MAPPING URBAN GREEN SPACES BASED ON 
REMOTE SENSING DATA: CASE STUDIES 
IN BULGARIA AND SLOVAKIA

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Abstract
Urban Green Spaces (UGS) contribute to the sustainable development of the urban ecosystem. Recently, UGS have been considered to be of substantial importance for the quality of life, since they have a significant impact on ecosystem functions, local microclimate, air quality, recreation and aesthetic perceptions. Remote sensing and geographic information system (GIS) provide powerful tools for mapping and analysis of UGS at various spatial and temporal scales. With the availability of high resolution remote sensing images and multi-source geospatial data, there is a great need to transform Earth observation data into useful information necessary for urban planning and decision making. Therefore, the current research is focused on mapping of UGS, based on remote sensing data. The present study aims to investigate and map the spatial distribution of urban green spaces in Sofia, Bulgaria and Bratislava, Slovakia using remote sensing data by implementing various spatial analysis techniques. The spatial detail of the mapping exceeds previously available land cover datasets such as CORINE Land Cover and Urban Atlas. Based on their function or morphology, fifteen different classes of UGS were mapped and quantified.

Keywords: Urban Green Spaces, Sentinel-2A, Remote Sensing, land cover, vegetation

INTRODUCTION

Urban Green Spaces (UGS) contribute to the sustainable development of the urban ecosystem and provide a range of ecological and social benefits. Recently, UGS have been considered to be of substantial importance for the quality of life, since they have a significant impact on ecosystem functions, local microclimate, air quality, noise absorption and water resources protection. At the same time, UGS are essential for maintaining and improving human well-being by contributing to recreation and aesthetic perceptions. In addition, UGS effectively support the biodiversity protection and the preservation of historic landscape features.

Vegetation of UGS plays a major role in urban environment from many aspects, e.g. mitigation of the urban heat island effect (UHI), maintaining ecological balance, protecting biodiversity, and promoting quality of life. The role of urban vegetation is becoming more important for mitigation of climate change effects on population even in the temperate climate zone. It is important to produce detailed vegetation maps to assist planners in designing strategies for the optimization of urban ecosystem services and climate change adaptation (Lovell and Taylor, 2013; Ahern et al., 2014; Lehmann et al., 2014; Niemelä, 2014; Butlin et al., 2015), and to ensure equal access to UGS for all urban residents. With the capacity to differentiate land cover (LC) types at a large scale, remote sensing has been widely used for vegetation mapping in various environments. Satellite imagery has been adopted for the monitoring of vegetation both in urban and rural areas (Nichol and Lee, 2005; Lang, 2008; Lang et al., 2008; Hofmann et al., 2011; Tigges et al. 2013; Liu et al., 2015).
Remote sensing data has also been the source of previously available ready-made European LC datasets such as CORINE Land Cover (CLC) and Urban Atlas (UA). The spatial detail of these datasets is, however, not sufficient for thorough evaluation of UGS. CLC has the minimum mapping unit of 25 ha, which can capture only the largest of urban parks and other UGS. However, many smaller patches ‘hidden’ in the urban fabric polygons are relevant too. UA data present a significant improvement, mapping patches of at least 0.25 ha. Nevertheless, in spatially fragmented urban landscape, smaller but frequently occurring patches of vegetation should be considered. The limitation of UA data is that they are updated only on six-year basis and released with delay after the reference year (UA 2012 was made public in 2015). The aim of this study is to present the spatial distribution and (mostly) functional classification of UGS in Sofia and Bratislava, based on recently available Sentinel-2A (S2A) multispectral satellite imagery, provided free of charge in the frame of European Copernicus Earth observation program. The target minimum mapping unit presents five-fold improvement compared to UA, i.e. 500 m². Moreover, given the short revisit time of Sentinel 2 (5 days in mid-latitudes once the second satellite of the mission, Sentinel-2B, is launched in 2016), the proposed method can deliver more frequent and timely information on UGS compared to UA.

STUDY AREA AND DATA

Definition of study area boundaries

As the first step of any urban comparison study, a common definition of “urban” should be specified. Such definition should be fit for the studied problem and based on the same and (more or less) objective criteria. Although the administrative definition of cities has the benefit of wide data availability, it is not suitable for most geographic studies. The principle behind the design of administrative boundaries differs from country to country and such boundaries often may (or may not) include large portions of exurban land, mostly with agricultural and (semi-) natural land cover, which makes international comparison difficult. In many socio-economic studies, spatially broader definition that includes the commuting hinterland of a city is preferred. The advantage of functional regions is that they are defined based on objective criteria, but they are not especially useful for evaluation of UGS that directly influences the well-being of city residents and intra-urban microclimatic conditions (e.g. the urban heat island phenomenon).

Therefore, we suggest that for UGS comparison a city should be defined rather by its continuously built-up area, where the concentration of people is the highest both during the daytime and nighttime, and the density of buildings and other impervious surfaces is so high, that it can alter the microclimate significantly. In the European context, the contiguous built-up area can be delineated quite easily based on open data from the Urban Atlas database, that has harmonized definition, suitable spatial detail and is updated and validated regularly. Particularly, we extracted all the artificial surfaces from Urban Atlas 2012 (code 1xxxx), excluding road and rail network (which is represented by a single extensive and complex polygon that spans the whole urban region including the commuting hinterland). Consequently, the polygons were buffered by 50 m and merged (to connect built-up blocks and join gaps in urban fabric up to 100 m wide). Holes in the resulting polygon were filled, and the result was buffered back by 50 m. This method produced quite accurate picture of the city (see Figure 1), where only minor manual editing was needed. Additionally, this definition can be applied to any EU city and can be updated on a six-year basis to account for city expansion.

The study area of Sofia city, the capital of Bulgaria, has an area of 188 km² and is located in the central part of western Bulgaria at 42°36′06″–42°45′52″N, 23°14′51″–23°26′44″E. The spatial structure of the urban territory is radial-concentric and its dynamics is mainly related to the transport infrastructure and environmental quality. The urban expansion is spatially limited by the Vitosha mountain located south-west of the city center of Sofia. The population of Sofia by the end of 2015 was 1,260,120 inhabitants. Sofia is the most urbanized area and the region with the most developed economy, concentrating more than 17% of the population and 18% of the industrial production in Bulgaria.

The Bratislava study area has an area of 109 km² and is situated in the south-west part of Slovakia bordering Austria in the west and Hungary in the south. Due to this fact and a good quality transport infrastructure, it is a territory with high potential for territorial development. The limiting factor for further expansion of the city is the Male Karpaty mountain range located North of the city center. Bratislava lies on the both banks of the Danube River, which crosses the city from the west to the south-east. The population of Bratislava by the end of 2015 was 422,453 inhabitants (7.78% of the population in Slovakia).

Input data

Apart from UA 2012 vector data we used for the delimitation of study areas, two 100% cloud-free S2A scenes acquired in 2015 (28th August for Sofia and 7th August for Bratislava) were downloaded from Copernicus Sentinels Scientific Data Hub (https://scihub.copernicus.eu/dhus/). We used orthorectified and radiometrically corrected images (processing level 1C). Since the study areas represent only a small fraction of the respective scene’s footprint, we have assumed constant atmospheric conditions and no atmospheric corrections were applied. Each scene contains 13 spectral bands
with native spatial resolutions of 10 m (blue, green, red, and near infrared bands), 20 m (red edge bands), or 60 m (short wave infrared bands); all bands were resampled to 10 m resolution for further processing. A true colour (red-green-blue) (RGB) composite of both images is displayed in Figure 1.

Since the proposed classification scheme of UGS is largely land use oriented (see the next section), it is not viable to obtain the information by automatic methods. Therefore, aerial or very high resolution satellite images were needed to perform on-screen interpretation and classification of individual UGS polygons extracted from the Sentinel data. Finer than 10 m spatial resolution imagery is useful (although not necessary) in the process of selecting the training samples for supervised automatic classification of the S2A imagery.

METHODS

Automatic land cover classification and extraction of UGS polygons

The spectral resolution and bandwidth of S2A data (13 bands ranging from 430 to 2,300 nm; Drusch et al. 2012) are superior compared to RGB or color infrared (CIR) aerial imagery and also to most of the previously available high resolution satellite data (such as SPOT). Thus we assume that S2A data has the potential to discriminate between several spectrally different LC types using automatic classification methods with reasonable accuracy. We use simple impervious-water-vegetation classification scheme; the vegetation is further divided into tree cover and non-woody classes. A supervised approach was preferred for higher accuracy – a set of manually pre-classified training was used to train the automatic classifier (around 100 samples for each study area were included). Finally, the commonly used maximum likelihood classifier was employed to perform the per-pixel classification (for results see Figure 2). The S2A data processing and classification were performed using ESA SNAP 3.0 and ESRI ArcGIS Desktop 10 software. To extract the final UGS polygons from the classified images, these were reclassified into a binary form vegetation/non-vegetation. Contiguous patches of vegetation were vectorised and further visually enhanced to remove pixelated borders. All polygons parts and holes smaller than 500 m² were removed. The geoprocessing steps are described in more detail by Rosina and Kopecka (2016).
Manual classification of UGS polygons

From the perspective of ecosystem services and urban planning it is important to consider how the identified UGS are utilized by city residents and, degree of human cultivation/intervention, and location relative to the prevalent use of urban land (residential, public, industrial). Considering these requirements, we have recognized the following 15 classes; the class definitions are presented in the study Rosina and Kopecka (2016).

1. Urban forest/Uncultivated park
2. Cultivated park
3. Cemetery
4. Urban public garden
5. Stream bank/lake shore vegetation
6. Urban greenery in apartment housing areas
7. Urban greenery in family housing areas
8. Urban greenery in public facilities
9. Greenery in sports facilities
10. Complex cultivation pattern
11. Cropland/pastures
12. Railway and roadside greenery
13. Green areas in industrial units
14. Airport greenery
15. Ruderal vegetation

UGS polygons extracted in the previous step were overlaid on top of recent aerial orthophotos and visually classified at the scale range 1:10,000 – 1:5,000. Most of the polygons were classified as such by filling the attribute values. In some cases (especially in places with abundant vegetation), the extracted polygons were spanning over larger areas and included multiple UGS classes. In such cases, the polygons were cut so that each polygon contains a single UGS class.
For instance in Bratislava study area, we initially extracted 2,200 polygons which we further split into about 2,900 more homogeneous UGS polygons. As an additional information, useful for decision making is the type of vegetation. We suggest that tree vegetation provides a wider range of ecosystem services compared to the herbaceous one. We have therefore estimated the share of tree cover for each polygon and UGS class (based on the initial automatic LC classification) as shown in Tables 1 and 2.

RESULTS AND DISCUSSION

The analysis of UGS distribution pattern allows comparing urban greenery in Bratislava and Sofia at several criteria. Quantitative and qualitative estimation of UGS is based on the total area and the proportion of different UGS classes. Taking into account the ecological benefits of different vegetation types, special attention was drawn to the area and percentage of tree vegetation as it has the most important functions to improve the urban environment, including microclimate, air quality, noise reduction, biodiversity and recreation.

Bratislava study area

According to the results of initial land cover classification, impervious surfaces covered 51.6% of the territory, urban vegetation covered 46.5% (out of which trees covered around 54%), and water covered 1.9%.

Map of urban greenery presented in Figure 3 provides information about the spatial distribution of the UGS classes within the city. The largest part was covered by class Urban greenery in family housing areas (7) with an area over 1,000 ha, in total more than 20% of the urban greenery. UGS defined as Urban greenery in apartment housing areas (class 6) covered the second largest area almost 680 ha, i.e. 13.2% of UGS. However, this class was represented by the highest number of patches (823 out of total number 2,909 UGS polygons). On the other hand, the class Urban public garden (4) covered the smallest part of green areas within the city.

Table 1 presents the statistical characteristics of UGS classes and provides insight into the tree cover percentage for each class. The highest proportions of woody vegetation was detected in class Urban forest/Uncultivated park (1) and Cemeteries (3). The lowest share of woody vegetation was found in the class 14 – Airport greenery (0.5%)

<table>
<thead>
<tr>
<th>UGS Class</th>
<th>Polygon count</th>
<th>Class area (ha)</th>
<th>Tree cover area (ha)</th>
<th>Tree cover percentage (%)</th>
<th>Class abundance (%)</th>
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<td>UGS total</td>
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<td>5127.35</td>
<td>2728.52</td>
<td>53.2</td>
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</tr>
</tbody>
</table>
Figure 3. Result of UGS mapping for Bratislava study area (map legend presents UGS class in Table 1)

Sofia study area

According to the results of initial land cover classification, impervious surfaces covered 51.4% of the territory, urban vegetation covered 48.6% (out of which trees covered around 26%), and water covered only 0.1%.

Map of urban greenery presented in Figure 4 provides information about the spatial distribution of the UGS classes within the city. The largest part was covered by class Urban greenery in family housing areas (7) with an area over 2,400 ha, in total almost than 27% of the urban greenery. UGS defined as Urban greenery in apartment housing areas (class 6) covered the second largest area almost 680 ha, i.e. 19.1% of UGS but, similarly to Bratislava, it was represented by the highest number of patches (2,114 out of total number 5,715 UGS polygons). In contrast, the least
abundant classes were Cropland/Pastures (11) and Stream bank/lake shore vegetation (5) which accounted for 0.4% and 1.4% of the UGS, respectively.

Figure 4. Result of UGS mapping for Sofia study area (map legend presents UGS class in Table 2)
Table 2 presents the statistical characteristics of UGS classes and provides insight into the tree cover percentage for each class. The highest proportions of woody vegetation were detected in class Urban forest/Uncultivated park (1) and the lowest share of woody vegetation was found in the class 14 – Airport greenery (0.5%).

Table 2. Results of UGS classification including tree cover percentage estimate for Sofia

<table>
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<tr>
<th>UGS Class</th>
<th>Polygon count</th>
<th>Class area (ha)</th>
<th>Tree cover area (ha)</th>
<th>Tree cover percentage (%)</th>
<th>Class abundance (%)</th>
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<td><strong>2390.19</strong></td>
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</table>

Comparison of Bratislava and Sofia

Interestingly, both study areas have almost the same proportion of impervious surface (over 51%). Sofia has slightly larger share of UGS than Bratislava (49% and 47% respectively), but the latter city has much larger share of water bodies. The most striking difference between the cities at the level of the initial LC classification is the overall proportion of tree cover, which in Bratislava is double compared to Sofia.

At the level of the UGS classification, the major difference is the scarcity of the class Cropland/Pastures (11) in Sofia. On the other hand, it has much larger proportion of the class Ruderal vegetation (15) than Bratislava. Sofia has also significantly higher share of UGS in residential areas (both family and apartment housing areas – classes 6 and 7), but lower share of other classes, e.g. Greenery in sports facilities (9), Urban greenery in public facilities (8), and Complex cultivation pattern (10).

CONCLUSION

Using the available high resolution remote sensing images researchers can transform Earth observation data into useful information necessary for urban planning and decision making. The mapping method applied in this study is well suited to provide reliable geoinformation based on satellite images and to produce high resolution maps of UGS in urban territories. Quantifying the UGS using remote sensing data proves to be key in the transfer of scientific knowledge to the urban environmental monitoring and management.

The presented case study showed the possibilities of semi-automatic extraction of UGS classes from Sentinel-2A data and proposed a 15-class classification scheme which was sufficient to characterize all UGS in both studied cities. Our method enables a comprehensive comparison of UGS in Bratislava and Sofia. The thematic accuracy of supervised automatic LC classification seemed good from visual assessment, although a systematic validation should be performed as a part of future research. Other methods not studied here might prove more accurate, such as sub-pixel classification, neural networks, multitemporal (using data acquired during multiple phenological phases), or multisensoral approach (e.g. a combination with Sentinel-1 synthetic aperture radar data). Also, using data from Landsat 8 thermal bands to estimate the surface temperature of various UGS classes under varying seasonal/weather conditions would be an exciting direction for future research in the context of ecosystem services of UGS.

There is considerable scope for further development of the presented comparative study of UGS in Bratislava and Sofia, such as improving the proposed nomenclature for UGS types and extending mapping applications for assessment of interconnection of green spaces, temporal changes of UGS spatial arrangement, distribution of different vegetation types, etc. in order to improve the practical applicability of output data and maps.
ACKNOWLEDGEMENT

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https://scihub.copernicus.eu/dhus/
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Monika Kopecká, Ph.D., a senior research scientist at the Institute of Geography, Slovak Academy of Sciences. Her research is focused on land use and land cover mapping, landscape changes, and landscape indicators. She participated in several projects related to spatial analysis and assessment of landscape structure. Currently, her research activities are oriented to monitoring of urban landscape dynamics and agricultural landscape abandonment.

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