Proceedings of the Fábos Conference on Landscape and Greenway Planning

Volume 6 *Adapting to Expanding and Contracting Cities*

Article 46

2019

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Recommended Citation

Jombach, Sándor; Li, Huawei; Wang, Guifang; Valánszki, István; and Kovács, Krisztina F. (2019) "Greenway Exploration in the Satellite Jungle: Discovery of Urban and Rural Green Network with Satellite Image Analysis in Hungary," *Proceedings of the Fábos Conference on Landscape and Greenway Planning*: Vol. 6 , Article 46.
DOI: https://doi.org/10.7275/wvhx-4078
Available at: https://scholarworks.umass.edu/fabos/vol6/iss1/46

Greenway Exploration in the Satellite Jungle: Discovery of Urban and Rural Green Network with Satellite Image Analysis in Hungary

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Abstract

Over the last few decades of growing data production in the field of remote sensing and GIS, we have experienced a rapid development of methods and tools in green network analysis. A series of journal articles, methodological and technical guidelines describe how to map green system based on aerial photography and satellite imagery. Many studies stress that green networks have a climatic conditioning role and outstanding ecological significance in landscapes. Environmental agreements and sustainability aspects emphasize the need for mapping and managing green infrastructure in urban and rural landscapes. The usual question is: What are the elements of green infrastructure in a study area? In the last few months, we have prepared a series of satellite images and aerial photo analyses and have processed freely available spatial data on green spaces, land use, climatic hot spots, and have searched for ecological and recreational potential of landscapes in Hungary, in order to explore greenway suitability. In this paper, we make a report about our research, discovering greenway potential of urban and rural landscapes.

Introduction

In Hungary, the mapping of green infrastructure has started recently. A key question dominates the analysis: what are the permanent green elements of landscapes? What elements form constant green coverage during the year? These are green corridors and core areas, valuable from ecological and social aspects as well. Many of the agriculture dominated landscapes of Hungary lack fixed green corridors that could be managed as potential greenway development sites. The permanent green elements of landscapes are mostly forested areas, scrublands, extensive natural grasslands especially nearby floodplain areas, forest bands and hedges of agricultural land, reeds and wetlands, green corridors and parks of towns, or even alleys of road network. The methodology to map these elements is under construction in Hungary.

Background and Literature Review

As greenways became a force in landscape planning in the 1990s (Fábos & Ryan 2006), so can green infrastructure become a force for the first decades of the 21st century. A series of papers introduced greenways as a suitable tool for planning landscapes, with a special concern on recreational purposes, ecological aspects, and understanding them as complex systems (Ahern 1995, Ribeiro & Barao 2006, Senes et al. 2019).

As greenways follow a clearly understandable concept, green infrastructure is also considered as a definition that can be easily understood in planning and development. Nevertheless, detailed mapping and planning of green networks means quite a challenge in a practical project.

This research uses two indices very common in remote sensing: NDVI and LST. NDVI is the Normalized Difference Vegetation Index that describes the existence and the vitality of vegetation cover based on the chlorophyll content of the leaves. It is modeled after Kriegler, who recommended its introduction in the 1960s (Gibson & Power 2000, 117). The index describes the vegetation with numeric values between -1 and +1. A general observation in Hungary is that below 0 value there is no vegetation vitality detected. The index is used in case of greenway, green cover or green space and green infrastructure mapping or analysis in some exemplary studies (Teng et al 2011, Austin 2014, 102-105., Bartesaghi-Koc et al. 2019).

The other important index is called Land Surface Temperature (LST), that represents the thermal conditions of land surface or any object's surface that is above land surface (Avdan & Jovanovska 2015). It calculates degrees in Celsius. There are authors who review or mention temperature as a significant factor for greenways (Senes et al. 2017, Bryant 2006) or uses for classification of green infrastructure typologies (Bartesaghi-Koc et al. 2019) LST was used for greenway development purposes from ecological aspect (Teng et al 2011) or used to illustrate in urban heat island effect (Austin 2014, 64-65) in green infrastructure analysis.

There are many scientific papers that prove the strong relationship between vegetation cover and land surface temperature. Green coverage provides lower temperature in cities. A study analyzed and proved the relation for Budapest already based on Landsat satellite image (Gábor & Jombach 2009). In this article the heat island effect became important related to non-urbanized land use types, greenways, hiking trails and biking routes and ecological network.

Goals and Objectives

The general goal in our research is to evolve a method that is suitable for mapping and planning green network for the following three purpose:

- Heat island effect mitigation
- Ecological network development
- Greenway planning

Heat island effect mitigation is a key issue in the adaptation for climate change. Ecological network development can enhance ecological benefits of green spaces, providing a sustainable environment for wildlife. Greenway planning, including additional social and recreational needs, can raise awareness and increase health and well-being. In order to support these goals, we seek to answer the following questions:

1. Where are the permanent green elements of our landscape located?
2. What are the permanent green elements of landscape?
3. What is the related dominant land use of these permanent green elements?
4. What is the relation of these elements to heat island surfaces?
5. What is the relation of these elements to the Hungarian National Ecological Network?
6. What is the greenway development potential of the permanent green elements considering ecological or climatic aspects and recreational purposes?

DOI: https://doi.org/10.7275/wvhx-4078

Methods

The research is carried out for Hungary, in Central Europe, and the results of the first half year are ready for one third of the country. The site is located in the central part of Hungary (Fig 1.) and has the size of 29,223 km^2. The research focuses on urban areas and non-urbanized rural and forested areas too. This is a general approach as conditioning, ecological and social role of the green network appears all around the landscape.

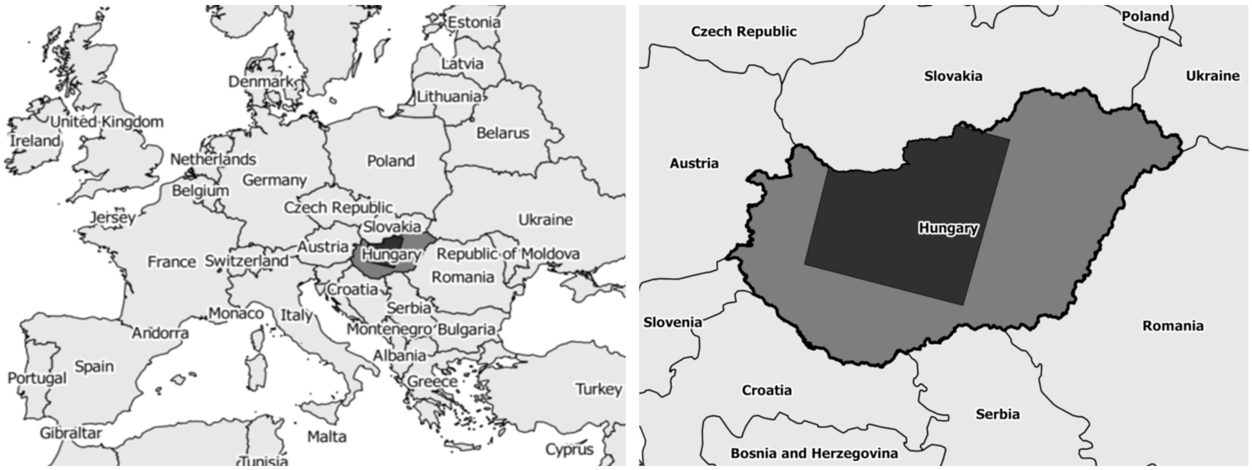

Fig. 1. Location of the study site in the central part of Hungary, in Central Europe

In order to analyze the spatial characteristics of green spaces in the landscape we:

- used GIS data management system of QGIS software,
- processed satellite images and spectral indices to analyze vegetation and temperature,
- studied very high resolution (VHR) orthophoto to increase spatial resolution,
- made field survey studies in order to ensure accuracy in the project,
- utilized additional spatial dataset of land use, nature protection and tourism.

We used the thermal, red and near infrared bands of Landsat 8 satellite images from term 2013-2018. The best 26 images with the lowest cloud coverage (15% in average) were selected from the summer months to map green coverage. To analyze the result maps we utilized:

- polygons of Corine Land Cover (CLC) Dataset 2018,
- polygons of Urban Atlas (UA) 2012 Dataset,
- polygons of Hungarian National Ecological Network (NEN),
- lines and buffer polygons of bike trails, hiking routes and the Blue Hiking Trail,
- polygons of municipal boundaries of Hungarian greenways.

In the analysis we used Normalized Difference Vegetation Index (NDVI) (Gibson & Powers 2000) to determine the intensity of green coverage. We used Land Surface Temperature (LST) method (Avdan & Jovanovska 2016) of Celsius degrees to describe the thermal conditions of landscapes. During the image processing we used the following steps:

- Downloading images from USGS website.
- Selection of images with low cloud cover.
- Calculation of NDVI and LST values for every single satellite image.

- Deleting data of areas disturbed with cloud coverage.
- Calculating mean, minimum and maximum values (NDVI and LST) of multiple images.
- Zonal statistics of values related to land use, hike and bike routes, network elements.

The final maps represents the mean values of 26 satellite images. Mean NDVI values we used to map the vegetation coverage and to define permanent green network. Mean LST values we used to define average summer heat island spatial distribution. In the result maps the higher values of NDVI (above 0.35) represent the permanent green coverage like forests, scrublines, green corridors etc, and the higher LST values represent thermal spatial distribution.

Results

The generated NDVI and LST maps for the central part of Hungary show that the permanent vegetation coverage consists of big forest patches in hill-lands, planted forests of the Great Hungarian Plain and floodplain forests of riverside or creekside landscapes. Additionally urban green areas, linear elements of agricultural landscapes and scrublands form the significant green surface of the pilot site (Fig. 2.). Besides water surfaces these are the coldest areas as the thermal values of LST show in Celsius degrees. The warmest areas do show up in cities but in the agriculture dominated countryside as well (Fig. 2.).

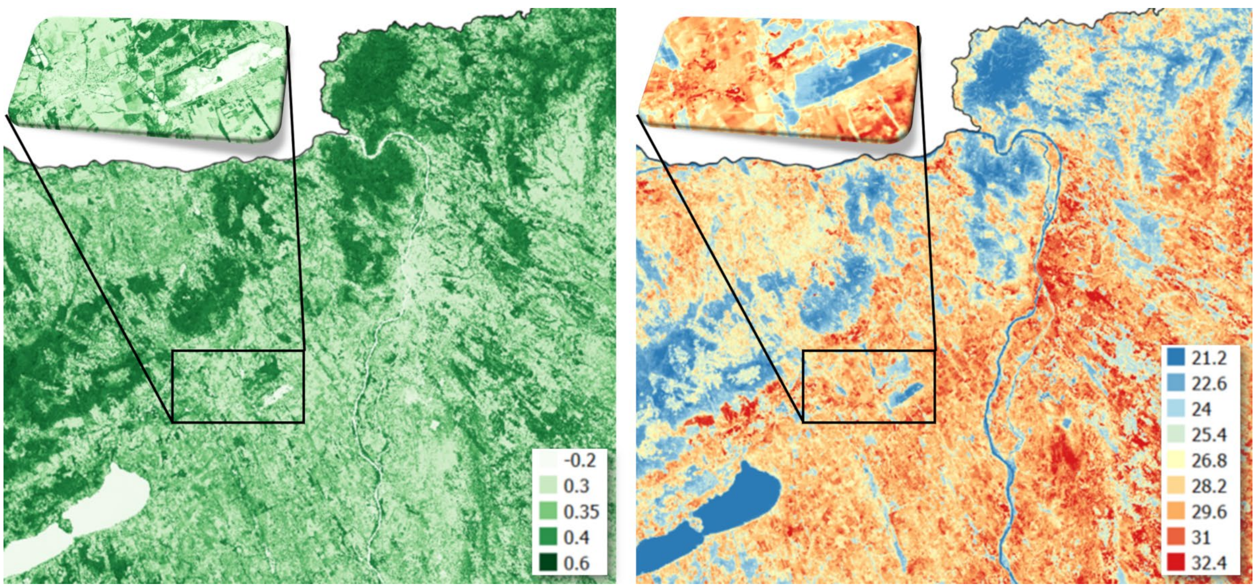

Fig 2. The green coverage map (based on mean NDVI (left) and the heat map of central part of Hungary based on mean LST in °C (right) from 26 satellite image in years 2013-2019

The land cover analysis, based on CLC typology using NDVI and LST statistics in different zones, proves that the heat island areas show up inside and outside of cities as well. Urban heat island effect can be obviously seen in case of towns having at least 30-50 thousand population. But the heat island is also presumable in non-urban context as well (Fig 3.). The southern slopes of hill-lands have typically warm surface temperature. Some land cover types like vineyards and sparsely vegetated areas do have almost the same heat island effect like urban fabric in towns (Table 1.).

We compared CLC and UA categories and these showed similar results. The hottest surfaces were airports (Table 1.) in both case even though the vegetation coverage is not the lowest. This can happen as there is no tree coverage in the airports while sheltering trees or buildings are more dominant in urban green spaces.

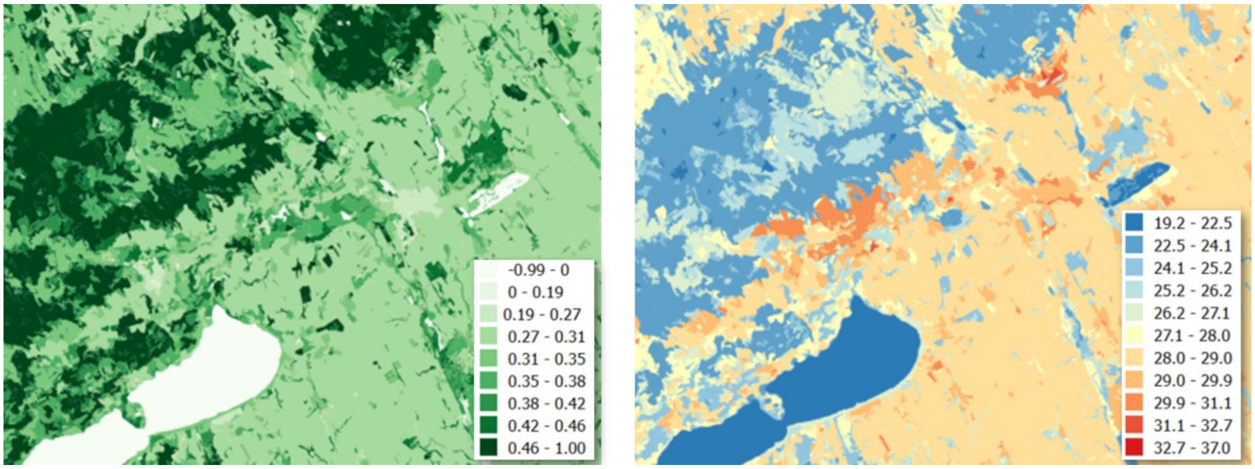

Fig 3. Mean NDVI and LST (ºC) values by land cover types in the central part of Hungary by CLC, near Lake Balaton and the southern slopes of Bakony and Vértes Hills.

Table 1. Characteristics of some land cover types (CLC) and functional categories (UA)

Land cover type (CLC) central part of Hungary	**NDVI** (-1…+1)	**LST** (ºC)	**Land cover type (Urban Atlas) in and near Budapest, FUA**	**NDVI** (-1…+1)	**LST** (ºC)
Airports	0,28	31,0	Airports	0,26	31,6
Continuous urban fabric	0,12	30,9	Continuous urban fabric (above 80%)	0,24	29,5
Vineyards	0,31	30,3	Arable land (annual crops)	0,30	29,2
Sparsely vegetated areas	0,22	30,5	Pastures	0,34	28,6
Green urban areas	0,36	27,0	Green urban areas	0,36	27,3
Peat bogs	0,42	25,5	Wetlands	0,37	25,9
Broad-leaved forest	0,47	23,7	Forests	0,45	24,4

The land cover analysis based on Urban Atlas typology using NDVI and LST statistics in different zones shows that continuous urban fabric is about 29.5 degrees (Celsius), while forest is about 24 degrees (Table 1.). The difference is 5.5 degrees in the average. The conclusion is that agriculture dominated landscapes with a mean temperature of 28.9 degrees (Celsius) were closer in temperature to urban areas than to forested lands (Fig 4.).

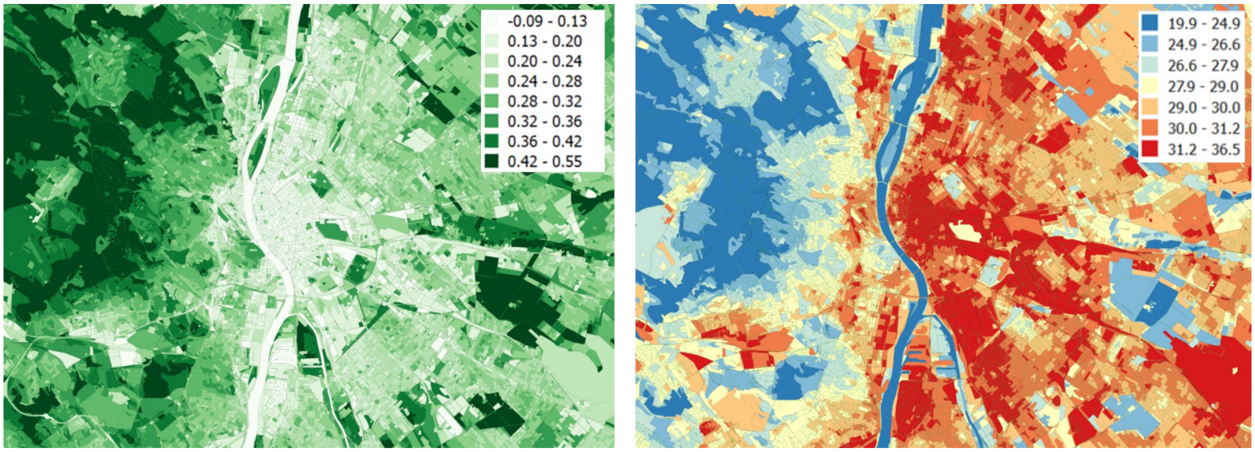

Fig 4. NDVI and LST (°C) by main land cover types in Budapest by Urban Atlas

We compared NDVI and LST characteristics of National Ecological Network (NEN) elements and the same with the areas out of NEN (Table 2.). The results show that the areas within the NEN have more vegetation coverage (NDVI average is 0,37) while areas out of NEN have only 0,32. The core areas that are the most significant habitats and the largest area have the most dense green coverage and the lowest surface temperature (25 °C).

Table 2. Elements in and out of National Ecological Network in central part of Hungary

Types based on National Ecological Network (NEN)	**Area** ***(km²)***	**NDVI** (-1…+1)				**LST** (°C)			
		Mean	***Min***	***Max***	***Range***	***Mean***	***Min***	***Max***	***Range***
Core areas (NEN)	6571	**0,38**	-0,20	0,62	0,81	**25,0**	18,2	42,2	24,0
Buffer zones (NEN)	1857	**0,37**	-0,19	0,60	0,79	**27,0**	18,0	38,1	19,5
Corridors (NEN)	2285	**0,36**	-0,18	0,60	0,78	**26,0**	18,4	38,6	20,2
Not part of NEN	18510	**0,32**	-0,18	0,61	0,79	**28,5**	18,3	43,5	25,2

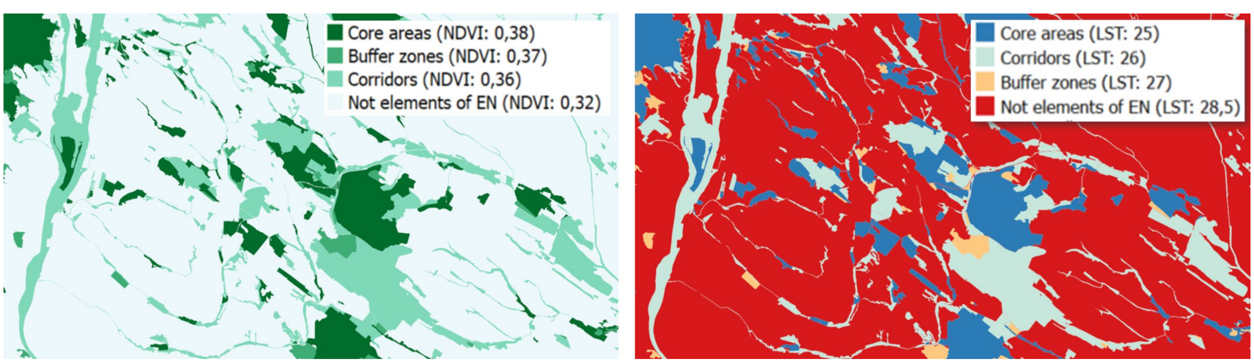

Fig. 5. Example for spatial distribution of National Ecological Network elements near Budapest

Although the buffer zones have higher NDVI values the corridors have lower temperature. This can be the result of the fact that in many case corridors are defined along creeks or rivers that have intensified cooling effect but smaller green coverage (Figure 5.). The maps show that the corridors provide 2,5 °C colder surface in general than the areas out of NEN. This provides more comfortable pathways for wildlife to migrate among core habitat patches.

We analyzed the bike routes and hiking trails within 50m buffer zones. The average values show that the routes have much better green and climatic attributes than the areas away from pathways. The only exception is bike routes that have even worse results than the regional average (Table 3.). The temperature is higher there thanks to the fact that bike routes were built mostly along main roads, within towns and the capital city.

Table 3. Characteristics of hiking trails and bike routes in the central part of Hungary

Route category	**Buffer dist. (m)**	**NDVI** (-1…+1)				**LST** (ºC)			
		Mean	***Min***	***Max***	***Range***	***Mean***	***Min***	***Max***	***Range***
Blue Hiking Trail	**50**	**0,44**	-0,10	0,60	0,70	**24,1**	18,5	32,3	13,8
Hiking routes	**50**	**0,39**	-0,16	0,61	0,77	**26,0**	18,3	38,2	20,0
Bike routes	**50**	**0,31**	-0,14	0,60	0,74	**27,7**	20,3	36,3	16,0
Central part of Hungary	**-**	**0,34**	-0,20	0,62	0,81	**27,4**	18,2	43,5	25,3

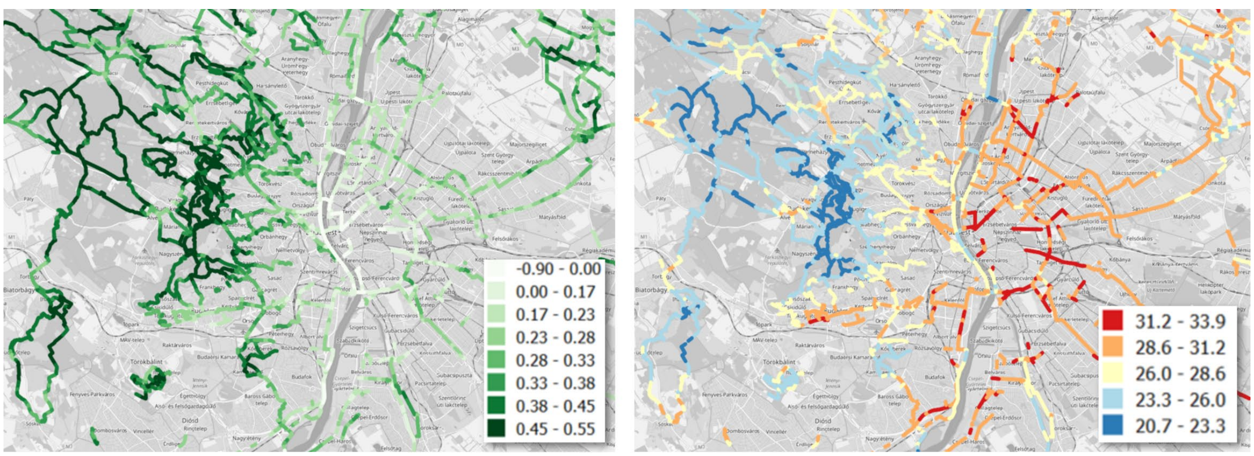

Fig. 6. NDVI and LST (ºC) spatial distribution of biking routes and hiking trails in Budapest

We prepared the route analysis for 250m long sections. Thus the NDVI and LST characteristics can be shown on the map for very short segments. The routes can be evaluated for the capital city in detail (Fig. 6.). The bike routes and few hiking sections have very poor conditions above 31 ºC in average.

Hungarian Greenways have a special character. Greenways mean here groups of activities in settlements rather than precisely defined trails or hiking routes. Although the routes and trails are necessary elements but greenways are more represented by stations and events of related communities and municipalities. Our analysis shows that most of the settlements involved in the Hungarian Greenway Movement do have significantly higher green coverage and lower temperatures than the central part of Hungary in average (Table 3.).

Table 4. Characteristics of Hungarian Greenways in the central part of Hungary

Name of Greenway (Gw.)	***Area (km²)***	**NDVI** (-1…+1)				**LST** (ºC)			
		Mean	***Min***	***Max***	***Range***	***Mean***	***Min***	***Max***	***Range***
Earth's Heart Pilis Gw.	479	0,38	-0,12	0,59	0,71	24,7	18,4	39,2	20,8
Danube-Ipoly Greenway	527	0,38	-0,12	0,60	0,72	25,0	18,5	39,6	21,2
On the trail of our Heritage Greenway	227	0,40	-0,05	0,59	0,64	25,4	20,1	32,7	12,6
Cserhát Greenway	478	0,41	-0,10	0,60	0,70	25,4	20,8	32,7	11,9
Town Greenway in Vác	62	0,33	-0,12	0,56	0,68	26,7	18,9	35,7	16,8
Budaside Greenway	267	0,35	-0,04	0,59	0,64	27,4	21,6	40,6	19,0
Out of Greenways in central part of Hungary	27 268	0,34	-0,20	0,62	0,81	27,6	18,2	43,5	25,3

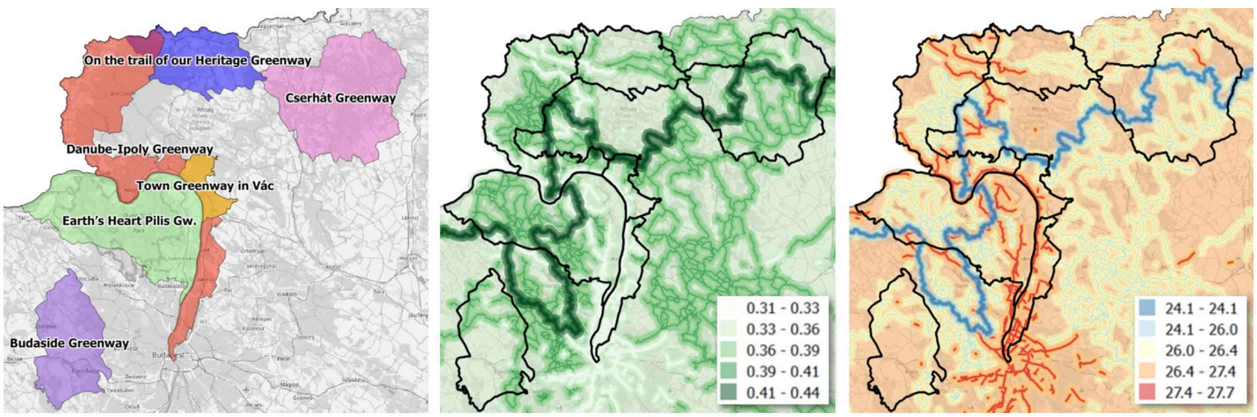

Fig. 7. Example for the spatial distribution of NDVI and LST in greenways

The most important hiking route the Blue Hiking Trail has the strongest connection to the Greenway Movement in Hungary. The trail passes by all and crosses most of the greenways (Fig. 7.). The trail has very good green coverage characteristics (Table 4.) and the temperature is the lowest. So, the Blue Hiking Trail is deservedly named blue (Figure 7.).

The most important result is that we managed to generate a map that shows what green coverage and temperature characteristics landscapes have. It can be sentenced that the green elements of central Hungarian landscapes:

- form a system that consists of island and corridor type of green spaces, with disperse located gaps in the network,
- have significant cooling effect on local climate, and these mitigate heat island effect within urban and rural regions as well,
- can have significant effects on habitats, as the areas with best condition overlap with sites of National Ecological Network.

In the next part of this paper is discussed, how the map and the findings can contribute to green network planning and greenway development.

Discussion

As the results illustrate, the mean NDVI map and the mean LST map can be used to describe current landscape characteristics. The higher values of NDVI represent the "permanent green" network. The question, whether we can give proposals based on the analysis results, may be answered! As the "permanent green map" is representing areas of fixed vegetation coverage and as the LST map is showing areas endangered with heat island, it is reasonable to compare the maps with landscape attendance. Attendance, in this case, integrates site visit and perception factors.

Landscape attendance was modelled in a 2008 research to discover the most appreciated and visited landscapes of Hungary (Jombach 2008). The landscape attendance method combined information about people's visits and human perception evaluating landscapes from 1 to 100. The highly attended landscapes (score above 50), we compared now to the present research results. We found that there are many overlapping areas. Most of the attended landscapes have significant green spaces but some of them are frequently attended with a high heat island effect (Figure 8.). This second case happens mostly in towns and cities, that is why our proposals need to concentrate on the development of greenways in or nearby cities. The capital of Hungary, Budapest, is a more attended landscape than it is provided with conditioning green areas.

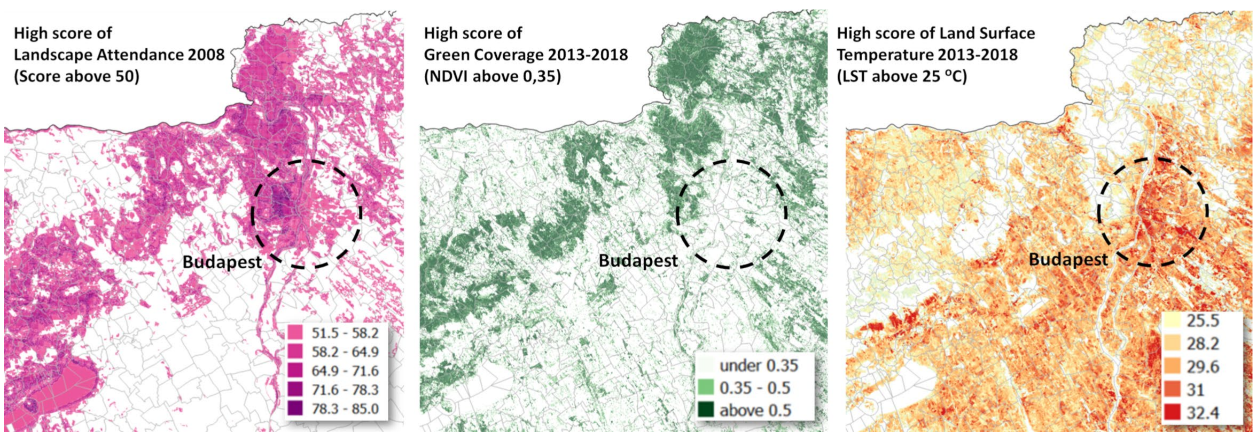

Fig 8. Comparison of landscape attendance, permanent green and high land surface temperature

Combination of the permanent green map and the highest temperature values can result in another new "product": A map that shows the cold green elements and the hot surfaces mixed together (Fig. 9.). This map is a good supporting analysis for landscapes. It clearly discovers rural heat island too.

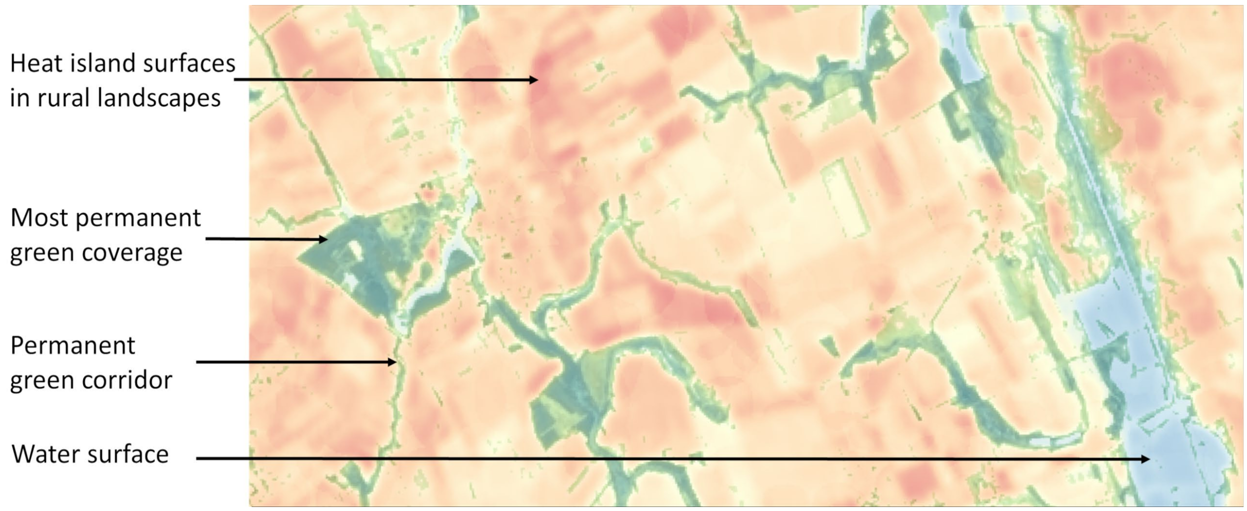

Fig 9. Mixed map of high NDVI and high LST, nearby Dég settlement in rural landscape

The mapped green elements have significant rehabilitation or development potential in greenway planning thanks to the findings listed above. In case we overlay the existing National Ecological Network and the "permanent green map" we recognize the unconnected elements of the network and the land potential for greenway planning. A kind of "greenway suitability map" can be based on permanent green elements (Figure 9.). Comparison with NEN can lead us to form proposals in the expansion of ecological network or in green infrastructure planning.

The abandoned railway lines have a great potential in greenway development. It is a considerable question to develop greenways along riversides on river flood protection dams too. A decade ago Csemez (2010) promoted to base Hungarian greenways on these structural elements. Almost every year comes up the topic that railway lines should be stopped as the under-use does not require the railroad traffic. It is still a great potential.

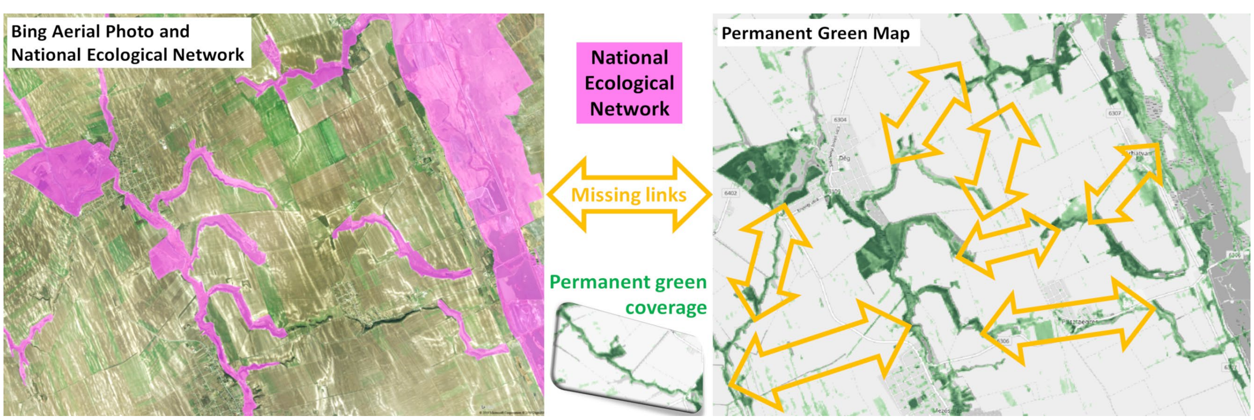

Fig 9. Some permanent elements of the landscape are almost invisible in aerial photos or VHR images (e.g. Bing Aerial on the left), but in permanent green map we can discover them.

The green network development proposals can be set in the form of:
- filling the gaps after finding the missing links in the green system,
- increasing corridor density in National Ecological Network (Figure 9.),
- rehabilitation of wildlife through wetland habitat restoration,

- "breaking through" heat island dominated areas to provide habitats of moderate climate,
- recommending abandoned or vacant land for green site development in cities,
- additional development using suitable built infrastructure (railroads, riverbanks, dams),
- planning various green infrastructure elements in densely built up urban areas

Conclusion

In Hungary, the mapping of green infrastructure was started with the processing of satellite images and collection of a GIS dataset to base our spatial analysis in 2018. The analysis concentrated on vegetation coverage (mean NDVI) and surface temperature (mean LST) that can be measured by satellite sensors. Based on 26 images and related literature of image processing, we developed a method to analyze only the useful (non-cloudy areas) of images. We generated a GIS based map that shows spatial differences in the landscape with a medium resolution of 30 meters. This dataset can also make statistical summaries for all spatial elements of ecological network, land use, hiking routes and greenways.

We came to the conclusion that green elements of central Hungarian landscapes are mostly hilly forests and floodplain forests, urban green spaces, scrublands, reeds and wetlands, and linear green elements, like forest bands or woodland strips, hedges or tree alleys. These elements:

- form a system that consists of island and corridor type of green spaces, in many case with missing linkages, thus with gaps in the network,
- have significant cooling effect on local climate, and these do mitigate heat island effect within urban and non-urbanized regions as well,
- can have significant effects on natural habitats, as the areas of best condition overlap with sites of National Ecological Network,
- are significant areas in towns and cities and belong to the most visited touristic landscapes of the country but are small in percentage and their surrounding is suffering from heat island effect.

These statements encourage us to recommend this satellite image driven method of discovering and mapping green network. It is recommended to keep the high resolution image analysis and field survey phases included. The method strongly supports planning proposals but offers freedom for design. The potential greenways

- can be discovered by satellite analysis based on vegetation indices,
- can be analyzed by thermal indices to certify the climatic effects,
- can contribute in a mixed result map and in a greenway suitability map,
- can be developed by planning strategies of filling, break through, density increase etc.,
- can be significant elements in wildlife rehabilitation process.

These provide possibility to explore greenway potential throughout Hungary. The careful and systematic combination of results can provide us basemaps to support green infrastructure development in regional and municipal scale as well.

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DOI: https://doi.org/10.7275/wvhx-4078