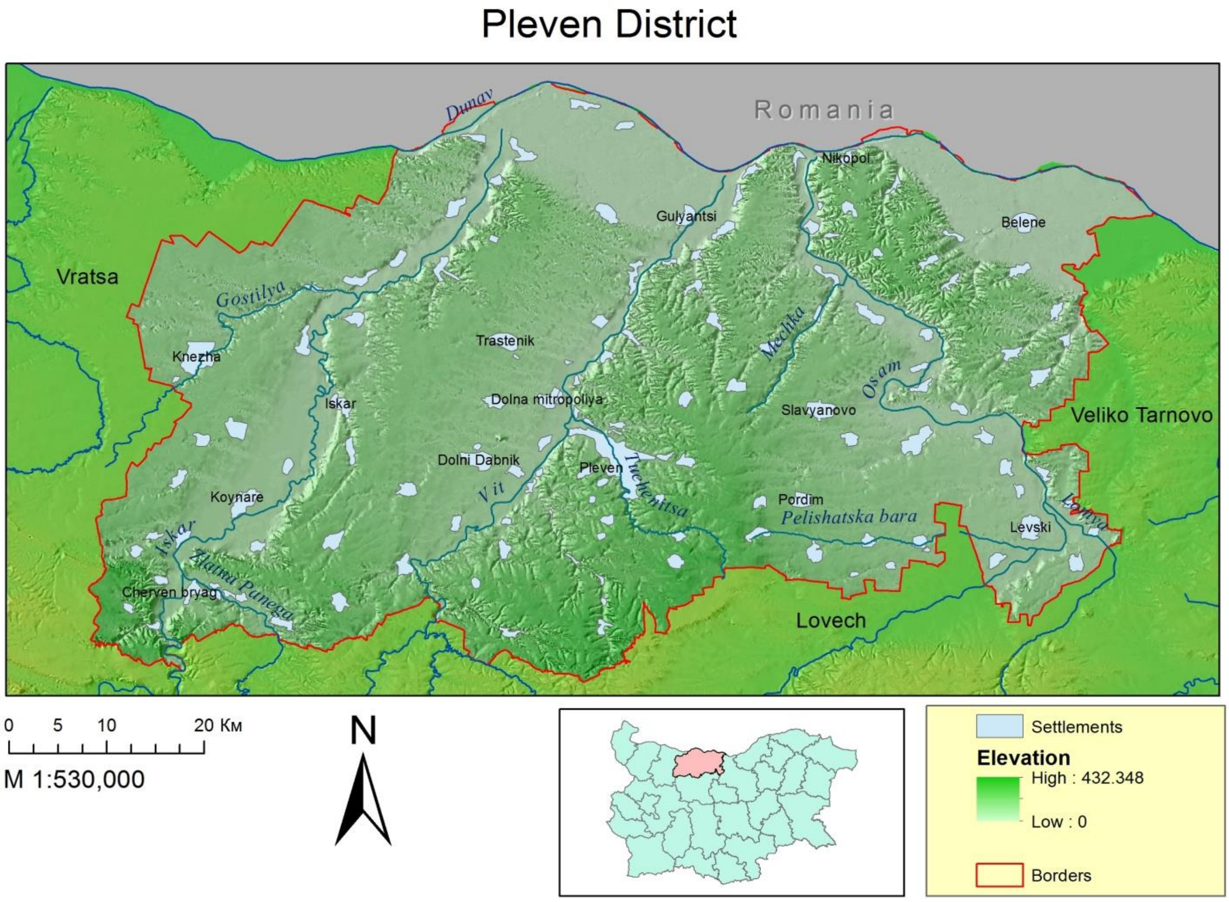

Figure 1. Case study area Pleven District

2.2 Identification of urban ecosystems and delineation of green infrastructure

Identification of ecosystems requires use of a proper typology, such as the one proposed by MAES. These main classes of this typology are designed for consistent assessments of state and services from local to regional, national and European scale. Information from a more detailed classification at higher spatial resolution could be combined with the European-wide classification and could be aggregated in a consistent manner (Maes, 2013). The MAES typology is organized in two main levels and its structure enables applying CORINE Land Cover (CLC) data for spatial delineation. It is also adjusted with the European Nature Information System (EUNIS) habitat types where necessary in order to ensure that further subdivision in the countries would be performed in a uniform and compatible manner. Subdivision for the urban ecosystems at third level in Bulgaria is proposed by a team of experts who developed a methodology for urban ecosystems mapping and assessment (Zhiyanski et al., 2015b). It consists of 10 classes which are defined in accordance with corresponds to the National concept for spatial development for the period 2013 – 2025 and EUNIS habitat at classification (table 1). This typology has to ensure appropriate classification framework to facilitate the mapping of urban ecosystems at national level. Level 3 is included in the national classification, indicating the sub-type of urban ecosystem type. Each ecosystem at level 3 corresponds to particular classes from EUNIS classification which ensures easy transfer of data for different purposes. For instance, J1 (residential and public areas of cities and towns) correspond to J1.1, J1.2, J1.3, J1.5, J1.6, X24 and X25 from EUNIS classification.

Table 1. Typology of urban ecosystems in Bulgaria (Zhiyanski et al. 2015b)

Level 1	Terrestrial
Level 2 (Type)	Urban
Level 3 (subtype)	J1. Residential and public areas of cities and towns
	J2. Sub-urban areas
	J3. Residential and public low density areas
	J4. Recreation area outside cities and towns
	J5. Urban green areas (incl. sport and leisure facilities)
	J6. Industrial sites (incl. commercial sites)
	J7. Transport networks and other constructed hard surfaced sites
	J8. Extractive industrial sites (incl. active underground mines and active opencast mineral extraction sites, and quarries)
	J9. Waste deposits
	J10. Highly artificial man made waters and associated structures

The delineation of urban ecosystems in the study area was performed in two steps. Firstly, the extend of urban ecosystems, which correspond to level 2 of the typology, was outlined and then the resulting polygons were divided into ecosystems from more detailed classification at level 3. This process necessitates detailed spatial data which is not available as one single database; therefore different data sources were used. The Restored Property Plan database was used as a main source for delineation of ecosystems at level 2. The Digital Cadastre of the settlements in Bulgaria is the most useful spatial data source but it is available only for some big cities. We used it as a complementary data for validation and update. For the differentiation of urban ecosystems into level 3 classes we developed flexible spatial approach that uses multiple data sources and incorporates several GIS tools and analyses. The outline of each ecosystem class requires specific data therefore it necessitates unique set or procedures incorporated in a common spatial analyses scheme. ArcGIS software was used as a main platform for the implementation of the approach. For urban ecosystems in the cities with available digital cadastre they were delineated using the information for land usage. The polygons were classified into ecosystems at level 3 and then they were aggregated in order to meet the requirement of 0.25 ha of the minimum mapping unit using specific algorithm of GIS procedures. The cities and villages without digital cadastre were mapped using Restored Property Plan database and Digital orthophoto map of Bulgaria as a complementary source.

The best approach to identify and map green infrastructure is by using actual remote sensing data. Green infrastructure is easily identified by visual interpretation but for larger and complex areas it is necessary to apply automatic techniques for mapping. The most convenient method is through extraction of NDVI index (Rouse et al., 1973). This approach necessitates choice of satellite image with high resolution taken in the summer when there is enough and clearly distinguished growing vegetation. The higher resolution ensures more precise outline of the mapped green infrastructure.

WorldView-2 satellite image taken on 17 July 2011 was chosen for mapping of green infrastructure in Pleven region. There were newer images but they had not so clear view because or clouds or have been taken during another part of the year. The WorldView-2 sensor has a high resolution panchromatic band (with 0.5 m or better spatial resolution) and eight multispectral bands (2 m spatial resolution). NDVI requires red and bear infrared bands therefore only four spectral bands (from eight) were ordered – Blue (450 - 510 nm), Green (510 - 580 nm), Red (630 -690 nm) and Near-IR1 (770 - 895 nm). The image is ordered as Ortho-Ready Standard (UTM, zone 35), bundle 4 bands, with 16 bit depth and has 43 sq. km area. For image fusion of spectral and panchromatic bands subtractive pan-sharpening is applied. That pan-sharpened image is used for ground control points (GCP) recognition. Total number of GCP is 22. Their coordinates are derived from eight sheets (E4-171, E4-172, E4-186, E4-187, E4-188, E4-201, E4-202 and E4-203) of National orthophoto map (2011). Both spectral bands and panchromatic band are orthorectified with the same 22 GCP and 30 m DEM. RMSE of spectral bands is 0.7 pixels, therefore the accuracy is appropriate for the purposes of this study.

NDVI index was calculated using the third and fourth bands of the orthorectified image. A value of 0.43 of NDVI index was defined as a threshold for identification of vegetating plants. It was defined empirically through comparison between index values and clearly defined land cover classes by visual interpretation. The 2 m raster image was reclassified into two classes corresponding to green and non-green areas and converted into GIS vector layer.

2.3 Indicators for ecosystem condition and ecosystem services assessment

An ecosystem assessment needs to provide both an analysis of the natural environment by looking at the state of biodiversity and ecosystems and by evaluating the level of ecosystem services provided to people (Maes et al. 2013). The analysis of natural environment requires use of indicators to quantify the condition of an ecosystem. The indicators have to be able to: i) provide information to policy makers and the wider public on the current state and changes in the conditions of the environment; ii) assist policy makers to better understand the linkages between the causes and effects of the impact of urban ecosystems and urban policy on the environment, and help to guide their responses to changes in environmental conditions; iii) contribute to monitoring and evaluation of the effectiveness of policies in promoting sustainable management (Zhiyanski et al., 2015b). A set of indicators for assessment of urban ecosystem condition was developed including five indicator groups such as biotic diversity, abiotic heterogeneity, energy budget, matter budget, water budget. Each of them contains particular number of individual indicators with specified parameters (dimensions). Two of them, vegetation cover and spatial structure of urban areas, are the most appropriate for carbon storage assessment and mapping, therefore are included in this study.

The indicator of spatial structure of urban areas is based on the classification of local climate zones for urban temperature studies developed by Steward and Oke (2012). They define the local climate zones as "regions of uniform surface cover, structure, material, and human activity that span hundred of meters to several kilometers in horizontal scale". Each zone has specific values for geometric and surface cover properties which could be used for calculation of local climate characteristics but also for ecological parameters, therefore these zones could be used in the assessment of ecosystem condition in urban areas. The classification scheme of local climate zones consists of two main parts: built type and land cover type. There are 10 built types indicated by number from 1 to 10 and seven land cover types indicated by capital letters from A to G (table 2). There are also four variable land properties, which are not used in our study because the temporal changes in ecosystem's condition were not assessed. The definitions of some built types were adapted to national specifics. Further analysis of the ecosystems data revealed that within single polygon there are usually several land cover types and sometimes more than one built type. Division of the polygons at this stage of the study was not recommended therefore it was developed an integrated index for spatial structure in urban areas which integrates built types and land cover types merged within each ecosystem subtype. For the identification of the built type within a polygon we used an approach of dominance which means that the type predominant area will define the index of the polygon. Some ecosystem subtypes such as green urban areas (J5) or artificial water bodies (J10) have no buildings therefore we added complementary built type 11 (no buildings) which corresponds to areas without buildings. For land cover types we applied different approach by combination of the existing types within a polygon. For instance, the residential area with scattered trees (type B), grasslands (type D) and paved areas (type E) is defined as BDE. This combination is added to the ecosystem subtype and built type to for the integrated index of spatial structure. For instance, J15BE means residential and public areas of cities and towns (J1), open arrangement of midrise buildings (5), scattered trees (B) and paved areas (E). The identification of the index was performed using visual interpretation of ortophoto maps of Pleven region.

Table 2. Classification scheme of spatial structure of urban areas (after Steward and Oke, 2012)

Built types	**Land cover types**
1. Compact high rise	A. Dense trees
2. Compact midrise.	B. Scattered trees
3. Compact low-rise.	C. Bush, scrub
4. Open high-rise	D. Low plants (grasslands)
5. Open midrise	E. Bare rock or paved
6. Open low-rise	F. Bare soil or sand
7. Lightweight low- rise	G. Water
8. Large low-rise	.
9. Sparsely built	
10. Heavy industry	
11. No buildings	

The vegetation cover of urban ecosystem is measured as the percentage of the total area for particular ecosystem subtype (Zhiyanskiy et al., 2015b). This is very important indicator because it reveals the role of the green infrastructure which is the main source of ecosystem services in urban areas. The identification and mapping of green infrastructure based on satellite images is the most convenient method (see 2.2) but it is expensive and time consuming hence not applicable at national scale. Therefore we decided to combine the results for green infrastructure in Pleven extracted from satellite image with the integrated index of spatial structure in urban areas. A representative number of polygons from each subtype were selected and spatial overlay procedure was performed in order to define the vegetation cover in each polygon. The results of this procedure were analyzed and the average percentages for the polygons with the same integrated index of spatial structure were calculated.

The second MAES report (2014) proposesd common indicators that can be used in European countries for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to map and assess biodiversity, ecosystem condition and ecosystem services according to the Common International Classification (CICES v4.3). Following these recommendations, Zhiyanski et al. (2015b) proposed "Carbon storage" as a key indicator for "Global climate regulation by reduction of greenhouse gas concentrations" services which is part of "Atmospheric composition and climate regulation" group. The indicator is measured by parameter of total organic matter matter storage (C; tC/ha).

The main natural carbon sinks are soil and tree vegetation. Carbon stock in soils is estimated for upper 30 cm of soils, using the information for soil types and information about the mean carbon content, bulk density and content of coarse fractions considering the anthropogenic pressure and formation of Anthrosols and modified natural soils in the selected region. Sources of information for the reference values of the contents of organic carbon are Koinov et al. (1998) for natural soils and Zhiyanski et al. (2013, 2015a) for urban soils. Further verification of soil carbon stock was carried out in 12 sites covering the main sub-types of urban ecosystems in the case study area (Grozeva, Nedkov – private archive, 2016). The measurements of the soil's parameters were made for three soil layers (0-10, 10-20 cm and 20-30 cm). The content of organic carbon is presented in percentage. In order to estimate the organic carbon stock (tC/ha), real data on bulk density is analyzed via volumetric method. Then the total organic matter stock in soils for Pleven is calculated as follow:

Organic matter stock (C) (t/ha) = C x H x Q x K (1)
where:
C - carbon content (%)
H – thickness of the soil layer (cm)
Q – bulk density (g/cm3)
К = (100 – Ck)/100 (%) correction coefficient considering skeletal fraction Ck

Then the values obtained have been grouped by sub-type of urban ecosystem and an average value for carbon stock in 0-30 cm of soil in different soil types has been derived. Therefore, the reference soil organic carbon stock in urban soil has been derived as a weighted mean from the averages SOCs of every particular soil types which are presented in Pleven region (Table 3). The procedure to derive the reference carbon stock in urban soils in Pleven, which has the value of 58.19 tC/ha (0-30 cm) is presented in table 3.

Table 3. Mean soil organic carbon (SOC) stock in Pleven region

Statistics for SOC stock 0-30 (tC/ha)	**values**
Trials	30
Min	14.5
Median	35
Mean	**58.19**
Max	170.49
Std. Dev.	42.80
Skewness	0.81
Kurtosis	-0.018

The estimation of aboveground biomass and the content of carbon are obtained using the GIS data of the integrated index of spatial structure, vegetation cover and average carbon content in the vegetation types (tree, shrub, grass) derived from different sources. The carbon stock in aboveground tree biomass from urban forest parks (J5) is based on the calculations of Zhiyanski et al. (2015a) which is defined as 36,5 tC/ha. According to the reference values the carbon stock in forest floor, which is presented in dense urban forest parks (J5) is considered as 4.55 tC/ha (Zhiyanski et al., 2015a), which value is calculated together with the value for mineral soil for all sub-types referred to J5. Thus the carbon storage in the urban forest parks (land cover class A) was assumed as 41 tC/ha (C stock in trees and forest floor). The carbon in the scattered urban trees class (B) was estimated using the calculation of Nowak et al. (2002) which is defined as 25 tC/ha. The carbon stock in bush and shrub biomass is estimated at 4.5 tC/ha while these land covers are considered as other land and often are abandoned lands within the territory of urban subtype. The carbon stock in urban grasslands based on field measurements is estimated at 2 tC/ha (Zhiyanski et al. 2013).

2.4 Mapping of ecosystem services in GIS environment

Based on the spatial units of the ecosystem subtypes identified from the existing sources of spatial data (see section 2.2) and the integrated index of spatial structure in urban ecosystems the values of the carbon storage supply were derived and maps representing their spatial distribution were produced. The values of carbon storage were assigned to every unit in their databases. GIS map layers, containing information about the carbon storage in the soil and ground biomass for every polygon, were created. The map of carbon storage was elaborated by overlaying the GIS map layers of the soil and ground biomass content of carbon. The carbon storage values were classified in five intervals using equal interval statistic method and the polygons were visualized using color scheme from light to dark green that corresponds to the scheme used in previous mapping studies (Burkhard et. al 2012; Nedkov et al. 2012; Boyanova et al. 2014). The polygons with zero value were separated as sixth class which corresponds to no capacity supply from the “matrix scheme” proposed by Burkhard et al. (2009; 2012). Thus, the maps can be easily transformed into ecosystem supply capacity maps of “Carbon storage” by urban ecosystems, which correspond to ES “Climate regulation by reduction of GHGs” for case-study area of Pleven and applied at national level.

3. Results

3.1 Spatial structure of the urban ecosystems in Pleven region

The urban ecosystems in Pleven region have been outlined and a GIS database has been created. The state of the ecosystems was assessed using two indicators – integrated index of spatial structure of urban areas and type of vegetation cover. The urban ecosystems in Pleven region are presented by eight ecosystem subtypes (Table 3). The residential and public low density areas (J3) cover the largest area in the region – 15622.3 ha (70.3% of the urban areas), followed by industrial sites (J6) with 3566,3 ha (16%). The urban green areas (J5) cover 1291,5 ha (5,8%) but for the city of Pleven their share is 15% which means that there is significant difference between cities and villages in the region. The city has larger urban green areas while in the villages and small towns (J3) this subtype is smaller. The residential and public areas of cities and towns (J1) covers only 702,3 ha (3,2%) and they are presented only in the regional centre – the city of Pleven. There are seven built types presented in the Pleven region. The most common is open arrangement of low-rise buildings (6) with 14978,8 ha (67%) followed by the areas of no buildings (11) with 2422,8 ha (10,8%) and open arrangement of large low-rise buildings (8) with 1950 ha (8,7%). There are 22 land cover class combinations found in the region but 80,9% of them are presented by scattered trees, low plants and paved areas (BDE). This combination is the most typical for the area but its vegetation cover varies between different ecosystems and built types. For instance, it has 35% in J1 open lo-rise, 55% in J3 open midrise, 80 % in J3 large low-rise and 95 % in J5 sparsely built. The integrated index of spatial structure comprises 55 different combinations within Pleven region (table 3). The greatest variety can be found in green urban spaces (J5) – thirteen, while in extractive industrial sites (J8) they are only four. The areas with J36BDE index have the largest extend with 14642,4 ha (65,5%). Areas with J68BDE cover 1618,3 ha (7,2%) and J39BCD cover 851 ha (3,8%). All other indexes are presented in areas that cover less than 2% of the region and 41 of them are found in areas that cover less than 1%. The vegetation cover in the urban ecosystems varies according to the built type land especially the cover type. In residential and public areas of cities and towns (J1) it varies between 0 and 55%, while in residential and public low density areas (J3) it varies between 0 and 95%. The share of vegetation cover is very low in transport network (J7) from 0 to 155 and waste deposits (J9) from 0 to 20%.Table 3. Integrated index of spatial structure of urban ecosystems and vegetation cover in Pleven region (for the meaning of indexes see table 1 and 2

Ecosystem subtype	Built type	Land cover type	Integrated index of sp. Structure	Vegetation cover	Ecosystem subtype	Built type	Land cover type	Integrated index of sp. structure	Vegetation cover
J1	4	BE	J14BE	55	J6	8	DE	J68DE	50
		BDE	J14BDE	55			E	J68E	0
	5	BDE	J15BDE	55			BD	J69BD	90
	6	BDE	J16BDE	35		9	BDE	J69BDE	80
		BCE	J16BCE	55			EBD	J610EBD	15
		BE	J16BE	35		10	BDE	J610BDE	50
		E	J16E	0			BE	J610BE	35
J3	5	BDE	J35BDE	55			CE	J6 10 CE	35
	6	E	J36E	0			DE	J610DE	35
		BDE	J36BDE	60			E	J610E	0
	9	BDE	J39BDE	80	J7	11	BDE	J711BDE	15
		BCD	J39BCD	95			BE	J711BE	10
J5	9	BDE	J5 9 BDE	95			DE	J711DE	10
		BCD	J59BCD	95			E	J711E	0
	11	A	J511A	100	J8	11	BDF	J811BDF	40
		AE	J5 11 AE	90			E	J811E	0
		AD	J511AD	100		9	BDF	J89BDF	40
		BCD	J511BCD	100			E	J89E	0
		BD	J511BD	100	J9	11	E	J911E	0
		BDE	J511BDE	90			DF	J911DF	20
		BDG	J511BDG	90			D	J911D	15
		BE	J511BE	90			EG	J911EG	0
		CD	J511CD	100			G	J911G	0
		D	J511D	100	J10	11	G	J1011G	0
		DE	J511DE	90			EG	J1011EG	0
J6	8	EBD	J68EBD	15			DG	J1011DG	10
		BDE	J68BDE	55			BDG	J1011BDG	95
		ED	J68ED	15			BDEG	J1011BDEG	90

3.2 Green infrastructure of the urban ecosystems in Pleven region

Different types of urban green areas are specific for Pleven region, where land cover type is formed by the combination of vegetation covers listed in table 2. Green infrastructure in J1, J3, J6 and J7 is mainly presented by scattered trees combined with low plants. The areas of private gardens with single orchard trees and low plants for agricultural use are widely presented in J3.

Urban walkways and transport networks J8 present combinations of paved areas surrounded by trees, bushes and low plants. Bare soil or sand is available only for J8 and J9 sub-types of urban ecosystems. Elements of blue infrastructure are observed in J10 and J9. Dense trees are distributed especially in J5. The most distributed elements of green infrastructure in case-study region are greening within the built up areas formed by scattered trees, bushes and low plants, urban parks in the central part, and urban park in the periphery of the Pleven city. Building greens is consisted mainly of balcony greening. While green roofs and walls are cited as a method to increase biodiversity in the design of new buildings, this nature-based solution is not applicable for Pleven case-study area. Tree alleys and street trees,

Hedges and residential gardens make up the biggest part of Pleven's urban agriculture sites. Commercial and institutional greening is formed by green playgrounds and school grounds. Riverbank greening is also present surrounding water bodies within the urban areas of Pleven district. Cemeteries and churchyard are located in the peri-urban areas of the urban territories. Large quantities of vegetables are produced in the private allotment and some community gardens for horticultures. Agricultural land within the territory of Pleven case-study are referred as areas with low plants and are formed by arable lands, meadows and grasslands. Shrublands are often observed in J1 and J3 urban sub-types, but also are typical for abandoned areas. Wetlands, ponds and canals are part of the blue elements in studied region. Among all elements of urban greening forests in cities can store the largest amounts of carbon (Strohbach and Haase, 2012).

3.3 Carbon storage in urban ecosystems in Pleven region

The total carbon storage in Pleven district in soils is 305 253 t. The residential and public low density areas (J3) sink 75,3% of it, followed by J6, J5, J1, J7, J10 and J9. Such distribution of carbon store by first three ecosystems subtypes corresponds very much to areas occupied by each of them in frames of Pleven district. In city of Pleven, J3 ecosystem subtype also sinks most of the total soil carbon (48%) but it is followed by J5, J1, J6, J10 and J7. The observed difference is due to better represented ecosystems from urban green areas (J5) and public areas of cities and towns (J1). In Pleven J5 cover 15% of the city territory and J1 – 3,2%, while in the district the share of J5 is only 5,8% and J1 is actually not represented.

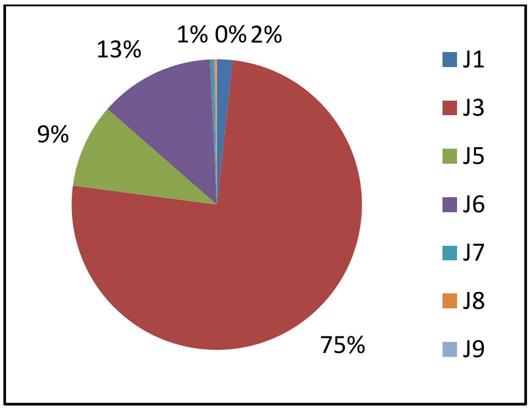

Figure 2. Distribution of carbon storage in soil in Pleven district by ecosystem subtypes

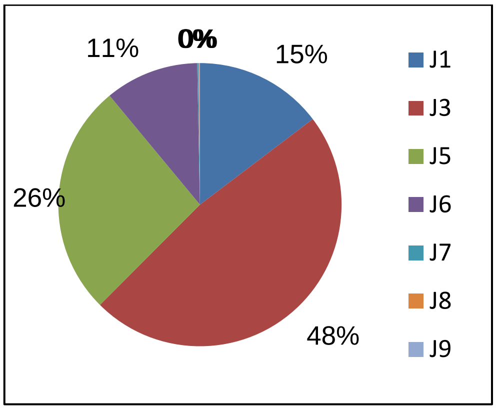

Figure 3. Distribution of carbon storage in soil in city of Pleven by ecosystem subtypes

The carbon stored in vegetation in district area is 280 490 t. Of it 94,9% is in trees, 4,5% in grass and 0,6% in shrub vegetation. The biggest share of tree carbon is stored in J3 (71,7%) followed by J6, J5, J1, J7, J8 and J10 (fig. 2). Such distribution is due again to the significant area which residential and public low density (J3), industrial sites (J6) and urban green areas (J5) cover in frames of the urbanized district territory. In city of Pleven tree carbon storage is distributed mainly between J6, J1, J3 and J5 (fig. 3). Carbon storage in shrub and grass vegetation is respectively 1603 t and 12670 t. In both district and city most of it is accumulated in J3.

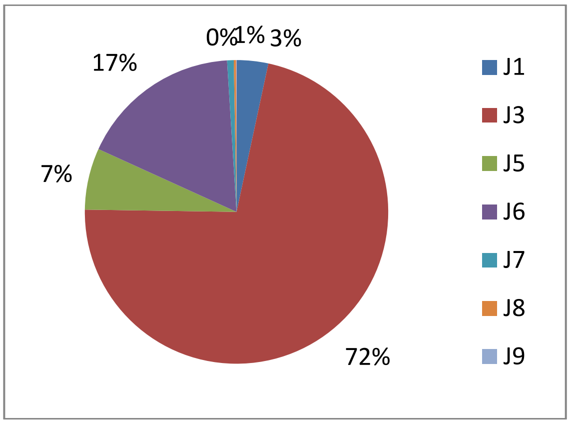

Figure 4. Distribution of carbon storage in vegetation in Pleven district by ecosystem subtypes

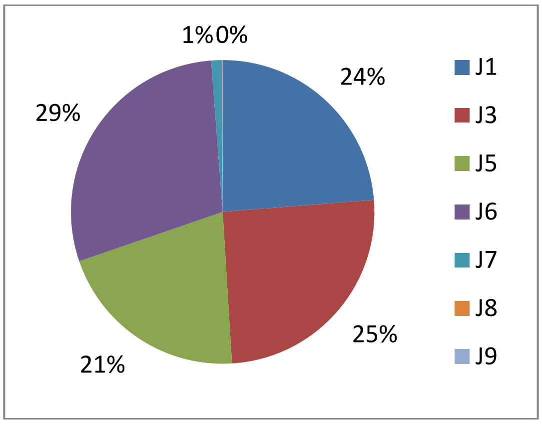

Figure 5. Distribution of carbon storage in vegetation in city of Pleven by ecosystem subtypes

Table 4. Carbon storage in the urban ecosystem in Pleven district in tC

	C soil	C trees	C schrub	C grass	C veg	C Total	C t/ha
J1	5327	9129	12	308	9449	14777	21,0
J3	229992	190972	1085	9531	201588	431580	27,6
J5	28511	16785	458	1134	18376	46888	36,4
J6	39138	46666	48	1574	48288	87426	24,5
J7	1362	1892	0	84	1976	3338	3,6
J8	557	626	0	20	646	1203	19,5
J9	112	0	0	8	8	120	3,7
J10	253	147	0	11	158	412	10,8
sum	305253	266217	1603	12670	280490	585743	

The total carbon storage in soil and vegetation in district of Pleven is estimated at 585 743 t. The highest quantity of carbon per ha is stored in ecosystems from urban green areas (J5) (36,4%), followed by J3, J6, J1, J8, J10, J9 and J7 (table 4). The similar distribution of carbon storage (t/ha) is observed between the urban ecosystems in the city of Pleven but J8 and J9 are not represented there (table 5, fig. 2). In district of Pleven in soil is stored 52,1% of total carbon storage and in vegetation respectively 48,9%. In city of Pleven the share of carbon stored in vegetation is 52,3% and its share in soils is 47,7% of totally 76 098 t stored in all represented ecosystems (Table 5). In the city the capacity of soils to store carbon is limited by the large paved areas and relatively higher density of the transport network which increase the share of vegetation carbon.

Table 5. Carbon storage in the urban ecosystem in the city of Pleven in tC

	C soil	C trees	C schrub	C grass	C veg	C Total	C t/ha
J1	5327	9129	12	308	9449	14777	21,0
J3	17355	8512	859	689	10061	27416	28,9
J5	9622	7769	138	333	8241	17862	36,2
J6	3886	11402	16	145	11563	15449	23,2
J7	55	441	0	3	444	499	3,6
J8	0	0	0	0	0	0	0
J9	0	0	0	0	0	0	0
J10	58	34	0	3	39	96	8,8
sum	36302	37287	1026	1480	39796	76098	

The Map of carbon storage in Pleven district (fig. 6) was generated using the results of carbon calculation for each polygon of urban ecosystems in the GIS database. The visualization of results is organized in six intervals in order to be coherent with the six-level relative scale proposed by Burkhard et al. (2009) for ecosystem services mapping. The intervals were defined using natural breaks method, which ensures the most appropriate statistical distribution for this particular case. The map shows that predominant part of the urban ecosystems in the district have middle level of carbon storage which corresponds to 18,8 - 24,9 and

25 - 32,3 tC/ha intervals. The areas with very low carbon storage (0 - 6,7 tC/ha) have limited extend and are not easily visible at the scale of the district’s map.

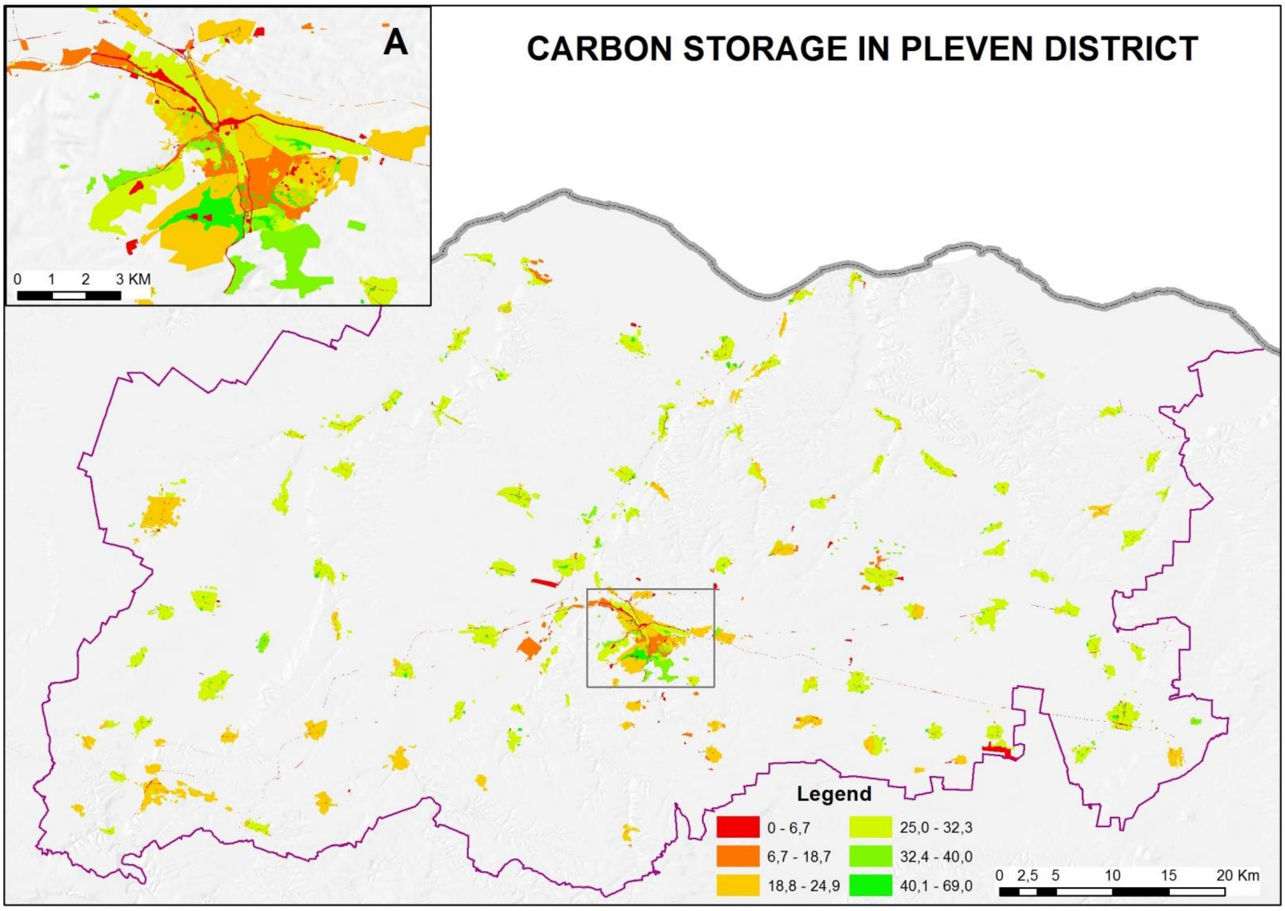

Figure 6. Carbon storage in Pleven district and the city of Pleven (A) in tC/ha

4. Conclusions

As urban condition is dependent on many factors, the combination of building type and land cover types in urban territories is informative complex indicator for assessment the state of specific subtypes of urban ecosystems.

The parameter “carbon storage” in green infrastructure applied to the complex indicator gives information about the capacity of carbon stored in ecosystems subtypes and for the role of greening in climate regulation. There has been uncertainty over the soil carbon stock in area of Pleven district due to high spatial variability, with a high variation between the least and greatest calculations. Considerable uncertainties remain in assessments of soil organic carbon storage, due to unquantified errors in soil density and rock fraction, lack of data on within-site organic carbon variability and missing or poorly quantified data for belowground biomass and environmental control parameters. Information about aboveground biomass in different vegetation cover types needs of more details. Application of remote data and in-situ measurements in different types of urban greening is recommended for obtaining more precise data for defining default data at national level. By incorporating better data for aboveground tree biomass of single trees and of forest stands in urban forest parks the uncertainties could be significantly reduced.

Despite of some limitations the approach presented in this study relies on estimations for green infrastructure distribution and carbon content in the soils and vegetation and gives an opportunity to assess the capacity of urban ecosystems to store carbon at national level using available data. The testing of the approach in the district of Pleven shows that it can provide sufficient data for carbon storage in the urban ecosystems, which can be used for elaboration ecosystem services maps and thus implement the requirement of the EU Biodiversity strategy on ecosystem mapping. As urban condition is dependent on many factors, the combination of building type and land cover types in urban territories is informative complex indicator for assessment the state of specific sub-types of urban ecosystems. The parameter “carbon storage” in green infrastructure applied to the complex indicator gives information about the capacity of carbon stored in ecosystems subtypes and for the role of greening in climate regulation at global scale by regulating greenhouse gases concentration. The share of carbon stored in urban green areas in both soil and vegetation is not dominant but their capacity to store carbon (t/ha) is utmost. The carbon storage in soil and vegetation is strongly influenced by the area covered by each urban ecosystem subtype and the presence or absence of some ecosystem subtypes in frames of a given territory. That is why the assessment has to be carried out in accordance with an analysis of the spatial infrastructure of the respective territory.

The testing of the proposed approach in Pleven district confirmed that it can provide sufficient data for carbon storage in the urban ecosystems, which can be used for elaboration of maps for ecosystem services and thus implement the requirement of the EU Biodiversity strategy.

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