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Greenness Indicator for Spatial and Settlement Planning Based on NDVI and LAI Indicators

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Abstract

In the international practice of green infrastructure research, many indicators have been developed to measure the social functions, naturalness, the role of the urban climate, interconnection, networking, multifunctionality, and ecosystem services. In 2007, an indicator of biological activity value (BA) was introduced into the Hungarian town planning practice and legislation, which shows the intensity of green areas in areas to be built and is the basis for counting land use changes of settlements. However, the actual biomass, which can be measured by remote sensing devices, has not yet been considered in determining the indicator values. The main purpose of this research was to develop an easy-to-use, easily adaptable indicator for spatial and settlement planning, which has good correlation with the green coverage of different land uses and with biomass; and which may be also suitable for monitoring the ecological value of land use changes.

Introduction

One of the challenges of spatial planning, town planning, environmental impact assessments and strategic impact assessments is to measure and count the environmental impact of planned interventions. Usually, different indicators are used to track environmental changes, but there are only a few such accepted methods available in the current planning toolbox internationally. Although there are such complex indicators in environmental research as the bio-capacity index, the natural capital index (NC), or the ecological footprint indicator, the indicators that can be used well in research are usually too complex, and time and resource-intensive for planning practice. The concept of green infrastructure in Europe was widespread at the beginning of the 2010s, although the term itself developed in the 60s in the United States [1], [2], [3]. The EU Biodiversity Convention has now raised the green infrastructure concept to the level of spatial planning, requiring the rehabilitation of 15 percent of degraded areas by 2020 [4]. At the design or planning level, the question often arises: how to measure this proposed 15 percent restauration, and what simple indicators can be used to track the changes in the green infrastructure?

[1] Mark A. Benedict és Edward T. McMahon, *Green Infrastructure: Smart Conservation for the 21st Century*, 2000, http://www.sprawlwatch.org/greeninfrastructure.pdf.

[2] EEA, "Green infrastructure and territorial cohesion The concept of green infrastructure and its integration into policies using monitoring systems" (EEA, 2011).

[3] "Spatial Analysis of Green Infrastructure in Europe — European Environment Agency", Publication, elérés 2016. február 22., http://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure.

[4] European Commission, „Our life insurance, our natural capital: an EU biodiversity strategy to 2020", Pub. L. No. Brussels, 3.5.2011, COM(2011) 244 (2014).

Background and Literature Review

In the international practice of green infrastructure research, many indicators have been developed to measure the social functions[1], naturalness[2], the role of the urban climate[3] [4], interconnection, networking[5], multifunctionality[6] and ecosystem services[7][8]. In design practice, the most common indicator is the green area supply indicator which is a simple green area size parameter relative to population. There are also slightly more complex accessibility indicators that measure distance from residential areas together with the size of green space[9]. Green surface access indicators can be applied to both urban and landscape scales. In 2007, the indicator of the biological activity value (BA) [10] was introduced into the Hungarian town planning practice and legislation, which shows the green intensity of areas planned to be built and is the basis for counting land use changes of settlements. The purpose of the legislation was to prevent the decrease of green areas at the settlement level. In order to simplify the calculation, the biological activity indicator values were assigned to each type of land use and zonation, based on practical experience. Thus, the biological activity value is a dimensionless unit of measurement per square meter, showing the relative values and importance of the areas. The actual biomass, which can be measured by remote sensing devices, has not yet been considered in determining the values of the indicator. A further disadvantage of the indicator is that it only needs to be determined where an area is to be built.

Goals and Objectives

The main purpose of this research was to develop an easy-to-use, easily adaptable indicator for spatial and settlement planning, which has good correlation with the green coverage of different land uses and with biomass, and which may be also suitable for monitoring the ecological value of land use changes. An

[1] Arne Arnberger, Wolfgang Haider, és Andreas Muhar, „Social Carrying Capacity of an Urban Park in Vienna", elérés 2017. december 24., http://mmv.boku.ac.at/refbase/files/arnberger_arne_hai-2004-social_carrying_capa.pdf.

[2] Åsa Ode és mtsai., „Indicators of perceived naturalness as drivers of landscape preference", *Journal of Environmental Management* 90, sz. 1 (2009): 375–83, https://doi.org/10.1016/j.jenvman.2007.10.013.

[3] Carlos Bartesaghi Koc, Paul Osmond, és Alan Peters, „A Green Infrastructure Typology Matrix to Support Urban Microclimate Studies", *Procedia Engineering* 169 (2016 31.): 183–90, https://doi.org/10.1016/j.proeng.2016.10.022.

[4] Carlos Bartesaghi Koc és mtsai., „Application of a green infrastructure typology and airborne remote sensing to classify and map urban vegetation for climate adaptation", 2016.

[5] Ted Weber, Anne Sloan, és John Wolf, „Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation", *Landscape and Urban Planning* 77, sz. 1–2 (2006 15.): 94–110, https://doi.org/10.1016/j.landurbplan.2005.02.002.

[6] Butlin, „The Value of Mapping Green Infrastructure", http://www.merseyforest.org.uk/files/The_Value_of_Mapping_Green_Infrastructure_pdf.pdf, 2011,

[7] Christian Albert és mtsai., „Applying ecosystem services indicators in landscape planning and management: The ES-in-Planning framework", *Ecological Indicators*, (visited 08. 10. 2015. https://doi.org/10.1016/j.ecolind.2015.03.029.

[8] Grazia Zulian és mtsai., *ESTIMAP: Ecosystem Services Mapping at European Scale.* (Luxembourg: Publications Office, 2013).

[9] „Providing Accessible Natural Greenspace in Towns and Cities A Practical Guide to Assessing the Resource and Implementing Local Standards for Provision"

[10] „9/2007. (IV. 3.) ÖTM Rendelet - a Területek Biológiai Aktivitásértékének Számításáról", (visited: 21. 01. 2019)., http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=a0700009.otm.

important goal was also to introduce a new indicator that can track the “greenness” of the entire study area, not just the area that is to be built. Further goals included developing an indicator that takes the material, temporal constraints of spatial planning, the practical possibilities of adaptation, and the technical constraints into account at the same time, based on real remote sensing data. It was also expected that the calculation of this greenness indicator would be so simple that in the course of planning, landscape architects, landscape planners, and town planners would not have to go back to the original detailed raw satellite image analysis, or require the help of external remote sensing specialists. According to European and Hungarian legislation, strategic environmental assessment is required for spatial plans and municipal plans[1]. The aim of the green biomass indicator calculation is, thus, to facilitate the estimation of the environmental impacts of spatial plans and the directions of environmental changes of the plan.

Methods

The guiding principle of the methodology was to create biomass indicators (NDVI, LAI) from remotely sensed images, then to aggregate these indicator values according to the spatial planning and settlement planning types and regulatory zones. On this basis, we can get an average value for each specific regulatory zone type. Two widely used indicators for the determination of biomass were used: the normalized vegetation index (NDVI[2]) and the leaf area index (LAI[3]). It was an important issue to define these indicators not only for one specific time and not only for one certain area, but preferably for the entire vegetation period, so that anomalies resulting from spatial or temporal variations can be eliminated or minimized. The research thus consisted of the following steps and phases:

1. Generation of a cumulative normalized difference vegetation index (NDVI) and a leaf area index (LAI) map for the vegetation period;
2. Counting of average NDVI and LAI values for land use and regulatory zoning per area;
3. Determining the Greenness Indicator value.

Data

The research builds upon the availability of free multispectral remote sensing images of the Sentinel-2A satellite family made in the framework of the Copernicus Earth Observation Program. The 10 m spatial resolution images were available from 2015 and were suitable for obtaining green biomass indicators (NDVI and LAI). For the analysis, the average of the images from three different times of the vegetation period (04/03/2017, 07/17/2017, 09/20/2017) was calculated. The average of the indicators defined what biomass quantity can be calculated for each type of land use or regulatory zone during the vegetation period. Calculation method of NDVI and LAI indicators from Sentinel-2A satellite images were based on the article by Delegido, 2011[4]. Figure 1 shows that by normalizing, and using the same color range and

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[1] „Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the Assessment of the Effects of Certain Plans and Programmes on the Environment”, Pub. L. No. 32001L0042, OJ L 197 (2001), http://data.europa.eu/eli/dir/2001/42/oj/eng.

[2] „Normalized Difference Vegetation Index”, in *Wikipedia*, (visited: 28. 01. 2019) https://en.wikipedia.org/w/index.php?title=Normalized_difference_vegetation_index&oldid=880565627.

[3] „Leaf Area Index”, in *Wikipedia*, 2018. november 13., https://en.wikipedia.org/w/index.php?title=Leaf_area_index&oldid=868603603.

[4] „Sensors | Free Full-Text | Evaluation of Sentinel-2 Red-Edge Bands for Empirical Estimation of Green LAI and Chlorophyll Content | HTML”, (visited: 31. 01. 2019), https://www.mdpi.com/1424-8220/11/7/7063/htm.

limits, NDVI indicates higher biomass (greener on the right map) in agricultural areas (grasslands or arable land). The reason for this is that while the NDVI only looks at the surface coverage, the LAI looks for the overlapping level of green leaf coverage, i.e. the amount of biomass. Although both values were calculated from the same remotely sensed images, in case of lower LAI values (which is typical in Hungary), LAI values are strongly correlating with NDVI values. Therefore, both indicators provided similar results in determining biomass indicator values.

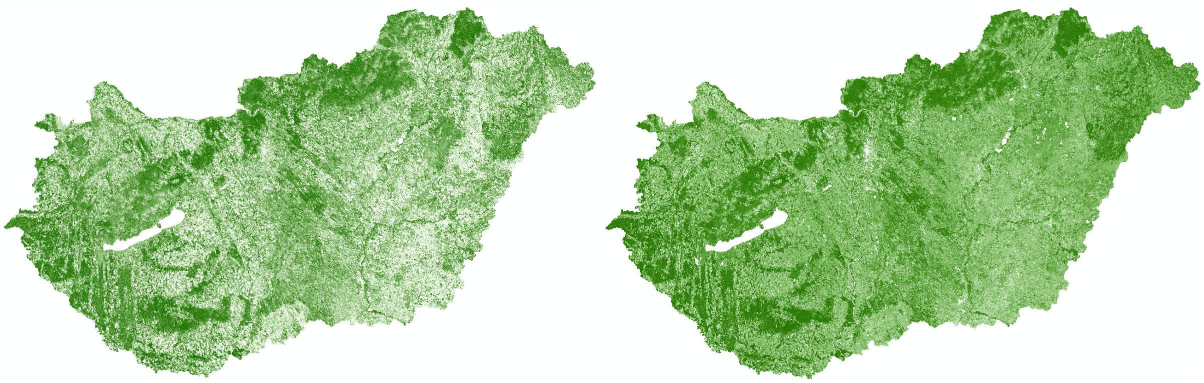

Figure 1: LAI and NDVI indices from Sentinel-2A satellite images

After calculating the NDVI and LAI values, the maps were normalized, and in both cases converted to a ly1-100 range (Figure 1). The results already show the more and less vegetated areas, and the map pattern (not accidentally) follows the pattern of land use map. However, there are many pixels of varying intensity within the boundaries of each land use type. The intensity of agricultural, forest or lawn areas from different parts of the country may vary from one region to another. For the purpose of standardization, the average and standard deviation of the pixel intensity values was also determined for each land use type (on country level) and for each regulatory zone (for Budapest). For statistics, we used the ArcGIS Zonal Statistic as Table command. The aggregation was based on these two types of zonal maps (at a country level, and for the Budapest area for regulatory zones). At the country level, 232 million pixels were compiled for 63 different types of land use. At the district level, we used the data of the Budapest Metropolitan Regulatory Framework Plan (FSZKT). In the latter case, the GIS database contained 17,547 patches of patches, classified into 53 different regulatory zones.

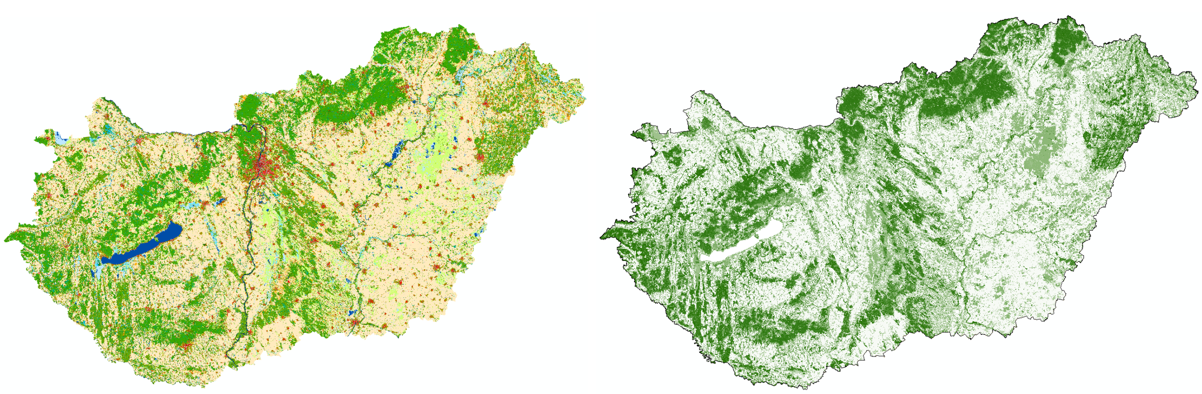

Figure 2 Hungary land use map (left) and the Greenness Indicator map based on average LAI values (right)

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The large number of patches and sampling sites for each type, zone, and the high-resolution LAI map enabled us to determine the average LAI values for each type with high accuracy and representativeness. At the country level, average LAI values were obtained for land use types, while for Budapest the aggregated values were obtained smaller units the for regulatory zones of Budapest municipal plan. Values represent the average biomass value for a given type or zone on a range of 1 to 100. This average biomass value was called Greenness Indicator (GRI). This indicator is also a dimensionless number per unit of area. The value of GRI is already suitable for calculating the amount of greenness in concrete plots, urban districts, municipals or landscape regions considering the sizes of the areas, the land use types or zonal types. One of the great benefits of this indicator is that we can count the cumulated GRI values for any spatial unit without using remote sensing images.

Results

By aggregating the LAI values for land use and zones, we obtained the value of Greenness Indicator. The indicator shows the 'greennees' rate of each land use on a 1-100 range scale and we can compare these greenness values relative to each other. Values only reflect the amount of biomass, and do not include any other evaluation criteria (e.g. the levels of protection, accessibility, or maintenance). Both the country-level analysis and the more detailed analysis of Budapest have produced similar results.

Land Use (Level 1)	Land Use (Level 2)	Greenness Indicator
Wetland		69
Forests and woody vegetation	Forests under water impact	84
	Natural riparian galleries	90
	Forests that are not dependent on excess water	85
	Tree plantation	85
	Woody vegetation	78
Grassland	Closed grassland in hill and mountainous areas	66
	Open rock grass	56
	Saline grassland	64
	Sandy grassland	59
Orchard, vineyard		61
Plow land		43
Green space in the settlement		66
Roads, areas along railways		52
Built-in urban areas		34

Table 1. GRI values by land use types (selected)

In both analyses, forest areas fell into the highest category of 74-100 scores. Grassland areas do not appear as separate categories (zones) in the settlement plans, thus the categories of the country level analysis are in the range of 56-66. Orchards and vineyards are also only included in the national analysis, their values there were around 61. The arable and agricultural land categories occurred in both studies. In the case of arable land, the 43 points at the country level can be acceptable. Because the agricultural area of the regulatory plan in Budapest may include grasslands and orchards, higher values can be detected.

Regulatory zones		**Greenness Indicator**
Residential areas	Large urban, typically enclosed residential area	16
	Urban, typically enclosed residential area	35
	Small town with a typically closed residential area	38
	Small town, typically a freestanding residential area	60
	Intensive suburban residential area	52
	Quiet suburban area, typically a freestanding residential area	64
	Mountain, suburban, typically freestanding residential area	75
	Mountain, suburban, freestanding, large-scale residential areas	92
	House-like living space	49
Mixed land use area	Institutions	37
	Institutional area - military area	76
	Significant green space	68
	City center areas	5
Economic or industrial area	Industrial areas	59
	Industrial area - energy production facility	46
Recreation area	Recreation area	86
Special Land-use Area	Special - shopping malls	52
	Special - large commercial areas	56
	Special - Health Areas (Hospital, Sanatorium, Spa Hotel, Spa Resort)	46
	Special - military areas	69
	Special - Large Areas for Sports (Beach, Leisure, Recreation)	56
	Special - thematic institution parks	61
	Special - energy service areas	54
	Areas of waste management	57
	Special transport areas mixed with institutions	27
	Special City Management - Logistics Area	27
	Wastewater treatment areas	61
	Public transport base area	1
	Cemeteries	88
Development purpose area	Infrastructure conditioned development area	77
	Long-term development reserve area	81
Traffic and public utilities area	Traffic areas	96
	Area for transport facilities	25
	Public space for transport	35
	Airport	69
	Railway Area	44
	Area for water transport constructions	12
Open space, green space	Green areas not intended for public use	76
	Wooded public spaces	28
	Public garden	69
	Public park	76
	City parks	74
Forested area	Tourist forest	97
	Protection- Nature conserved forest	100
	Protection – Protection forest	74
Agricultural area	Agricultural areas	75
	Recreation area for agricultural purposes for farm use	94
Water management area	Areas of flood protection facilities	86
	Water supply areas	86

Table 2. Zone categories and their Greenness Indicator values

The categories of the living area depend on the intensity of the installation. Areas with the highest GRI value are close to forest areas, while intense metropolitan, closed installations are approaching the GRI values of paved surfaces. Depending on their type, institutional and economic areas also show high dispersion. Traffic areas are generally of low value. Exceptions are the large airports, where grasslands and forest areas make up for the large paved surfaces of runways.

GRI values multiplied by specific area sizes and plot sizes are already available to determine relative biomass quantities. The GRI calculation is thus suitable for comparing biomass quantities between the current and the planned state. The aggregated value of GRI can be calculated as either plots, zones, districts, settlements or for larger landscapes, administrational units. The net change in GRI values can reflect the direction of interventions in a plan. To calculate the value, only the size of the area and the type of land use are needed, so GRI can be easily calculated for every plan and can be used as a tool for monitoring green space balance. It is an important aspect that this tool or indicator considers all of green infrastructure elements, not only those that have been officially delimited by regulations for this purpose. Figure 3 shows the big difference among officially dedicated green areas (left) and the real green intensity (right). The calculation of GRI can help to more accurately count the green infrastructure volume in a city and can help in achieving the 15 percent rehabilitation requirement of the EU Biological Diversity Convention.

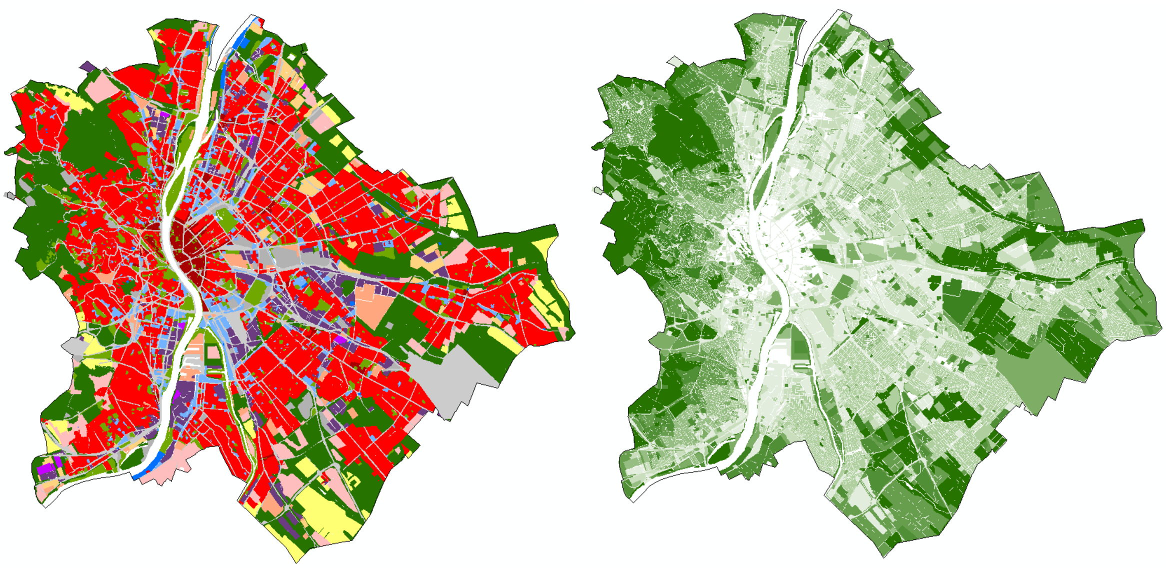

Figure 3: The regulatory zones of Budapest (left) and the Greenness Indicator (GRI) based on zonal LAI averages (right)

Discussion and Conclusion

Of course, an indicator which correlates with the amount of GRI biomass only examines and qualifies the value of green surfaces in one aspect. Therefore, the calculation based on the amount of biomass only complements and does not replace other green surface assessment methods. However, GRI can help in quantifying and preserving green capital in green infrastructure planning. Combined with other green surface evaluation methods (e.g. accessibility; Angst[1], usage intensity or maintenance level), the values obtained can also be used to develop a complex ecosystem service indicator. The method can be used well

[1] "Providing Accessible Natural Greenspace in Towns and Cities A Practical Guide to Assessing the Resource and Implementing Local Standards for Provision".

in settlement planning and regional plans or in environmental impact assessments. In the Hungarian Green Infrastructure Plan currently being prepared, the method will be further clarified and its legal enforceability examined.

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