MAPPING OF URBAN GREEN SPACES USING SENTINEL-2A DATA: METHODICAL ASPECTS

Konštantín Rosina, Monika Kopecká

Mgr. Konštatín Rosina, PhD., RNDr. Monika Kopecká, PhD., Institute of Geography, Slovak Academy of Sciences, Štefánikova 49, 814 73 Bratislava, tel. +421 2 57 510 218,
e-mail: monika.kopecka@savba.sk, konstantin.rosina@gmail.com;

Abstract
Urban green spaces (UGS) such as parks, forests, green roofs, streams, and community gardens provide a broad range of ecosystem services (urban heat mitigation, stormwater infiltration, food security, physical recreation, and psychological well-being of residents). Proper evaluation and inter-city comparison of UGS, therefore, requires not only information on its relative quantity, but also a closer examination of UGS in terms of quality and related ecosystem services, which can be derived from its land cover composition and spatial structure. Here we present an approach to UGS extraction from newly available Sentinel-2A satellite imagery, provided in the frame of European Copernicus program. The multispectral imagery includes 13 spectral bands (from visible, through near-infrared to short wave infrared bands) with high spatial resolution (from 10 m to 60 m) and frequent revisit time (currently around ten days). Supervised maximum likelihood classification was used to identify UGS polygons. For the purpose of their classification the nomenclature was defined, and each UGS polygon was assigned to one of the 15 classes. To assess which ecosystem services may be linked to the identified UGS patches, each class is further described by the proportion of tree canopy. Aerial orthophotos are used along the classified Sentinel images to support this goal.

Keywords*: Urban green spaces, Sentinel-2A, classification, land cover, remote sensing*

INTRODUCTION

The diversity and quality of urban green spaces (UGS) such as parks, forests, green roofs, streams, and community gardens are tightly linked to human well-being as UGS provide a number of benefits (ecosystem services) for people. The crucial ecosystem service of urban vegetation is its regulatory effect on the urban micro-climate (Lehman et al. 2014), other relevant benefits are stormwater infiltration, food security, physical recreation, and psychological well-being of residents (Wolch et al. 2014, Tzoulas et al., 2007, Niemelä 2014).

By definition, ecosystem services have societal relevance: they provide benefits that humans want or need. These desired outcomes (improving air quality, decrease the volume of stormwater runoff, air temperature regulation, etc.) must be identified and compared to the current potential of the UGS. Knowing the current potential (quantity, quality, and spatial distribution of UGS) is therefore a vital a first step in planning and realization of improved urban greenery designs.

Urban vegetation is significantly different from (semi-)natural vegetation because of intense human impact. For instance, compared with forests, urban vegetation cover is much more divided and fragmented by impervious land cover, exposed to polluted air, and specific microclimate (the urban heat island phenomenon – UHI). Vegetation within densely built-up areas is vulnerable and often relies on human maintenance, irrigation, and fertilization. The impervious-vegetated mix is heterogeneous at much finer spatial scale in urban landscape than elsewhere. This poses a challenge also for classification of urban land cover using medium resolution satellite imagery, such as the widely used Landsat TM/ETM and SPOT imagery (Nichol and Lee 2005). The heterogeneity demonstrates itself in a higher proportion of so-called mixed pixels (compared to rural landscape) when sensed at 20 m – 30 m spatial resolution.

As a result, for a long time, conventional methods of mapping urban vegetation have relied on a visual interpretation of analog aerial images and fieldwork. Later on, digital RGB or CIR (color infrared) aerial imagery with high spatial resolution has been employed. The drawback of such data sources is that they have inferior spectral bandwidth and resolution compared to multispectral satellite data, which limits the feasibility of automatic classification methods. Also, the temporal frequency of aerial remote sensing is in practice lower due to high cost.

More recently developed very high resolution (VHR) satellite remote sensing systems (IKONOS, QuickBird, GeoEye, RapidEye, WorldView, Pleiades) are capable of providing imagery with similar detail to aerial photography and they offer opportunities to overcome the lack of reliable and reproducible information on urban vegetation across large areas. Chengqi et al. (2003) have studied the application of IKONOS images in Xiamen City on urban vegetation cover and discussed the difference between VHR images and traditional classification of coarser spatial resolution images. Nichol and Lee (2005) have used multispectral IKONOS images to quantify urban vegetation using two parameters: vegetation cover and vegetation density. Tigges et al. (2013) have investigated different spectral and temporal band combinations of five RapidEye images acquired during the phenological season and proposed tree genera classification in an urban environment. The drawback of VHR satellites is their narrow swath and therefore limited coverage of the Earth's surface. The VHR satellites are commercially oriented services, i.e. the acquisitions are based on demand, and the cost is relatively high. The latest technology available for UGS mapping is unmanned aerial vehicles (UAVs) capable of mapping at ultra-high spatial resolution due to the low altitude acquisition (Feng et al. 2015) as well as constellations of small satellites (CubeSats) such as the one owned by Planet Lab company.

Monitoring of UGS by European Copernicus services

Pan-European harmonized land cover/land use databases derived from satellite images also provides information about UGS spatial structure. Alavipanah et al. (2015) analyzed the role of vegetation in mitigating urban land surface temperatures based on data derived from CORINE Land Cover database. Another data source for urban greenery assessment provides Urban Atlas – a database based on satellite images with a 2.5 m spatial resolution. Comparable land use data are available for all of the European core cities and respective larger urban zones with more than 100,000 inhabitants. For example, Cvejic et al. (2015) have calculated the total amount of the land use classes per city and the per capita values of green spaces provision on city level using Urban Atlas data and population data. However, Niemela (2014) underlined the importance of developing new tools to detect and measure green infrastructure.

To study the impact of green infrastructure on biodiversity and UHI mitigation, current information about the quantities, qualities, and configuration of UGS are needed. The most recent data on land cover, including urban green spaces, are available from Sentinel-2A (S2A), a high-resolution optical Earth observation mission developed within the Copernicus program (previously called GMES). The program is a joint initiative of European Commission and European Space Agency to establish a European capacity for the provisioning and use of information for environmental monitoring and security applications. Fletcher (2012) provides an overview of this mission, including the technical concept, image quality, and operational applications. S2A multispectral imager is covering 13 spectral bands with a swath width of 290 km and spatial resolutions of 10 m (three visible and a near-infrared band), 20 m (6 red-edge/shortwave infrared bands) and 60 m (3 atmospheric correction bands). The mission is intended to monitor variability in land surface conditions, and its wide swath width and high revisit time (10 days with one satellite and five days with two satellites after Sentinel-2B is launched in 2016) will support monitoring of changes to vegetation within the growing season. It also provides data and applications for operational land monitoring, emergency response, and security services. The coverage limits are from between latitudes 56° south and 84° north. According to Drush et al. (2012), the mission objective is to provide systematic multispectral imaging for:

- land cover, land use, and land-use change detection maps
- maps of biogeophysical variables such as leaf chlorophyll content, leaf water content, leaf area index (LAI)
- risk mapping
- acquisition and rapid delivery of images to support disaster relief efforts.

The objective of this contribution is to explore the potential of S2A satellite imagery for UGS mapping at the city level and to illustrate a procedure of UGS extraction and classification. UGS mapping can be defined as the identification of land cover types over urban vegetated areas. Each type of land use is linked to specific patterns of built-up and greenery or other natural surfaces (e.g.,. water) which can be defined by their size, location, and structure. Lehman et al. (2014) recognized 13 main categories of urban vegetation structure types (UVST) that were divided into 57 subcategories by considering the structural parameters of building and greenery. Ahern et al. (2014) presented a set of indicators and metrics that have been used to assess ecosystem services in urban settings. The UGS classification presented in this contribution is based on land use context since linking urban greenery physical structure and its function is crucial for further identification of the urban ecosystem services.

DATA AND METHODS

Input data

S2A data are available from mid-2015 from the Copernicus Sentinels Scientific Data Hub (scihub.copernicus.eu/dhus). The highest processing level available for download is 1C – radiometrically corrected and orthorectified images. For further processing, all 13 contained spectral bands should be resampled to the highest of the resolutions (10 m), which is native only for blue, green, red, and one of near-infrared bands). A true color (red-green-blue) composite from S2A data is displayed in Figure 2a.

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 (VHR) satellite images are needed to perform on-screen interpretation and classification of individual UGS polygons extracted from the S2A 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 (see the following sections).

Methods

Automatic land cover classification

Given the spectral resolution and bandwidth of S2A data, we assume that it has the potential to discriminate between a small number of spectrally different LC types using automatic classification methods with reasonable accuracy. We suggest a simple impervious-water-vegetation classification scheme; the vegetation is further divided into tree cover and non-woody classes. A supervised approach is preferred for higher accuracy – a set of manually pre-classified training is used to train the automatic classifier. A sufficient number of sample plots located evenly in the study area should be created for each of the land cover classes. Finally, the commonly used maximum likelihood classifier is employed to perform the per-pixel classification (see the visual scheme of employed data sources and methods in Figure 1). The S2A data processing and classification were performed using ESA SNAP 3.0 and ESRI ArcGIS Desktop 10 software. For the results of the initial classification, see Figure 2b.

UGS polygons extraction from the classified data

To extract the final UGS polygons from the classified images, these were reclassified into a binary form vegetation/non-vegetation. Contiguous pixels classified as vegetation were grouped (based on queen neighborhood – each pixel can have maximum eight neighbors) and converted to vector polygons (Figure 2c). All polygon parts and holes smaller than 500 m^2 were removed. The remaining polygons were smoothed and generalized in order to remove pixelated borders, reduce size, and improve the visual appearance (see Figure 2d).

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 list below. 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 (see Figure 2e).

The definitions of UGS classes

1. **Urban forest/Uncultivated park** – Ares characterized by more than 50% woody vegetation with no signs of cultivation and without paved roads/paths.
2. **Cultivated park –** Areas characterized by more than 50% woody vegetation with paved paths and scattered lawns.
3. **Cemetery –** Areas of cemeteries with dominant vegetation.
4. **Urban public garden –** Areas characterized by the regular shape of lawns, flowerbeds, shrubs, paths and scattered trees.
5. **Stream bank/lake shore vegetation –** Green areas adjacent to ponds, lakes, rivers, or canals.
6. **Urban greenery in apartment housing areas –** Public greenery in residential zones between multi-flat houses and/or small commercial buildings.
7. **Urban greenery in family housing areas –** Greenery in residential zones between family houses, mostly comprising private horticultural gardens.
8. **Urban greenery in public facilities –** Greenery in compact areas with particular public services, like hospitals, universities, school campus, ZOO etc. Sports facilities are not included in this class.
9. **Greenery in sports facilities –** Green areas used for sports and leisure mainly covered by grass, such as football field, golf course, playground, and horse race circuit.

10. **Complex cultivation pattern –** Area with small parcels of annual crops, pastures, fallow land and/or permanent crops, with scattered garden cottages.
11. **Cropland/pastures –** Agricultural areas with signs of cultivation (e.g., tracks from plowing or tractor use). This class contains both cropped areas and areas with grass in rotation, as well as orchards and vineyards.
12. **Railway and roadside greenery –** verge with grass or other vegetation accompanying a railway, road, or motorway.
13. **Green areas in industrial units –** areas covered by vegetation in factories with industrial production, storage facilities, logistic centers, etc.
14. **Airport greenery –** Grass areas of airports associated to runways.
15. **Ruderal vegetation** – Areas with grass, herbaceous, shrub and/or scattered woody vegetation with no signs of recent cultivation. Usually heterogeneous in texture and color. Fallow land and brownfields can also be part of this class.

Tree cover fraction extraction

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 (Figure 2f) and UGS class (based on the initial automatic LC classification).

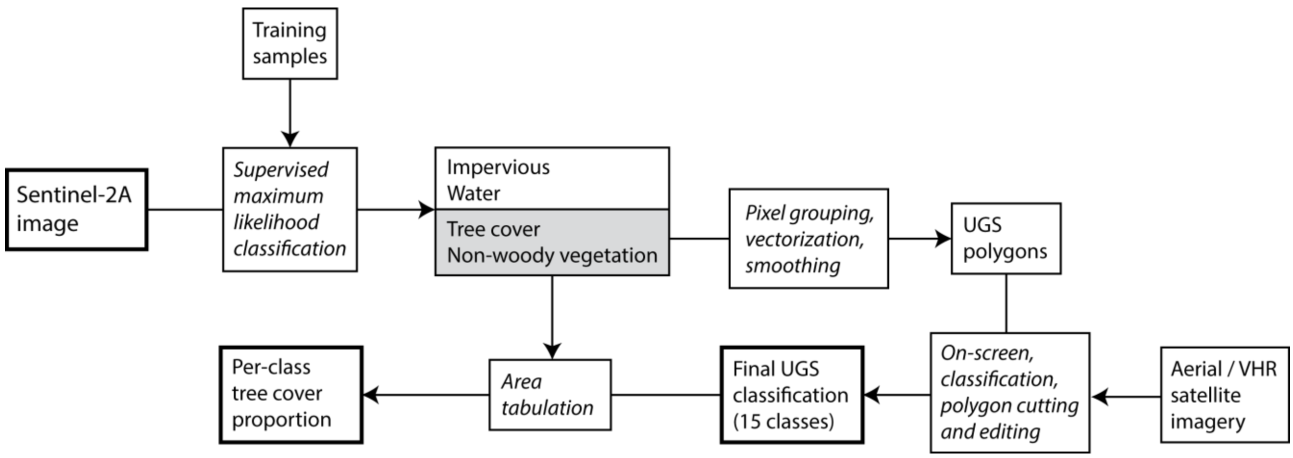


Figure 1. Scheme of the proposed methodology

RESULTS

From visual inspection of the results and comparison with VHR imagery, the overall quality of UGS extraction seems to be satisfactory. Nevertheless, in comparison studies also quantitative accuracy assessment (validation) should be performed to ensure that the results are fully comparable. In particular, the distinction between tree and non-woody vegetation may be subject to commission and omission errors. The distinction is rather of continuous than binary nature since there are many tree, shrub, and other plant species of various ages and phenological phases. The amount of trees can also be biased by the number, location, and selection of training samples. Also, the morpohology of the urban fabric may affect the results. In data derived from remote sensing, the classes that are dominant in a particular area tend to be overestimated and vice versa (Hurbanek et al. 2010). This effect is caused by cross-pixel spectral contamination (backscattered radiation from adjacent pixels influences the spectral response of a given pixel). Thus, cities with more fragmented UGS can be underestimated. With increasing fragmentation and heterogeneity of urban landscape, the amount of mixed pixels increases (when 10 or 20 m pixels are considered), and the accuracy of classification decreases. Five-meter resolution satellite data would be perhaps more suitable for UGS mapping. However, the wide swath, frequent revisit, spectral richness, and free availability of S2A data makes it very worthwhile to investigate its potential for UGS mapping further.

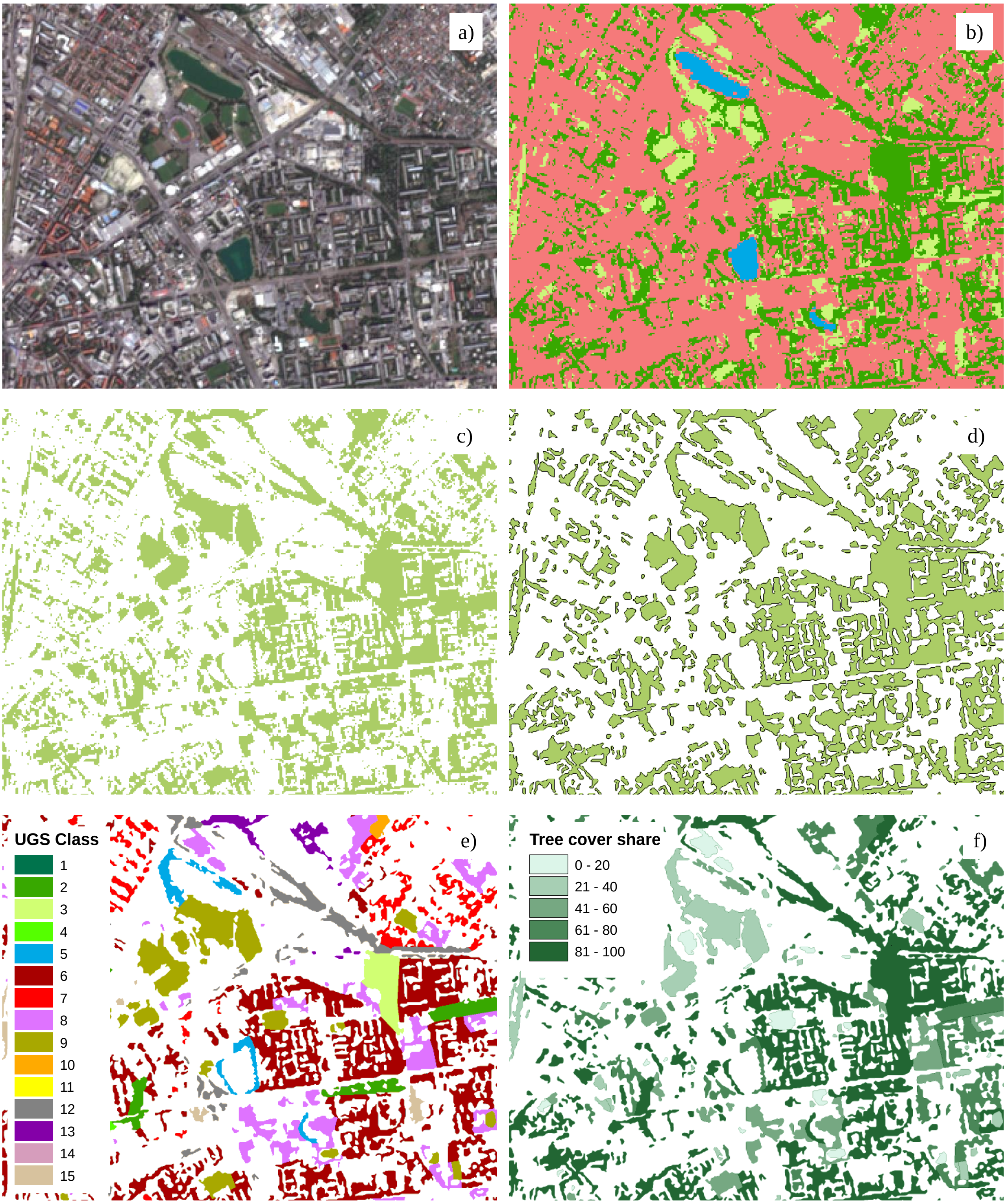


Figure 2. Six processing steps of the UGS extraction and classification (an example from Bratislava, Slovakia). 2a) A true color composite produced from S2A data; 2b) result of the maximum likelihood supervised automatic classification; 2c) binary map of vegetation/non-vegetation land cover; 2d) vectorized and visually enhanced polygons with the minimum mapping unit of 500 m2 applied; 2e) result of UGS visual interpretation and polygon editing; 2f) tree cover share estimated using 2b and 2e on a per-polygon basis

CONCLUSION

The key ecological characteristics of cities are the proportion of impervious surfaces and the quality of green spaces, the overall site structure and the specifics of land use. Effective urban planning and policy making can be achieved only when reliable data and meaningful indicators become available. S2A data provide free of charge and up-to-date spatial data that can be used to derive useful information about UGS (as well as other components of the urban landscape) for decision-makers and urban planners. However, it demands new techniques and approaches of image processing.

Presented approach enabled us to obtain detailed, objective, timely, and comparable information about quantity and quality of UGS and is reproducible for most cities in Europe and elsewhere. The proposed approach combines semi-automatic UGS extraction from S2A data and classification of the extracted polygons based on visual interpretation based on aerial orthophotos. In this way, the amount of manual digitizing is minimized while keeping the accuracy at a high level thanks to the visual assessment. Also, the information exceeds the readily available data from the Urban Atlas project in terms of spatial detail, thematic detail, and has the potential for much more frequent updates.

Future research should try to quantify the accuracy of the employed semi-automatic method and eventually improve its accuracy, e.g. by using multitemporal, multisensoral approach, or other classification methods. Also, it should be tested if the proposed nomenclature fits the diverse urban landscapes of European and other cities. We see another challenging research prospect in the detection of UGS changes over time. Further information on UGS useful for closer examination of the related ecosystem services might be obtained, e.g. from Landsat 8 thermal bands (to estimate the surface temperature of various UGS classes under varying seasonal/weather conditions), from a digital terrain model, or other ancillary data.

ACKNOWLEDGEMENT

The study was supported by the Slovak Scientific Grant Agency VEGA under Grant No. 1/0275/13 “Production, verification, and application of population and settlement spatial models based on European land monitoring services”.

REFERENCES

Ahern, J., Cilliers, S., Niemelä, J. (2014): The concept of ecosystem services in adaptive urban planning and design: A framework for supporting innovation. Landscape and Urban Planning, 125, 254 – 259.

Alavipanah, S., Wegmann , M. Qureshi, S.., Weng, Q. Koellner T (2015) The Role of Vegetation in Mitigating Urban Land Surface. Temperatures: A Case Study of Munich, Germany during the Warm Season. *Sustainability*, 7, 4689 – 4706.

Chengqi, Ch., Bin, L., Ting, M. (2003): The application of very high resolution satellite image in urban vegetation cover investigation: a case study of Xiamen City. *Journal of Geographical Sciences*, 13, 3, pp. 265 – 270.

Cvejić, R., Eler, K., Pintar, M., Železnikar, Š., Haase, D., Kabisch, N., Strohbach M. (2015): A typology of urban green spaces, ecosystem provisioning services and demands. The report outlines the different types of urban green spaces, ESS provisioning and demand for green space as a part of the EU FP7 GREEN SURGE project (2013-2017). Available at: http://greensurge.eu/working-packages/wp3/files/D3.1_Typology_of_urban_green_spaces_1_.pdf/D3.1_Typology_of_urban_green_spaces_v2_.pdf

Drusch, M., Del Bello, U., Carlier, S., Colin, O., Fernandez, V., Gascon, F., Hoersch, B., . Isola, C., Laberinti, Martimort, P., Meygret, P., Spoto, F, Sy, O., Marchese, F., Bargellini, P. (2012) Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services. *Remote Sensing of Environment* , Vol. 120, pp. 25 – 36.

Feng, Q., Liu, J., Gong, J. (2015): UAV Remote Sensing for Urban Vegetation Mapping Using Random Forest and Texture Analysis. *Remote Sensing*, 7, 1074 – 1094.

Fletcher, K. (2012): Sentinel 2: ESA´s Optical High-Resolution Mission for GMES Operational Services. ESA Communications, Noordwijk, The Netherlands, 72 p. Available at: http://www.esa.int/About_Us/ESA_Publications/ESA_Publications_Monographs/ESA_SP-1322_2_Sentinel_2

Hurbanek, P., Atkinson, P.M., Chockalingam, J., Pazúr, R., Rosina, K. (2010): Accuracy of Built-up Area Mapping in Europe at Varying Scales and Thresholds. In Accuracy 2010: proceedings of the Ninth International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences. Leicester : University of Leicester, 2010, s. 385-388.

Lehman, I., Mathey, J. Rößler, S., Bräuer, A., Goldberg, V. (2014): Urban vegetation structure types as a methodological approach for identifying ecosystem services – Application to the analysis of micro-climatic effects. *Ecological Indicators*, 42, 58 – 72.

Nichol, J., Lee, C.M. (2005): Urban vegetation monitoring in Hong Kong using high resolution multispectral images. *International Journal of Remote Sensing*, Vol. 26, No. 5, 903 – 918.

Niemela, J. (2014): Ecology of urban green spaces: The way forward in answering major research questions. Landscape and Urban Planning, 125, 298 – 303.

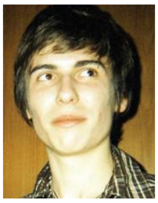
Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., Pouyat, R. V., Whitlow, T. H., Zipperer, W. C.(2011): Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, Vol. 9, Iss.1, 27 – 36.

Tigges, J., Lakes, T., Hostert, P. (2013): Urban vegetation classification: Benefits of multitemporal RapidEye satelite data. *Remote Sensing of Environment*, 136, 66 – 75.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmiercak, A., Niemelä, J., James., P. (2007): Promoting ecosystem and human health in urban areas using Green infrastructure. A literature review. *Landscape and Urban Planning*, 81, 167 – 178.

Wolch, J. R., Byrne, J., Newell, J. P. (2014): Urban green space, public health and environmental justice: The challenge of making cities just green enough. *Landscape and Urban Planning,* 125, 234 – 244.

BIOGRAPHY



Konštantín Rosina, Ph.D., a junior research scientist at the Institute of Geography, Slovak Academy of Sciences. His main interest is in the field of geoinformatics, particularly spatial disaggregation methods, validation of geographic datasets, and identification of land cover changes using remote sensing data. Previously, he worked for one year as a GIS consultant for the OECD, Public Governance and Territorial Development Directorate.

Monika Kopecká, PhD., 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.