Green Space Intensity, Land Surface Temperature and Green Canopy Top Mapping: A Case Study in the Suburban Settlement of Törökbálint, Hungary

Sándor Jombach[1], Laura Üsztöke[1], Yaseen N. Hassan[1,2], Du Chenyu[1]

[1]Department of Landscape Planning and Regional Development, Institute of Landscape Architecture, Urban Planning and Garden Art, Hungarian University of Agriculture and Life Sciences, 1152, Budapest/Hungary · jombach.sandor@uni.mate.hu

[2]Department of Horticulture, College of Agricultural Engineering Sciences, University of Sulaimani, 46001, Sulaimani/Iraq

Abstract: Our research aimed to generate maps for an online decision support platform of the municipal website of the town Törökbálint, in the Agglomeration of Budapest, Hungary. The town is rapidly developing, thus green space management, and urban heat island effect mitigation have become important issues. We used vegetation index, land surface temperature calculation method and image classification methods. We processed satellite images, orthophotos and digital surface models to generate map layers showing the vitality of green space, the surface heat average, and the height of green canopy top. The maps were requested to be understandable for lay people and local decision-makers but relevant for experts in spatial development, urban planning and town management. These requirements meet with several points of geodesign framework but there are further steps recommended based on the feedback of users.

Keywords: Remote sensing, green space, heat island, image classification, decision support

1 Introduction

The moderate urban development and outward expansion in the **agglomeration of Budapest** results in green space loss and growing urban heat island effect in small towns. The green space changes, thanks to the moderate spatial development, appear sometimes in the heart but mostly on the edge of the city (BMM 2017). The urban fringe meets with the suburban settlements that are rapidly growing in population, **intensifying in artificial land use types,** and **enhancing services and transport functions**.

Most of the studies mapping vegetation coverage use the well-known **NDVI** index (GIBSON & POWER 2000) while the heat island mapping studies use Land Surface Temperature (LST) calculation (SOBRINO et al. 2004). The majority of the studies use both methods to document the strong **relation between vegetation coverage and surface temperature** (BOKAIE et al. 2016, PARK & CHO 2016, RANAGALAGE et al. 2017). Many studies use these methods **to analyse** land use or green space **changes** based on spatial development (SANNIGRAHI et al. 2018, NASAR-U-MINALLAH 2020). Related to medium resolution of 30-100 meters, the satellite image-based indices are mostly used for bigger cities or metropolitan regions of more than five hundred square kilometres by territory. Only a few of the studies use these for single settlements, which are usually a few dozen square kilometres in size. This scale sometimes requires high number of details, that needs a **higher resolution, and higher accuracy of VHR images** or LIDAR data (FLOHR et al. 2022). Some of the publications show that researchers are using **surface models** for mapping tree canopy cover (PARMEHR et al. 2016) or for surveying development of potential green roofs (SANTOS et al. 2016).

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The "VHR demand" leads to the use of occasional data representing coincidental situations during the year, instead of representing the whole year or the vegetation period. The research made at settlement level usually faces the dilemma of whether to use a high number of satellite images with medium and high resolution for low price, or to use a few VRH images (orthophotographs, UAV images) with a higher resolution, high costs and snapshot situations. Some research **combines data from different sources and resolutions** like OSM and Sentinel image for differentiating public and non-public green spaces (LUDWIG et al. 2021), or Sentinel and Landsat images for higher resolution surface temperature maps (ONAČILLOVÁ et al. 2022). The research that applies spectral **indices** (e. g. NDVI, EVI etc.) combined with supervised **classification** (KWAN et al. 2020) or that which uses **thresholds** to separate vegetation and non-vegetation sites (ARYAL et al. 2022) have also interesting results in mapping green space.

2 Pilot Site, Aims, Methods and Materials

The pilot site, the town of Törökbálint, has a territory of 29 km^2 and 14 thousand inhabitants, growing yearly by 180 people in the last decade. The new residential and logistical areas have been using almost 1% of the town's total territory annually in the last 12 years based on Urban Atlas dataset. This is a typical suburban settlement in the Budapest Agglomeration (Fig. 1).

The municipal government and the mayor's office run a website (MUNICIPALITY OF TÖRÖKBÁLINT 2022) with map server. It uses different layers for mapping natural capacity, social services and future developments of the town. The website is openly available for any user, but it is mostly applied by architects, town planners and town management. It supports decision-making simply through its geographic layers. There was a need for an easily understandable layer showing the intensity of green space in a range from 0 to 100%. The decision-makers and lay people prefer the simple range instead of the NDVI values from -1 to +1 with the green cover range only from 0 minimum to 0.7 maximum. Additionally, the NDVI has not been convincing for green space change studies in towns of Hungary in the last decades.

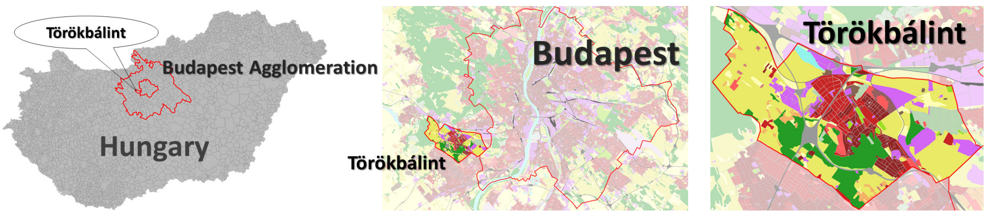

Fig. 1: The location of the town Törökbálint in Budapest Agglomeration (Hungary)

Our research used vegetation index and thermal bands of satellite images to generate a 30m and a 10m resolution Green Space Intensity (GSI) map of the year 2022, and a 30m resolution Land Surface Temperature (LST) map of the years 2021-2022. The analysis was based on many images of frequently used satellites (Landsat 7, Landsat 8, Landsat 9 and Sentinel 2) focused on the vegetation period from 1 May to 31 September using "Collection2 Level2" data from Earth Explorer website (U.S. GEOLOGICAL SURVEY 2022). All together 45 satellite images were used to prepare the **mean NDVI map** that was the base map of green space intensity generation. Some of the images had small cloud coverage with shadows. These needed special processing based on automatic and manual cloud and shadow removal actions.

The mean NDVI map was **adjusted geographically** to VHR images prepared by the institute responsible for remote sensing and geodesy in Hungary (LECHNER KNOWLEDGE CENTRE 2022). The orthophotos, used for the geocorrection of satellite analysis results, were prepared in the years of 2015, 2016 and 2019 with very high geographic accuracy (+/-0.5m), and very high spatial resolution (0.4m). The NDVI mean map prepared from satellites was **calibrated** to the infrared orthophotos and other real colour imagery of various sources (VHR images of Google Earth from 2019 to 2022). This calibration is based on the adjustment of NDVI values to the green minimum and green maximum using visual interpretation of VHR images in control sites. Based on this process, the **Green Space Intensity** (GSI) map was prepared.

The **Land Surface Temperature** (LST) **map** was processed based on the most frequently used method (SOBRINO et al. 2004) using Landsat 7, 8 and 9 satellites of two years: 2021 and 2022. The reasons why we used images of **two years** (from May to September) were:

1) The summer of 2022 was extremely dry. For more than 50 days there was no precipitation in the town. The summer of 2021 was close to the average.
2) The number of usable images reached the required minimum (Nr. 10) only in the two years (2021 and 2022). In this case, the "usable image" means "cloud free" or "non-disturbingly cloudy (less than 40% cloud and shadow affected) images.

Additionally, a map that shows the **height of "Green Canopy Top"** was generated based on an orthophotograph and a surface model. **Supervised image classification** method based on **training areas** was used on infrared ortho imagery to generate green area coverage maps with the resolution of 0.4m. The classification used multiple training areas to identify green and non-green areas (built-up, paved, bare soil and water). The **Normalized Digital Surface Model** (NDSM) is prepared every three years by the remote sensing institute of Hungary (LECHNER KNOWLEDGE CENTRE 2019) for the territory of the country. It is a practical side product of orthophoto generation based on stereophotographic analysis. It shows only the height of the landscape elements above ground (buildings, vegetation and built structures), as the terrain model was deducted from the surface model. That is why it is called "normalized" surface model. With the coupled use of green space (classified image) and height of landscape elements (NDSM) the height of Green Canopy Top map was generated (Fig. 3).

3 Results

The maps, as a result, became part of the municipal **website** of the town Törökbálint, openly available through the municipal online platform (MUNICIPALITY OF TÖRÖKBÁLINT 2022):

1) Green Space Intensity (GSI) map 2022 (30m res., based on 13 Landsat images)
2) Green Space Intensity (GSI) map 2022 (10m res., based on 32 Sentinel images)
3) Land Surface Temperature (LST) map (30m res., 33 Landsat im., years: 2021-22)
4) Green Canopy Top (GCT) map 06.15.2019 (1m res., based on orthoph. and NDSM)

The Green Space Intensity (GSI) is generated, as described in method chapter, by calibrating NDVI values. Green Space Intensity (GSI) shows what is the territorial ratio and vitality of vegetation in the site. The numeric values were described as percentage (%). The zero percent GSI is representing areas without green coverage. Hundred percent GSI means the existence of total green coverage in good health condition during the vegetation period (mostly tree covered parks, woodlands or forest patches). The **validation** of GSI values was done at 70 different locations in 210 sampling boxes (Fig. 2). The **visual interpretation** was based on six different images using infrared and real colour, summer and early spring VHR images from the years 2019-2022). The average difference between the visual interpretation of green coverage and the GSI calculations was less than 5%.

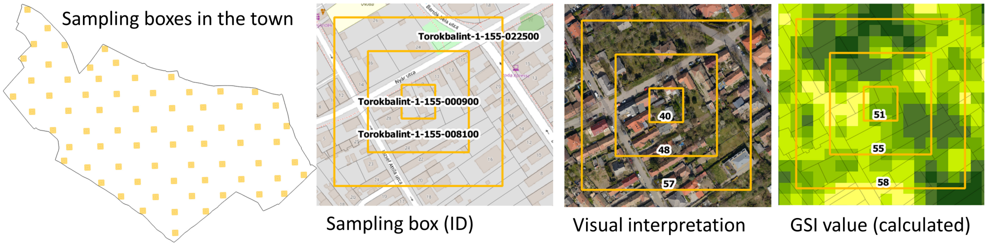

Fig. 2: Validation of Green Space Intensity map based on sampling boxes

The **Green Space Intensity** maps summed up 64% and 65% (GSI) for the whole territory of the town. Thus, these maps based on different sources and resolution (Landsat and Sentinel) had only a minor (1%) difference. Based on the Green Space Intensity maps with zonal statistics function of QGIS software, it was possible to **describe and illustrate** that:

- the forests and the orchards or vineyards (here mostly abandoned) have the highest GSI values (95% and 86%) based on the polygons of Urban Atlas dataset,
- the GSI value of residential area types (medium, dense, continuous) range from 55% to 62% while the industrial and commercial areas have only 39% GSI,
- the average GSI of rural areas (mostly grasslands and few plough lands, which are partly abandoned) vary from 66% to 73%,
- there is surprisingly high ratio of green space along railroads (69%) but it is moderate for roads (49%) and is especially low in case of highway roads (34%).

Most of the “action areas” defined by the settlement development strategy have 40-44% GSI, but the action area Nr. 8 had 74% GSI in 2022. This is very high value for a future industrial park development site. Based on this result, the reconsideration of future use was recommended. Luckily the centre of the town, and the sites of historical character, defined by the town’s guidebook, are located in a small valley, and have good GSI values (55-60%). The average GSI in the 30m neighbourhood of factory buildings is very low (27%) and it is the highest nearby holiday dwellings (63%). The residential building surroundings (within 30 meter) have 54% while the public buildings have only 46% GSI.

Based on the **Land Surface Temperature** map used as dataset with zonal statistics function of QGIS software, it was possible to **describe and illustrate** that:

- the coldest surface is the only lake of Törökbálint (21°C, 70°F) and the green corridors along the creeks (23-24°C, 74-75°F), that is “warm”, considering that this is an average value of 5 months in the middle of the year (recorded at 11:33 am);
- the warmest surface is the so-called DEPO area which is the biggest warehouse area in the settlement, and the average value is 34°C, (93°F), while the extreme single values in the middle of the summer are higher than 40°C (104°F);

- the former military site with an average of 30°C, (86°F) is among the warmest areas;
- the action area Nr. 4. is planned to be an intermodal transport hub but is currently an arable land crossed by a creek with linear forest and shrubland providing moderate GSI (44%) and low temperature average (25°C, 76°F) for the total action area.

The supervised classification results (of VHR infrared ortho imagery) generated a 40 cm resolution layer showing green surface (and non-green surface). This dataset was suitable:

1) to map green spaces in the town with high spatial resolution and accuracy,
2) to measure the ratio of green space for districts, residential blocks and plots,
3) to combine with surface model and to prepare the “Green Canopy Top” (Fig. 3).

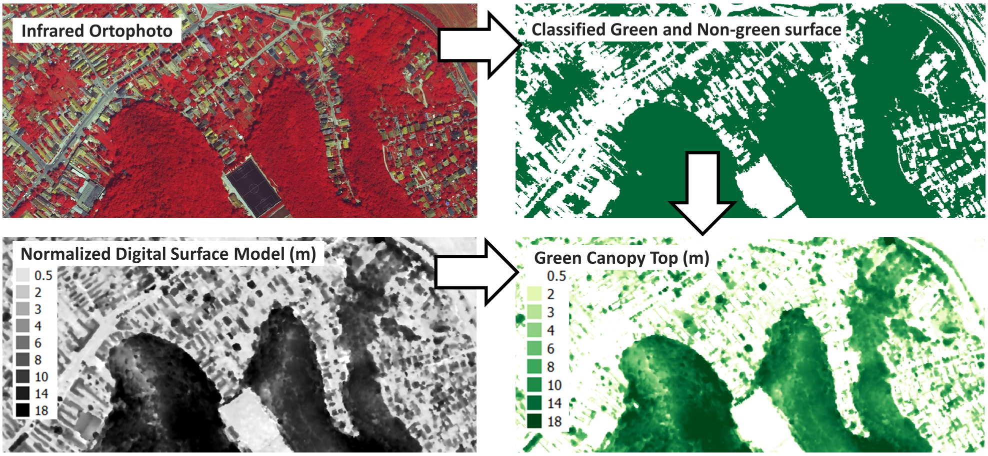

Fig. 3: The generation process of Green Canopy Top Map based on Orthophoto, Classified Green Sites and Normalized Digital Surface Modell

It is necessary to mention that the classified green space map, prepared from a single VHR ortho image, provided high spatial details but did not offer temporal average and thus it did not represent the complete vegetation period. It is a snapshot from 15 June 2019, which is usually the most vital part of the year considering the chlorophyll content of the vegetation.

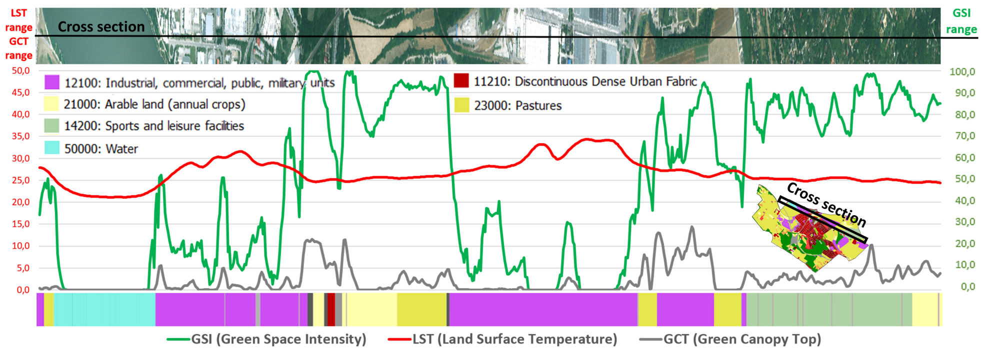

Fig. 4: LST values (°C), GSI and GCT (Green Canopy Top) values along a cross section

A strong **correlation was illustrated** between the green spaces and the areas represented by low Land Surface Temperature. Most of the forests had an average value of 23°C (73°F), but most of the hill-land grasslands' averages were already 30°C (86°F), because of the extremely dry summer and very thin layer of the soil. Compared to the wetlands and lake area of 21°C (70°F), the industrial and commercial sites had 33°C (91°F) (Fig 4). The LST is usually higher in cases where the Green Canopy Top (GCT) is lower, and it is lower where the canopy top is high. In case of grasslands and plough lands, GSI is high in average (65-70%) but the Green Canopy Top is very low (0-2 meters) and the LST values are outstandingly high (27-28°C, 81-82°F). This suggests that the GCT can have more influence on LST than GSI.

4 Discussion

The Green Space Intensity maps and the Land Surface Temperature map were overlaid in Google Earth Pro software as a top layer to provide a perspective 2.5-dimensional view with visual graphic effects to make it comparable with photorealistic elements (Fig. 5).

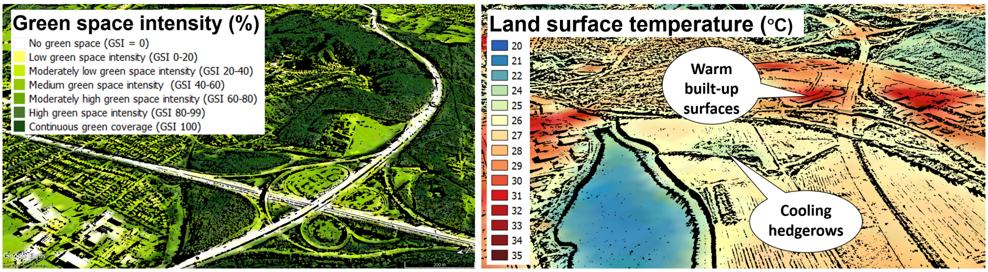

Fig. 5: Green Space Intensity of a highway junction and Land Surface Temperature near the lake in the town of Törökbálint, panoramic cartoon style view in Google Earth Pro

Five years ago, a complete country scale map was prepared with 10m resolution using NDVI and Leaf Area Index (LAI) data of Sentinel satellite transformed to a **Greenness Indicator for Hungary** based on 2017 images (KOLLÁNYI et al. 2019). That research used only few images prepared on three different days within the year. The map is good for country level but needs to be enriched in the number of processed images for the settlement level. Our actual research in Törökbálint shows the best practice of using mean value maps for green space and surface temperature analysis. This enhanced method was tested and elaborated in other cities and towns of Hungary in the last decade (Budapest, Debrecen and Szeged). Our research is innovative in Hungary in preparation of the Green Canopy Top map, that applies a combined use of two data sources and big amount of VHR data. The future development of this analysis is highly recommended as green infrastructure plans must be prepared for 81 towns of Hungary in the near future. The type of analysis we made could be a crucial part of these plans.

In our research, the **application of remote sensing methods** contributed to the general town planning process in Törökbálint and is linked to most of the **topics related and published with geodesign** (DEBNATH et al. 2022). It was decided to protect and partly enhance the old town character area's moderate green space intensity. The further use of two action areas (Nr. 4 and 8 on Fig. 5) defined by the settlement plan started to be reconsidered and revised as these areas have strong roles in green system, and an outstanding role in urban climate mitigation.

We conducted to fill the website of the town Törökbálint with map layers, illustrations and written explanations for decision support purposes. Our research generally fits to the **Geodesign framework** of STEINITZ (2012), even if some of the approaches are not completely covered. In our research, the stakeholders and locals as the "**people of the place"** are free to read or view the results. The data was converted to be understood easily by the decision-makers but there were only a few occasions when the opinions turned into direct feedback.

Our research is missing the purpose of modelling and simulation. The users, stakeholders need to point out the risks, threats and opportunities themselves that should be integrated in the geodesign process ideally from a technological viewpoint (ERVIN 2016) e. g. with scenario modelling. Based on the scheme of our maps a worst-case future scenario and a more heat-resilient scenario with different suburban residential types could be prepared and lead to a more complex and interactive decisions-support system.

Even if there was limited feedback it was clear that the research should be enhanced further with:

1) green space per capita calculations
2) shaded area calculation, or a special calculation for under-canopy layer volume
3) canopy volume calculation, with related field survey.

5 Conclusion and Outlook

Based on the maps, derived from satellite images, the Green Space Intensity and Land Surface Temperature were determined for different land use types, building surroundings, character areas and action sites. The supervised classification of VHR image and surface model processing was used for mapping the height of a Green Canopy Top. In our future research this could be a good base map for per capita calculation, for shaded area measurement, for under canopy volume or canopy volume analysis. We illustrated the relations of green space, surface temperature and canopy height in a diagram of cross section and in perspective visualisations. All maps were integrated in the municipal website of town development. In the town of Törökbálint the research results are can support decisions about land use and green infrastructure planning, considering urban heat island mitigating goals as well.

References

ARYAL, J., SITAULA, C. & ARYAL, S. (2022), NDVI Threshold-Based Urban Green Space Mapping from Sentinel-2A at the Local Governmental Area (LGA) Level of Victoria, Australia. Land, 11, 351.

BMM – Budapest Metropolitan Municipality (2017), The concept of green system development of Budapest, 2017, BFVT Ltd. Hungary.

BOKAIE, M., ZARKESH, M. K., ARASTEH, P. D. & HOSSEINI, A. (2016), Assessment of Urban Heat Island based on the relationship between land surface temperature and Land Use/ Land Cover in Tehran. Sustainable Cities and Society, 23, 94-104.

DEBNATH, R., PETTIT, C. & LEAO, S. Z. (2022), Geodesign Approaches to City Resilience Planning: A Systematic Review. Sustainability, 14, 938.

ERVIN, S. M. (2016), Technology in geodesign. Landscape and Urban Pl., 156, 12-16.

FLOHR, T., HERIS, M. & DERYCKE, E. (2022), An ENVI-met Simulation Data Pipeline for Evaluating Urban Tree Patterns Impact on Urban Microclimate. Journal of Digital Landscape Architecture, 7-2022, 538-548.

GIBSON, P., J., POWER, C. H. (2000), Indroductory Remote Sensing – Digital Image Processing and Applications. Routledge, London.

KOLLÁNYI, L., MÁTÉ, K., PROHÁSZKA, V., DANCSOKNÉ FÓRIS, E. & SALLAY, Á. (2019), Greenness Indicator for Spatial and Settlement Planning Based on NDVI and LAI Indicators, Proceedings of the Fábos Conference on Landscape and Greenway Planning, 6, A 41.

KWAN C., GRIBBEN, D. AYHAN, B., LI, J., BERNABE, S. & PLAZA, A. (2020), An Accurate Vegetation and Non-Vegetation Differentiation Approach Based on Land Cover Classification. Remote Sensing, 12 (23), 3880.

LECHNER KNOWLEDGE CENTRE (2022), Website. https://lechnerkozpont.hu/.

LECHNER KNOWLEDGE CENTRE (2019), Website of surface models. https://lechnerkozpont.hu/oldal/digitalis-felszinmodell (02.01.2023).

LUDWIG, C., L., HECHT, R., LAUTENBACH, S., SCHORCHT, M. & ZIPF, A. (2021), Mapping Public Urban Green Spaces Based on OpenStreetMap and Sentinel-2 Imagery Using Belief Functions. ISPRS Int. J. Geo-Information, 10, 251.

MUNICIPALITY OF TÖRÖKBÁLINT (2022), Municipal Website of Maps in Törökbálint. https://terkep.torokbalint.hu/ (02.01.2023).

NASAR-U-MINALLAH, M. (2020), Exploring the Relationship Between Land Surface Temperatureand Land Use Change in Lahore Using Landsat Data, Pakistan. Journal of Scientific and Industrial Research, Series A: Physical Sciences, 63A (3), 188-200.

ONAČILLOVÁ, K., GALLAY, M., PALUBA, D., PÉLIOVÁ, A., TOKARČÍK, O. & LAUBERTOVÁ, D. (2022), Combining Landsat 8 and Sentinel-2 Data in Google Earth Engine to Derive Higher Resolution Land Surface Temperature Maps inUrban Environment. Remote Sensing, 14, 4076.

PARK, J-H. & CHO, G-H. (2016), Examining the Association between Physical Characteristics of Green Space and Land Surface Temperature: A Case Study of Ulsan, Korea. Sustainabilit, 8 (8), 777.

PARMEHR, E. G., AMATI, M. & FASER, C. S. (2016), Mapping Urban tree canopy cover using fused airborne LIDAR and satellite imagery data, ISPRS Annals of the Photogrammetry, Remote Sen. and Spatial Info. Sciences, Vol. III-7, 2016 XXIII ISPRS Cong. Prague, CZ.

RANAGALAGE, M., ESTOQUE, R. C. & MURAYAMA, Y. (2017), An Urban Heat Island Study of the Colombo Metropolitan Area, Sri Lanka, Based on Landsat Data (1997-2017). International Journal of Geo-Information, 6, 189.

SANNIGRAHI, S., BHATT, S., RAHMAT, S., UNIYAL, B., BANERJEE, S., CHAKRABORTI, S., JHA, S., LAHIRI, S., SANTRA, K. & BHATT, A. (2018), Analyzing the role of biophysical compositions in minimizing urban land surface temperature and urban heating. Urban Climate, 24, 803-819.

SANTOS, T., TENEDÓRIO, J. A. & GONÇALVES, J. A. (2016), Quantifying the City's Green Area Potential Gain Using Remote Sensing Data, Sustainability, 8, 1247.

SOBRINO, J. A., JIMÉNEZ-MUÑOZ, J. C. & PAOLINI, L. (2004), Land surface temperature retrieval from LANDSAT TM 5. Remote Sensing of Environment, 90, 434-440.

STEINITZ, C. (2012), A Framework for Geodesign: Changing Geography by Design. ESRI Press, Redlands, CA.

U.S. GEOLOGICAL SURVEY (2022), Earth Explorer Website. https://earthexplorer.usgs.gov/ (02.01.2023).