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Urban Planning Based on Nature—A Nature-Based Solution

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Abstract

After an international contest announced by the City of Abu Dhabi "Cool Abu Dhabi Challenge"[1] and the article published as a digest of a paper titled A Nature-based Solution [1], the decision has been made to take part in improving thermal comfort in public spaces by mitigating the impact of the effect of Urban Heat Islands (UHI)[2] in the city of the Belgrade. The basic research aims at achieving the balance between the conflicting impacts when the buildings with their infrastructure and water-green surrounding area are in such correlation that it fulfils acceptable living and heating standards and reduces the use of fossil fuels for cooling the urban areas (buildings). By implementing the remote detection it is possible to analyze and quantify the impact of over-building on the temperature rise in urban areas as well as the disturbance of the heating comfort and the increased demand for additional cooling. Now it is possible to create virtual models that will incorporate this newly-added urban vegetation into urban plans, depending on the evaporation potential that will affect the microclimate of the urban area. Such natural cooling can be measured and adapted and hence aimed at a potential decrease in areas with UHI emissions [2]. Suitable greenery in the summer season can be a useful improvement which concurrently enables and complements several cooling mechanisms—evaporative cooling and evapotranspiration, *i.e.* natural cooling systems. The remote detection shall establish and map the "healthy" and "unhealthy" greenery zones—that is the vegetation zones with

[1]The Department of Municipalities and Transport of Abu Dhabi invited architects and engineers to participate in global creative ideas competition to improve outdoor thermal comfort in the public space by mitigation the impact of Urban Heat Island Effect in the city. The dead line was May 12, 2020.

[2]Urban heat islands are, as their name suggests, a type of heat (thermal) islands that occur in urban environments, with temperatures that are inappropriately higher than in the natural environment. Urban heat islands occur due to the increase of artificial urban areas that heat up more and increase the temperature compared to the natural environment.

the highest evaporative potential with the "cooling by evaporation" effect and also, by implementing the urban prediction model, it shall propose green infrastructure corridors aimed at a potential decrease in the Urban Heat Island Emission.

Keywords

Nature-Base Solution (NBS), Urban Heat Islands (UHI), Land Surface Temperature (LST), Land Use and Land Cover (LULC), Normalized Difference Vegetation Index (NDVI)

1. Introduction

For the purposes of this study, an innovative, state-of-the-art technology was implemented. There has been a number of theoretical and experimental works (regarding spectral wavelengths) to quantify land surface temperature (LST) and land use and land cover (LULC), such as [3] [4]. The novelty lies in remodeling higher LST urban areas which was then implemented on the project model with lower LST vegetation patches. Through the repeated multi spectral analysis these classifications were synthesized which resulted in a temperature change and a reduction of urban heat islands. Such cooling effectiveness can be measured and adapted and therefore facilitate green infrastructure corridors aimed at a potential decrease in the urban heat islands emission. Using remote sensing, now it is possible to create a prediction model that will incorporate urban vegetation into space depending on the evaporation potential of the leaves—canopy, wind direction, humidity, irrigation of plants, and physical urban shape (buildings and infrastructures) that will affect the microclimate of the urban area. By implementing the geospatial method-remote sensing it is possible to analyze and quantify the impact of over-building on the rise of temperature in urban areas, as well as the disturbance of the heating comfort and the increasing demands for additional cooling. Implementing the method of multispectral analysis of satellite images on the city's urban block and its contact with the bordering areas, a possible development of UHI will be shown [5] [6] [7].

By analyzing the cause/effect relationship of the envelope of built-up (high-rise) objects and of the solar radiation distribution on the environment, we carried out the estimation of the lack of green vegetation as the factor of regulating the micro-climate of the inner city area. Appropriate greenery in the summer season can be an effective enhancement, which at the same time enables and supplements several cooling mechanisms evaporative cooling and evapotranspiration, *i.e.* natural cooling systems. Method—remote sensing and method of calculating Normalized Difference Vegetation Index (NDVI) [6] [7], shall establish and classify the map of the healthy and unhealthy greenery zones, that is the vegetation zones with the highest evaporative potential that can be incorporated in the urban prediction model [1]. The reclassification method was used in the following way: a certain spectral wavelength (that is reflected in the near-infrared (NIR) range of classification for healthy greenery) was implemented on the prediction model, as was the lowest temperature range of that zone [8]. The synthesis method was applied to the LULC to determine the new reduced temperature range (LST) which modified the model. The energy model applied in the research served to confirm the remote sensing results as summer solar exposure in the urban area strongly influences energy consumption, especially for high building densities. This study analyzed how the energy consumption and morphology of buildings are in relation to the surrounding environment (like humidity, airspeed, and the shape of buildings), and how they cause local variations of microclimate [2] [9].

Case Study

The wider area of interest is the central part of the city of Belgrade. The area extends between the following geographic CRS coordinates: EPSG: 32634-WGS 84/UTM zone 34N, spatial coordinates: 455171.1731362311984412, 4960311.7453266866505146, 457102.1731362311984412, 49642585.76425885. The sample is a rectangular polygon for the boundaries of coverage, shown the color composite (BRG), **Figure 1**. The same could be applied on the surface included in the Master plan, **Figure 2(a)** (Legal Acts, Službeni list, Beograd, Nos. 11/2016) or the like. It should be noted that the method of spatial analysis is identical both for the given example of the central zone of Belgrade (**Figure 1**) and for any corresponding urban or spatial plans (**Figure 2(a)**). **Figure 2(b)** shows the diagram of annual wind strengths for the locality.

The focus of the research and the nature-based design solutions was to answer the two basic questions:

- What is the relationship between urban blue-green infrastructure and urban thermal comfort?
- How does this concept reduce urban heat islands (UHI) and improve thermal comfort of the residents?
- Can design solutions be implemented in standard urban planning procdures?

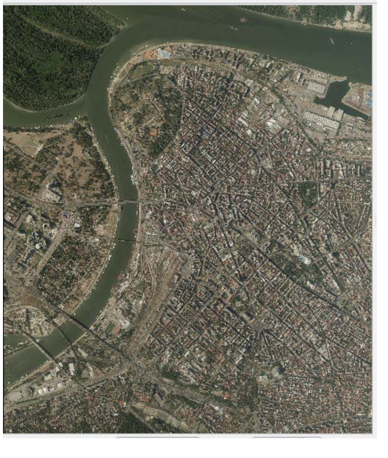
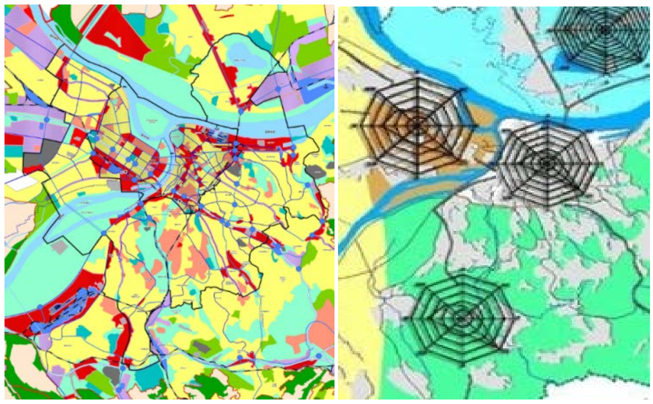


Figure 1. Coverage (B + R + G).



(a) (b)

Figure 2. (a) Master plan, 2016; (b) Wind rose.

2. Methodology

2.1. Geospatial Methods and Analysis

As far as the time frame of the study is concerned, it dates from the summer periods of 2013 to 2022, (aerial images, (wavelengths in the visible range B + R + G with near-infrared spectrum (NIR) band)), (source: Republic Geodetic Authority (RGA)), overlapping with the data from the Landsat 8 satellite (bands: B2, B3, B4, B5 + NIR) and Thermal Infrared band images (TIRs: (TR 10 + TR 11)) to improve the accuracy of land use and land cover (LULC) and land surface temperature (LST), (**Figures 3(a)-(c)**).

2.2. Detection of UHI by Thermal Bands (TIR), Taken from *Landsat* 8

The basic specifications for Land sat 8 data were GeoTIFF as the output format and they were resampled using the Cubic Convolution method in 30 m pixel size, while Universal Transverse Mercator (UTM)[3], as the datum.

The applied multispectral bands were initially processed as Level 1 data and delivered in a 16-bit unsigned integer format. The data were rescaled at the top of the atmosphere (TOA) reflectance and TOA brightness temperature, with a 30 m spatial resolution as it was set in the research [8], proposed a method for deriving the surface temperature (LST) in two steps: First, digital numbers (DNs) are converted to brightness. Second, radiation is converted to surface temperature using Landsat's specific estimate of Inverse Planck's law[4] [2] [4].

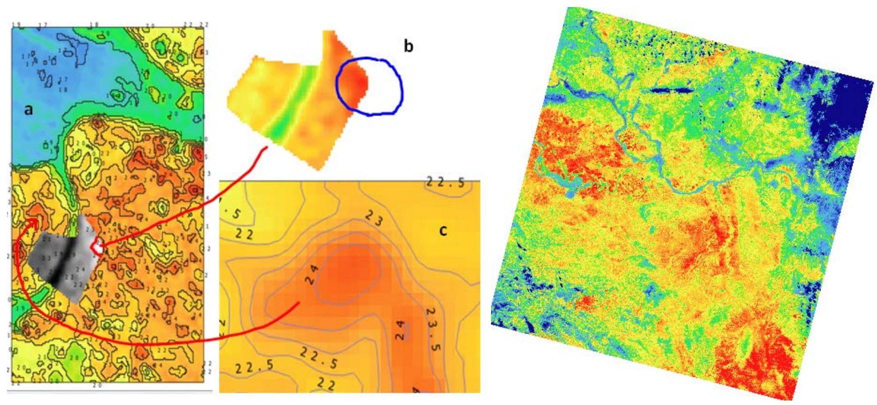
TOA brightness temperature or Land Surface Temperature (LST) was calculated by applying the inverse of the Planck function and the arithmetic mean of LST from bands TIR (10 and 11).

Using the spectral analysis and classification method (such as Normalized Difference Vegetation Index (NDVI)) [6] [7] [8] [10], urban structure and vegetation

[3]The UTM is a coordinate system designed for projecting a 3D sphere (Earth) onto a 2D map.

[4]Planck's law describes the spectral density of electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature T, when there is no net flow of matter or energy between the body and its environment.

(a) (b)



(c)

Figure 3. (a) False color composite, R + G + B; (b) False color composite, B + G + NIR (RGA, 2013); (c) arithmetic mean of TIR 10 and TIR 11 (2013, Landsat 8).

zones that affect microclimate changes in the urban area were classified. By manipulating geometric, attributive and temporal components of spatial data, (especially thermal, vegetation and physical structures), the pollution zones were determined by increasing thermal characteristics, which were categorized through the concept of urban heat islands (UHI). This method also determined the zones of forest vegetation that influence the regulation of the acceptable temperature comfort zone [1].

Satellite Data Processing

All associated science data for the method applied were provided in accordance with the Landsat 8 Data Users Handbook [11]. The first step in the processing of thermal satellite images was the conversion of pixel values DN into at-sensor spectral radiance, [1]. The conversion was done using the following formula:

1) $L\lambda = ML * DN + AL$

where: $L\lambda$ is the spectral emission registered at sensor (Watts/(m^2 * srad * µm); ML is a multiplicative scale factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number); AL is an additive scale factor from the meta data (REFLECTANCE_ADD_BAND_x, where x is a band number).

The second step was to convert the reflectance to the atmospheric temperature over the land surface, according to the USGB hand book:

2) $T = K2/\ln\left(K1L\lambda + 1\right) - 273.15$ (Planck's inverse equation)

where: $K1$ and $K2$ are radiation constants from the metadata, and $L\lambda$ is the effective wavelength, (Đorđević, 2021).

Metadata data from Landsat images: $K1$ and $K2$ values for Landsat 8 thermal bands:

$$K1\_CONSTANT\_BAND\_10 = 774.8853$$

$$K2\_CONSTANT\_BAND\_10 = 1321.0789$$

$$K1\_CONSTANT\_BAND\_11 = 480.8883$$

$$K2\_CONSTANT\_BAND\_11 = 1201.1442$$

The following calculation was used: arithmetic mean for LST (an average of a set of numerical values for LST band 10 and LST band 11). Such calculation based on arithmetic mean gives a better precision as compared to single-band values. As a side note, there are a few methods to calculate the emissivity of each pixel of the NDVI classification. One is "split windows" and the other—"singe windows", (Đorđević, 2021).

3) The "single window" model was used:

$$\text{Land surface temperature} = BT/1 + w * (BT/p) * \ln(e)$$

where:

BT = At satellite temperature.

W = wavelength of emitted radiance (11 μm).

$q = h * c/s (1.438 \times 10^{-2}$ m K).

h = Planck's constant (6.626×10^{-34} J/K).

s = Boltzmann constant (1.38×10^{23} J/K).

c = velocity of light (2.998×10^{8} m/s).

For Landsat 8, $w = 10.8$, and equation $p = h * s * c = 14,380$, BT is T from step 2), actually the atmospheric temperature. The emissivity was calculated as follows in the description.

Each type of earth land cover has a different emissivity that is influenced by the instant physical state of the object. Therefore, it is important that the value of ε is measured at the time of the passage of the satellite platform for each individual image. Since we do not have such field measurements, we need to use one of the methods already described to calculate this parameter. An average value (based on the published measurements of spectral libraries) for each type of land surface was assigned to the classification method, but the current state of the site could not be taken into account. Therefore, the method of calculating NDVI (Normalised Difference Vegetation Index) was used.

For the Landsat images, we used threshold values for NDVI as follows:

If NDVI < 0.2 type of land cover is considered soil, and $\varepsilon = 0.97$;

If NDVI > 0.5 type of land cover is considered vegetation, and $\varepsilon = 0.99$;

If 0.2 ≤ NDVI ≤ 0.5 type of land cover is considered mixed.

The equation for calculating NDVI (vegetation index) [3]-[8] [10] was:

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

The range lies between −1 and 1 so that the values from −1 to 0 relate to the urban area and from 0 to 1—to natural vegetation.

1) $\varepsilon = mPv + n$,

where:

P is the proportion of vegetation and ε is emissiveness.

2) $P = \left(\text{NDVI} - \text{NDVI}_{\min} / \text{NDVI}_{\max} - \text{NDVI}_{\min}\right)^2$.

3) $\varepsilon = 0.004Pv + 0.986$.

3. Results and Discussion

3.1. Thermal Maps

In the course of measurement, during the summer months 2013-2021, in the area of the River Sava banks, the sensors noted a constant difference in temperature between the forest zones (such as Veliko ratno ostrvo[5], Košutnjak[6] and some others) and the central parts of the city with the heavy thermal innertion structure and albedo effect (SRI < 20) [12]. Veliko ratno ostrvo is characterized by large areas of dense forests with canopy/tree-top temperature of about 17˚C as compared to central metropolitan areas with temperatures over 25˚C (referential date 25/08/2013). The constant difference in temperatures measured in the summer periods from 2013 to 2021 could potentially establish the trend (**Table 1**).

Adequate vegetation during the summer period can be a very effective measure that simultaneously provides and complements several cooling mechanisms, evaporative cooling and evapotranspiration, *i.e.* cooling on a natural basis [13]. In contrast to these effects in the central parts of the city, where the physical structures with a heavy type of construction (concrete, brick, etc.), and high thermal inertia and without the minimum required greenery, "patches", distinctive for urban heat islands (UHI), can be clearly observed. Owing to the inadequate expansion of the physical structures, they increasingly group into units whose frequency of impact on the border with the UHI has a tendency to further pollute the living space and disturb the comfort. There is also an increasing need for the use of artificial cooling devices (HVC) in the wider area of the central city zone, and therefore the need for more intensive use of the Nikola Tesla thermal power plant (Tent A and B), which undoubtedly contributes to further pollution not only by three-atom gases (CO_2, O_3, NO_2, etc.) but also PM 2.5 and PM 10 particles.[7]

Although the dates from **Table 2** indicate the appearance of a trend, from a scientific point of view there is not a sufficient number of samples in the appropriate time intervals to characterize the changes as a "trend" that indicate a tem-

[5]An island at the confluence of the Sava and the Danube.

[6]A park/forest area between the central municipalities of Čukarica and Savski venac of about 330 Ha and altitude over 120 m. It comprises both deciduous and evergreen tree species.

[7]These are very small particles, the designation PM10 and PM2.5 means that we are talking about particles with a size of 10 and 2.5 micrometers. Since they are very small and light, fine particles tend to stay longer in the air than heavier particles, and the concentration of PM2.5 during 24 hours is considered unhealthy if the value is over 35.4 μg/m^3.

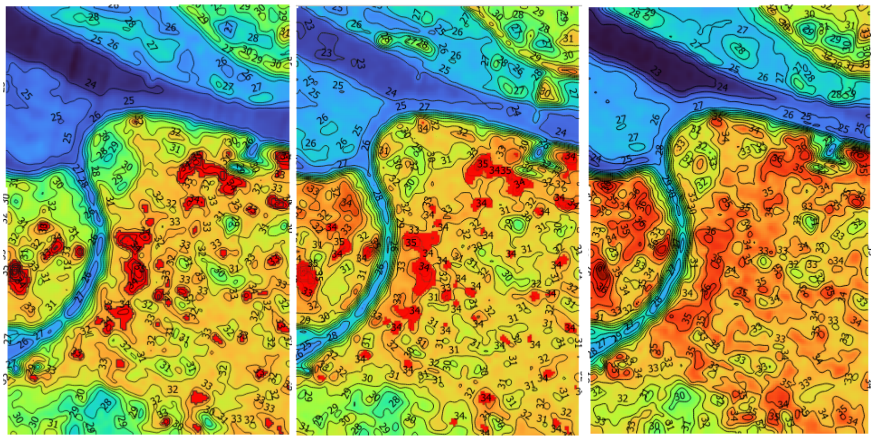
perature increase that definitely affects climate change. Figures 4(a)-(c), show the dynamics of changes over time and the emergence of UHI. Regardless of insufficient research data, the phenomena that marked the summer period especially of 2021 and later in 2022 are worrying. The extreme temperature, within the central city zone, recorded on August 15, 2021, ranged from 32˚C to 39˚C, (Figure 5). During the summer period of 2021, several heat waves lasting longer than 7 days were observed. The level of stress that affected the population as well as the surrounding biodiversity depended on the duration of those heat waves.

Table 1. Differences in temperature oscillations.

TEMPERATURE TABLE BY YEAR		
YEAR	DIFFERENCE ˚C TREND	AVERAGE ˚C
2021. August	17.20	34.20
2019. May	10.12	19.20
2018. August	8.71	28.67
2017. September	11,00	31.50
2016. April	8.87	23.84
2015. August	10.54	31.10
2013. August	9.09	21.75

Table 2. Presentation of the percentage of UHI in the central city zone for 2015; 2018; 2021.

2015		**2018**		**2021**	
ZONE	AREA Ha	ZONE	AREA Ha	ZONE	AREA Ha
UHI ≥ 34˚C	1.37	UHI ≥ 34˚C	1.39	UHI ≥ 34˚C	11.33
SCOPE	281.1	SCOPE	281.1	SCOPE	281.1
% UHI	4.80%	% UHI	4.90%	% UHI	39.90%
AVERAGE	31.10˚C	AVERAGE	28.8˚C	AVERAGE	34.42˚C



(a) (b) (c)

Figure 4. (a) Landsat 8, 2015; (b) Landsat 8, 2018; (c) Landsat 8, 2021.

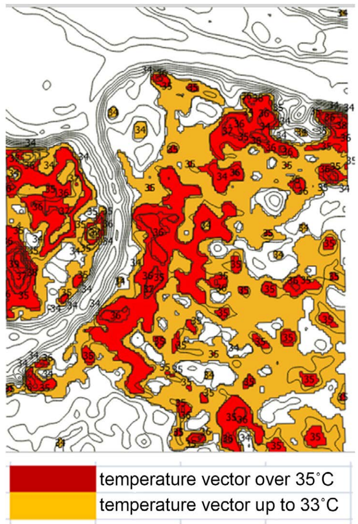


Figure 5. Areas with extreme thermal values.

Detection (Quantification) of LULC and LST

Figure 6(a) and Figure 6(b) show a detailed situation of the influence of land cover typology according to land use/land covered (LULC). Figure 6(a) presents the classification according to the methodology of NDVI which quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). So, the range 0.6 - 0.8 indicates the presence of healthy trees, whereas other classifications are represented by several classes (range: −1 to 0, artificial features and water bodies; 0.2 to 0.4, bare soil and grass; 0.6 to 0.8, forest variety). Figure 6(b) represents Sieve classes method and looks into the neighboring 4 or 8 pixels to determine if a pixel is grouped with pixels of the same monitored class.

Table 3 shows the intersection of LULC classifications and thermal maps, so that each NDVI shows its thermal footprint on the ground.

3.2. Detection (Quantification) of Vegetation

Forest greenery is an important source of adiabatic cooling. As Table 3 shows, forest greenery, although integrated in urban space, poses as a corrective of heat accumulative and emission of the physical structure. The method of evaporative humidification (cooling) is the process of evaporation, which is the physical process of evaporation of moisture formed on leaves, trees and forest ground. Evapotranspiration is the physiological evaporation that accompanies photosynthesis.

The remote sensing method was used to classify, among other things, other vegetation, which is important for evaporative processes of natural cooling. NDVI has been used for over 30 years. It has been used for global vegetation analysis, which is based on linear regression of NDVI values with direct examination of biomass factors and percent of coverage [13] [14]. This index is very important because it can monitor seasonal and perennial vegetation changes.

Average temperatures by NDVI classes indicate that flowing river streams and then forest vegetation function as a corrective factor in mitigating extreme temperature pollution that occurs in urban areas (Table 3). The question arises whether we can measure our impact on anthropogenic changes. With abiotic factors (excessive construction, removal of appropriate vegetation, creation of physical obstacles in the direction of air flow, generation of dust particles as well as three-atom gases and traffic frequency) we directly affect the pollution caused by heat islands and the creation of an urban city microclimate that adversely affects the health of the population. The result from the previous analysis indicates that the integrated forest vegetation on the surface of approx. 281 ha, (including the central city zone) reduces the total average temperature by 2.82˚C.

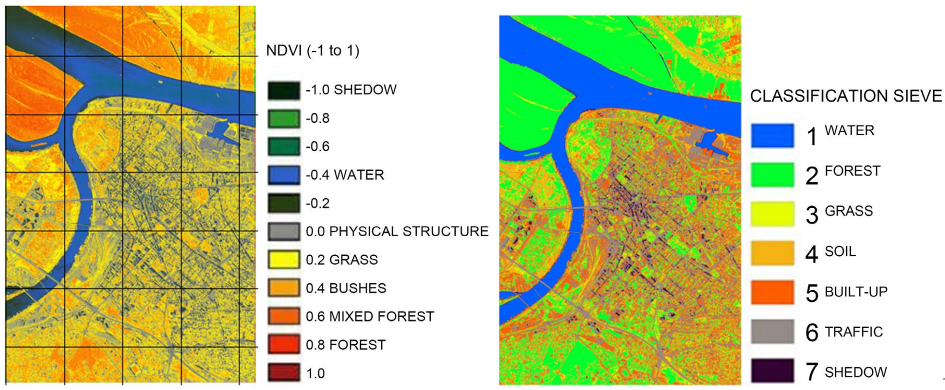


Figure 6. (a) NDVI, 25.08.2013, in the range from −1 to 1; (b) LULC classification.

Table 3. Intersection of NDVI classes with LST isotherms.

Temperate ˚C	Uncategorized classification	Water	Forest	Grass	Soil	Built up	Traffic	Shadow
17	280	1,276,243	1,479,430	13,267	6293	2187	4158	8999
18	1794	1,565,067	1,838,957	79,063	42,162	17,348	15,924	25,982
19	4186	830,150	732,426	121,576	108,567	75,309	30,402	27,339
20	17,890	280,137	897,617	362,654	390,483	221,531	67,236	24,179
21	53,196	76,174	1,225,129	673,401	1,060,632	689,687	326,936	30,955
22	92,073	15,117	1,098,525	818,766	1,689,985	1,986,128	1,561,182	126,429
23	50,100	5313	421,349	365,595	823,555	1,554,826	1,692,875	242,102
24	6690	1255	34,246	29,494	103,605	249,322	315,817	39,201
25	561	68	1088	1529	9224	33,711	33,949	1227
	m^2	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**
	226,771	4,049,525	7,728,767	2,465,346	4,234,504	4,830,050	4,048,478	526,413
							TOTAL m^2	28,109,854
˚C	**21.8**	**18.11**	**19.48**	**21.3**	**21.69**	**22.15**	**22.44**	**22.03**
Forest vegetation affects the reduction of LST in the area of coverage for:				**2.82**	˚C			
Representation of plants that can be considered a forest and that affect the microclimate:				**27.49%**	percentage			

3.3. Case Study, (August 23, 2013, Plot 2337/2, Location: New Belgrade—Shopping Center Ušće)

The application of the relatively new Geographic Information System (GIS) tools was simplified by the use of remote sensing which enabled the efficiency of data networking and classification according to several criteria, as well as their analysis and proposal of measures for the remediation of urban space. The following figures and tables show specific elements for the graphic and textual part of the urban detailed plan related to each individual cadastral plot (referral date August 25, 2013). The accuracy of the calculated area of plots was made by comparing it with official data in Table 4. In the following example, plot 2337/2 (Novi Beograd) with built-up facilities and a vegetative environment was analyzed (Figure 7 and Table 3). A rough review of Figure 8 shows the difference between the isotherms of 24˚C on the part of the building and the tangent road. The vegetation on the north-western edge of the plot establishes a temperature balance at the level of 22˚C. Figure 9 shows the level of detailed urban plan (cadastral plots overlapped with thermal—LST) in order to see the thermal effects on each plot. Figure 10 is a comparative map which shows cadastral parcels overlap with LULC.

Table 4. Data from the Republican Geodetic Institute (RGI) with a registered total plot area of 48,545 m^2.

Land data (plots and parts of plots)					
No. parcel	Parts of parcel	**AREA m^2**	**street**	**Land use**	**Land type**
2337/2	1	18,495	Boulevard Mihaila Pupina	land under the building	city building land
2337/2	3	1251	Boulevard Mihaila Pupina	land under the building	city building land
2337/2	4	28,799	Boulevard Mihaila Pupina	land surrounding the building	city building land

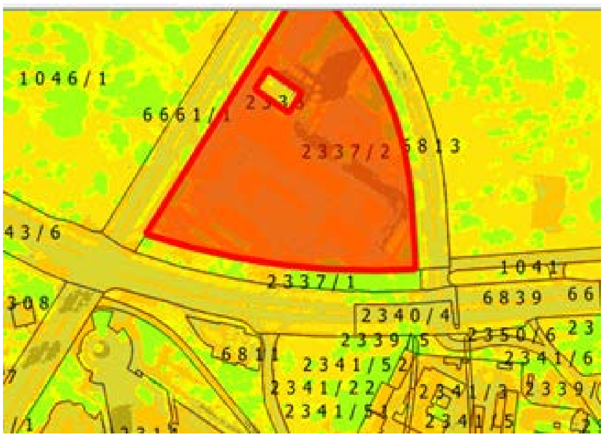


Figure 7. Plot 2337/2 (New Belgrade).

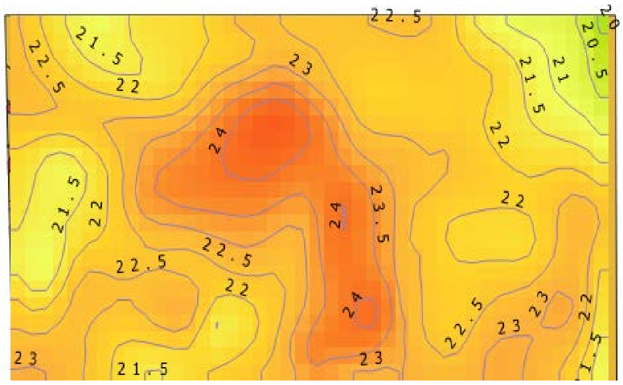


Figure 8. Isotherms on 23.8.2013 (TIRs. 10 and 11, LandSat 8).

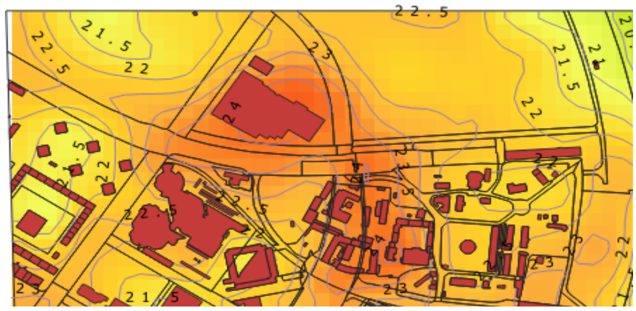


Figure 9. Cadastral plots overlapped with thermal—LST.

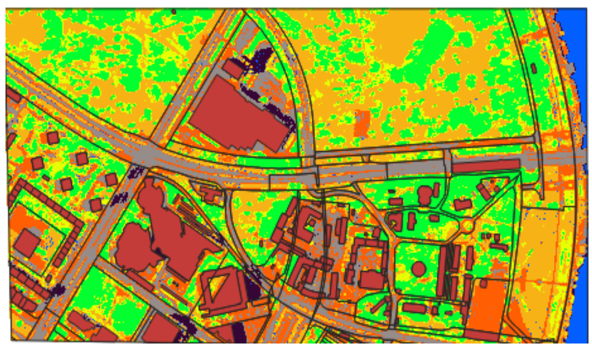
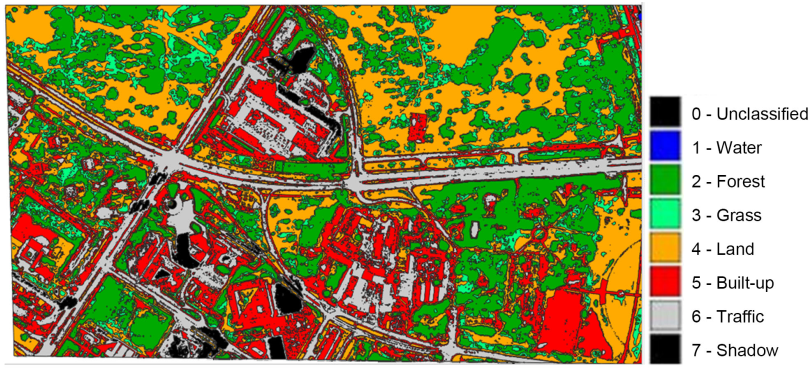


Figure 10. Cadastral plots overlapped with LULC.

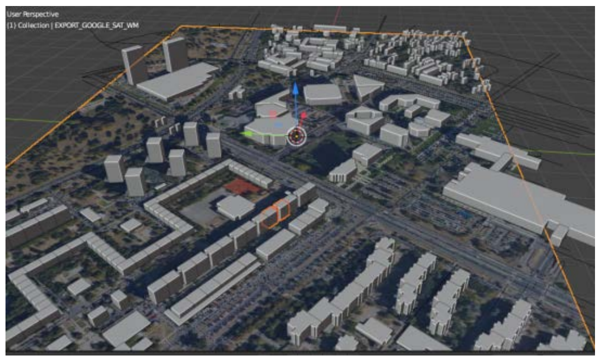
Using the GIS tools (Table 5), temperature classification (LST) was performed for each individual plot. The plots in question have three temperature levels ranging from 22˚C to 24˚C. Verified calculated surface is: Σ48,512 m^2 (foult: −33 m^2, precision 94%).

The existing condition of the plot in question 2337/2—Novi Beograd, on August 25, 2013—the way of using the land cover areas, (*i.e.* the purpose of the land use) LULC is shown in Figure 11(a)—realistic height ratio and volumes of built-up are shown in Figure 11(b)—the implemented NDVI classification was determined for each class through the area it occupies on the plot (Table 6). Table 7, which follows, shows the intersection of LULC classifications and thermal maps, so that each class (NDVI) reflects its thermal footprint on the ground.

The average temperature (T) was determined to be 21.75˚C. The temperature index is the quotient of the average temperature increased by the difference to the average temperature of the heat island by 10%, in this case, it is 23.9˚C, so the calculated heat coefficient index of 0.917 is less than 1.



(a)



(b)

Figure 11. (a) Graphic display of LULC classifications for the urban block (shopping centre Ušće—New Belgrade); (b) 3D model of the wider area (2022).

Table 5. Numerical representation of LST classification for plot 2337/2—New Belgrade (Ušće shopping centre).

	TEMPERATURE ˚C					
	19	20	21	22	23	24
No. Plot	m^2	m^2	m^2	m^2	m^2	m^2
661/1	0	0	0	9311	4127	0
2337/2	0	0	0	**7149**	**22,096**	**19,267**
2341/29	0	0	0	0	515	0

Table 6. Numerical representation of LULC classification for plot 2337/2—New Belgrade.

No. PARCEL	Non classification	WATER	FOREST	GRASS	LAND	BUILT-UP	TRAFFIC	SHEDOW
1042/1	68	0	91	168	1118	2972	2033	0
6661/1	194	0	1225	873	2680	4482	4041	0
2337/2	190	0	3476	1767	2934	16,975	18,923	4249
2341/29	3	0	39	20	50	296	108	0

Table 7. Intersection of LST and LULC classification for plot 2337/2—Novi Beograd.

No. of the plot	Temperature	19˚C	20˚C	21˚C	22˚C	23˚C	24˚C	Σ m²
2337/2		**0**	**0**	**0**	**7149**	**22,096**	**19,267**	**48,512**
classification	Non-classified	Water	Forest	Grass	Land	Built -up	Traffic	

The Thermal Coefficient Calculation

A large part of urban planning is related to the building plot. Terms such as the level of development, permitted occupation, regulation line, and construction line are parameters with which every urban planner deals. The mentioned parameters largely determine the mutual influences (relationships) between the objects, the plot and the environment. Only rules well determined for the optimization of the plots, buildings and surroundings provide results that can affect the reduction of energy consumption and CO_2 emissions.

The thermal coefficient is calculated by dividing the average temperature within the scope of the urban plan (GUP, PGR, PDR, UP) by the total average temperature within the scope of the PGR (plan scope) and is calculated according to the following formula.

$$I = T_{(zone)} / (Tn + 10\%)$$

Here T is the individual zone temperature, Tn is the average temperature of the total surface area (which naturally represents the average temperature of the urban plans (Master, PGRa, PDR[8] or similar). 10% is added to the average temperature Tn, since the temperature obtained in this way is considered to be the temperature that characterizes an UHI. If the coefficient is greater than 1, it is necessary to implement remediation measures to reduce UHI. In other cases, when the coefficient is less than 1, they are considered to be a healthy space free from heat islands.

The case study analysis for plot 2337/2—New Belgrade, indicates that there is no reason for remediation or thermal rehabilitation. The average temperature (T) was determined to be 21.75˚C. The temperature coefficient is the quotient of the average temperature increased by the difference to the average temperature of the heat island by 10%, in this case it is 23.9˚C, so the calculated heat coefficient 0.917 is less than 1 and for that reason it is considered a non-polluted environment.

4. The Influence of the Building Envelope on the Process of Generating UHI

The total absorbed radiation was determined for the assumed thermal conductivity parameters for the structural façade of the tower of the Ušće building, Uf = 1.1 W/(m² K), emissivity 0.85%. The relative ratio of incoming incident radiation calculated cumulatively for the summer period from May 29 to August 30, is shown in **Figure 12**, with the fact that the roof surface is the most exposed to

[8]Plan of general regulation, Detailed plan etc.

radiation and reflects about 648,000 Wh/m² in sunny weather during that period. The north-east and north-west façades are exposed to solar radiation in the amount of 1,821,600 Wh, while the south-west and south-east façades are exposed in the amount of 3,280,700 Wh. The plot 2337/2—New Belgrade, reflects about 85% of the facade radiation, while the surroundings absorb up to 50% of the radiation value (4,347,000 kWh * 85% * 50% = 1,847,475 kWh on the surface of the plot), the average additional heat is 38,000 Wh/m² (as it does not extend linearly as can be seen in **Figure 12**, which is caused by an increase in the average ambient temperature (from 21.5˚C to 23.4˚C) by 1.9˚C), [2] [9].

5. Urban Modeling

The process of urban "green" remediation[9] of the urban structure (the objects that significantly influence the microclimate through radiation, emission and thermal inertia) is carried out by introducing suitable vegetation with evaporative potential. The new model was based on the Urban Planning Project named "Varoš na Vodi", by Dragoljub Dik Manojlović. The project was created at the request of the Serbian Academy of Sciences and Arts as a preparation for a public International urbanity competition for the central zone of Belgrade, [15].

5.1. Research Area (Level of Remediation Plan)

The area of interest is the central part of the city of Belgrade, the left and right banks of the Sava River. Coordinate reference system CRS: EPSG: 32634-WGS 84/UTM zone 34N, spatial coordinates: 455171.1731362311984412, 4960311.7453266866505146, 457102.1731362311984412, 49628385.6506.7466.7453266866505146. Geopositioning was carried out within these outlined boundaries which are the basis of the project "Varoš na vodi" (**Figure 13**). In **Figure 13(a)** and **Figure 13(b)** [15], the new prediction model to the left and right of the Sava River (the Sava banks) is shown as a base layer on the urban concept "Varoš na vodi" as follows:

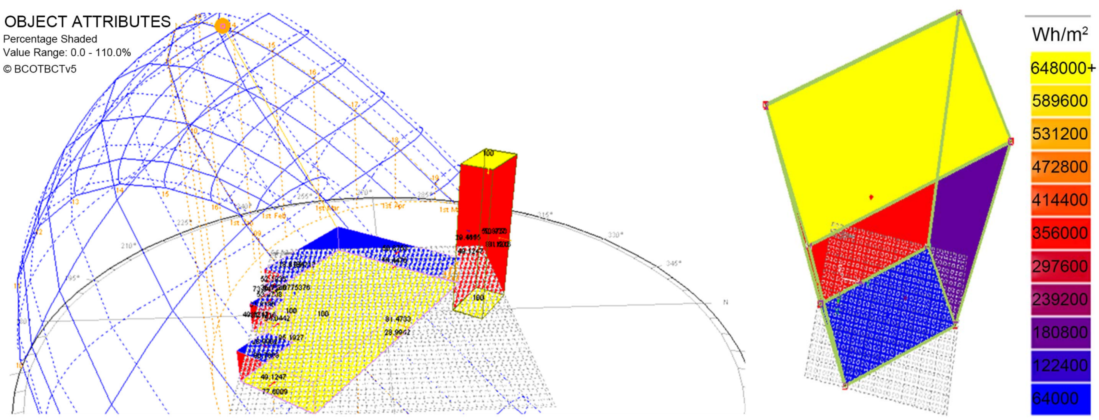
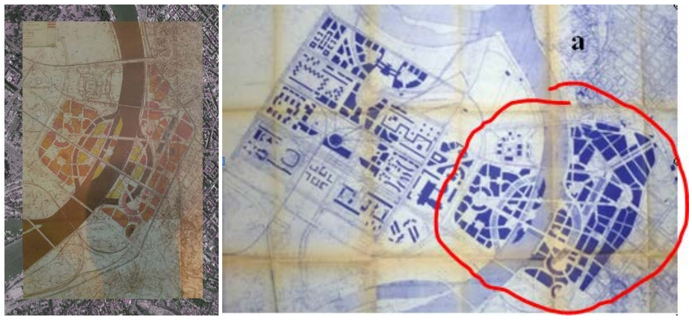


Figure 12. Total solar radiation on August 23, 2013.

[9]Remediation in the environment is a measure for recovery of existing pollution in order to lower the concentration of pollutants to a level that does not pose danger to the environment.



(a) (b)

Figure 13. (a) wavelength B + R + G; (b) The urban concept "Varoš na vodi".

Georeferenced base (Figure 13(a)—wavelength B + R + G), the area covering approx. 155 ha., as a background for that layout (Figure 13(b)) on a referential day—August 25, 2013.

5.2. Results and Discussion

The benefits of urban blue-green infrastructures have become known because they intercept airborne three-atom particles, thus reducing pollution levels, particularly extreme heat. They provide shade and cooling by means of evapotranspiration. Through the manipulation of geometric, attributive and temporal components and geospatial data (Figure 14), especially thermal, vegetation and physical structures, the existing characteristics of land use were changed and a newly designed LULC classification was introduced. According to the model created on the basis of the urban concept "Varoš na Vodi", by 4.62-fold increase in the area of forest vegetation is predicted, primarily on the right bank of the Sava River which has a high cooling potential. For instance, for the newly predicted forest vegetation, the mean values of the spectral footprint for the NDVI class (wavelength for the forest), within zones Veliko Ratno Ostrvo and Košutnjak were taken. The new concept was edited as "the new wavelength of forests" as green envelopes to roofs and building façades and tree lines to the streets. The areas of new classes from LULC are shown in Table 8(a) and Table 8(b) as follows:

The Water class in the model was increased by approx. 30% (the Sava River was expanded by two associated channels). Streaming water surfaces with their temperature attributes have a favorable effect on the sustainable development of the city, primarily as a factor in regulating the surrounding gravitating microclimate (reduction of UHI, elimination of greenhouse gases, reduction of fine particulate matter PM 2, 5 and PM 10). There are also a number of other dependent advantages such as health benefits, social values, economy benefits, location rent, traffic, etc.

The results of the model created on the concept of "Varoš na vodi" reduce the average temperature on the analyzed area of 154 ha, as compared to the reference (initial) temperature on August 25, 2013. The result of the created comparative model (Table 9) is in favor of the reduction of the average temperatures by 1.16˚C in the prediction model area.

Green roofs, green façades, evenly distributed vegetation with lush canopies along traffic corridors (with a developed irrigation system), add to the volume of the physical structure and influence the neutralization of urban heat islands. By introducing river backwaters, the author of the solution “Varoš na vodi” not only created a suitable sustainable ecological environment, but also defined the space in several different thematic levels. The level of attractiveness of the first order of urban rent is maintained not only for buildings overlooking the Sava

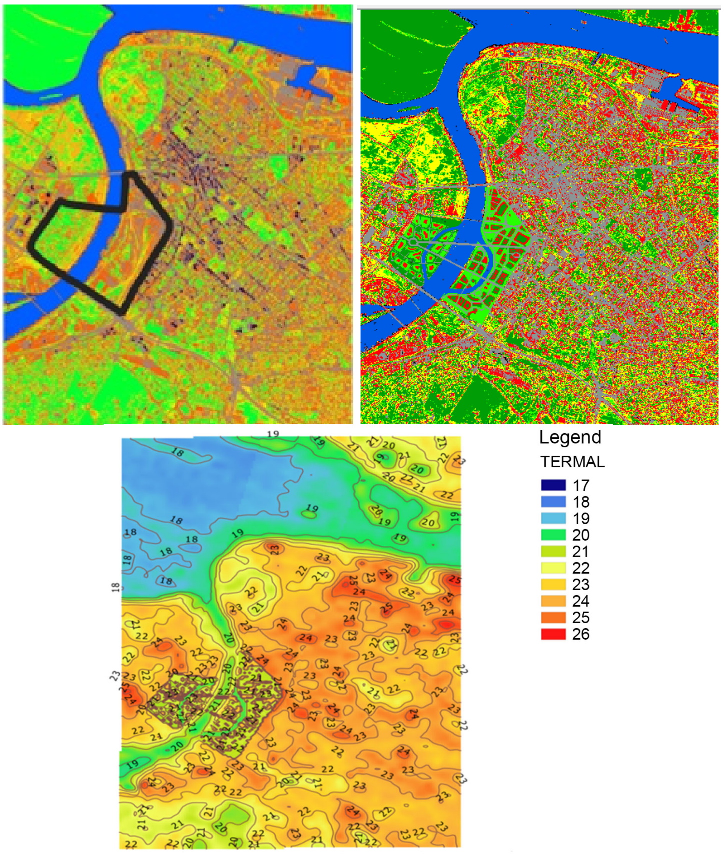


Figure 14. Prediction model “Varoš na vodi”. Base Layout LST, (August 25, 2013.) with newly designed classes.

Table 8. (a) Modeled classes “Varoš na Vodi” and (b) Existing classes on 25, Aug. 2013.

(a)

CLASS	Percentage (%)	Area (m^2)
WATER	21.894	339,489.24
FOREST	22.115	342,921.61
GRASS	29.952	464,436.72
LAND	0.228	3,531.09
BUILT-UP	12.077	187,271.99
TRAFFIC	13.683	212,171.11
SHADOW	0.030	463.77
TOTAL	99.980	1,550,285.52

(b)

CLASS	Area (m^2)
0 physical structure	177,856.01
1 bushes, grass, traffic, etc.	693,637.73
2 bushes/wood etc.	367,998.32
3 deciduous forest	69,688.21
4 mix forest	4353.89
5 ever green forest	148.98
6 water	235,187.02
TOTAL	1,548,870.18

Table 9. Comparative results of isotherm surfaces—(reference condition on August 25, 2013.) as compared to the prediction concept "Varoš na vodi".

Model "*City on the water*"		**Temperature condition on the day August 25, 2013.**	
Temperature ˚C	**Area (m^2)**	**Temperature ˚C**	**Are (m^2)**
19	130,500.00	**19**	119,700.00
20	918,900.00	**20**	99,900.00
21	79,200.00	**21**	430,200.00
22	326,700.00	**22**	470,700.00
23	42,300.00	**23**	271,800.00
24	45,000.00	**24**	126,900.00
25	900.00	**25**	24,300.00
Total:	1,543,500.00	Total:	1,543,500.00
Average temperature:	**20.59˚C**	**Average temperature:**	**21.75˚C**
Result of the temperature Reduction:	**1.16˚C**		

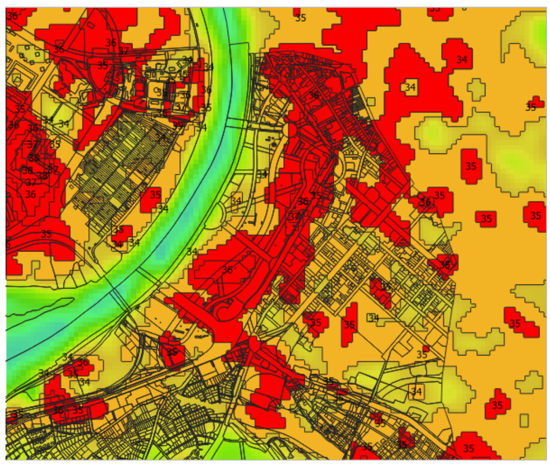
River, but also for the inner area of the urban space, *i.e.* Savska Street. The attractiveness of at least four additional levels of visibility is created, river traffic is integrated into public traffic and a differentiated solution is created with an optimal quotient of physical structure and vegetation.

5.3. An Overview of the Thermal Condition of the Central City Zone (Reference Date August 15, 2021)

The area of the central city zone currently represents a dynamic investment project along the right bank of the Sava River. The appearance of the Sava banks changes from year to year. That process can also be followed through the thermal footprint detected on densely built high-rise. With the implementation of the "Belgrade Waterfront", in the volume and layout of the built physical structure and in the absence of appropriate vegetation (**Figure 15(b)**), a phenomenon that indicates the possible appearance of urban heat islands occurs. The formation of physical non-transparent obstacles along the right bank of the Sava River has made ventilation of the Vračar plateau almost impossible and poses a threat to the overall city airing (necessary flow speed of 5 m/sec). The flow of air from the direction of the Sava River towards the higher elevations of Vračar is limited to 0.5 m/sec in the summer period. Urban pockets are ideal for the accumulation of air pollution, not only thermal but also PM 2.5 and PM 10 particles. Current results are in favor of an increase in temperature directly next to the residential towers linearly by almost 4˚C, (attachment **Figure 15(a)**, showing the zone UHI > 34˚C, marked with red polygons).

6. Time/Space Classification

The Time Analysis during the period between 2013 and 2022 shows direction and maybe even a trend of the UHI emergence due to excessive construction on the observed area. The classification, which was carried out on the samples (of August 2015 and August 2022), showed that the degradation of vegetation is the consequence of the sprawl of new urban areas (**Figure 16** and **Figure 17**). A new practice—appropriately dubbed urbicide—has been established to build new constructions with accompanying infrastructure at the expense of green areas. It is obvious that the profession and decision-makers have primarily been following the demands of capital, so that about 14.9% of greenery has irretrievably disappeared or been degraded in the previous 7 years mostly due to excessive construction (**Table 10**). The primary consequences are greater pollution from urban heat islands and air pollution that directly impact human health and biodiversity.



(a)

(b)

Figure 15. (a) UHI zones > 34˚C determine the increasing thermal pollution at the location of Belgrade Waterfront; (b) Photo of the construction area with some greenery on the site in question.

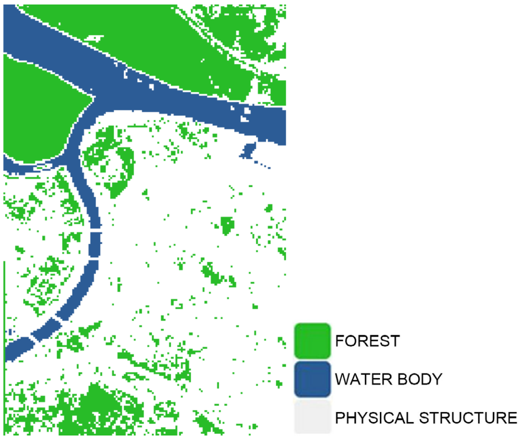


Figure 16. Classification August 2015.

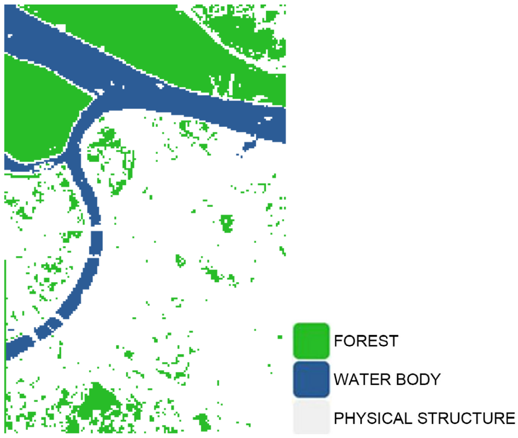


Figure 17. Classification August 2022.

Table 10. Comparative classification results for the period from 2015 to 2022.

class	area 2015	area 2022	difference Ha	%
Forest	73,120	62,170	10,950	14.97%
Water	34,450	34,500	−50	−0.13%
Built-up	169,960	180,890	−10,930	−6.04%

A note: All errors that occur in the tables result from the pixel size and the scaling of the images downloaded from the "LandSat 8" satellite. The size of downloaded pixels for wavelengths of the visible spectrum (RGB) is 30/30m, while for thermal (TIR) channels, they are 90/90m.

7. Conclusions

It is important to point out that whenever the balance and consensus between major stakeholders involved in the development of cities are not reached, it results in the degradation of one or more elements of sustainable development. The proposed method of remote sensing refers to the participation of the evaporative potential of vegetation in the reduction of UHI. The procedure was carried out with a deductive urban analysis from a smaller scale (master plan level), then urban blocks (level of detailed urban plan) and finally to the plot itself. The results of the analysis should enable urban planners and the city administration to make a Yes/No decision about the need to develop a Remediation plan to balance opposite influences on the Blue, Green and Grey infrastructures which should be in the thermal comfort zone (a healthy space free from UHI). The absence of adequate proportion of vegetation can modify the reflective effect, such as the calculated incident solar, direct, and diffuse solar radiations falling on objects that increase the temperature in the area. The need to reduce the harmful effects of excessive adiabatic expansion (the uncontrolled sprawl of urban areas) compels the cities of today to adapt to the needs of their inhabitants as well as to the profit. Otherwise, the result remains a greater thermal stress (pollution) to which the population is exposed, greater energy consumption for cooling and definitely—greater emission of three-atom gases (mainly CO_2)—the primary cause of the greenhouse effect.

During the summer months 2013-2021, in the area of the River Sava banks, the sensors noted a constant difference in temperature between the forest zones and the central parts of the city of Belgrade. The difference in temperatures between dense forests with tree-top temperature of about 17˚C and central metropolitan areas with temperatures over 25˚C was noted. Forest vegetation affected the reduction of LST in the area of 281.1 ha of coverage for 2.82˚C on the referential day 25 August 2013. During the monitoring period of previous 7 years, more than 14.9% of greenery has irretrievably disappeared or been degraded mostly due to excessive construction.

The thermal effects on the zone of implementation of the urban plan—Special Purpose Plan "Belgrade Waterfront"—affect all locations exposed to temperature influences with the excessive and inadequate expansion of urban zones. The measured temperatures are inappropriately higher than in the natural environment and show the phenomenon of UHI. Regardless of insufficient research data, the phenomena that marked the summer period especially of 2021 and later in 2022 are worrying. The extreme temperature, within the central city zone, recorded on 15 August 2021, ranged from 32˚C to 39˚C. During the summer period of 2021, several heat waves lasting longer than 7 days were observed. The level of stress that affected the population as well as the surrounding biodiversity depended on the duration of those heat waves.

The result of balancing the Blue, Green and Grey infrastructures should be an appropriate urban remediation plan as the case study for plot 2337/2 (Novi Beograd). The absorbed and transmitted solar radiations, which are dependent on the built-up and surface material (thermal inertia) of the urban construction, were also calculated. They reflect about 85% of the façade radiation, while the surroundings absorb up to 50% of the radiation. The radiation is about 1,850,000 kWh on the surface of the plot. The average additional heat is 38,000 Wh/m^2 (as it does not extend linearly) which is caused by an increase in the average ambient temperature (from 21.5˚C to 23.4˚C) by 1.9˚C. This should result in the green infrastructure diminishing the surface temperature of the land in the affected area which, if the thermal index is <1, should model the missing green infrastructure in such a way that it neutralizes UHI.

One of the solutions *A Nature-based Solution* (*NBS*)[10] aims to solve the problem of UHI. It opens up a possibility of a wide implementation of new urban-planner tools in accordance with the "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [16].

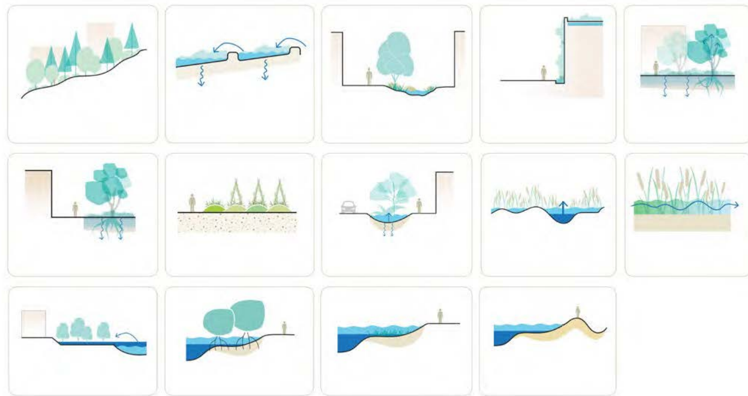


Figure 2-2: Example ofa hybrid solution integrating green and gray infrastructure

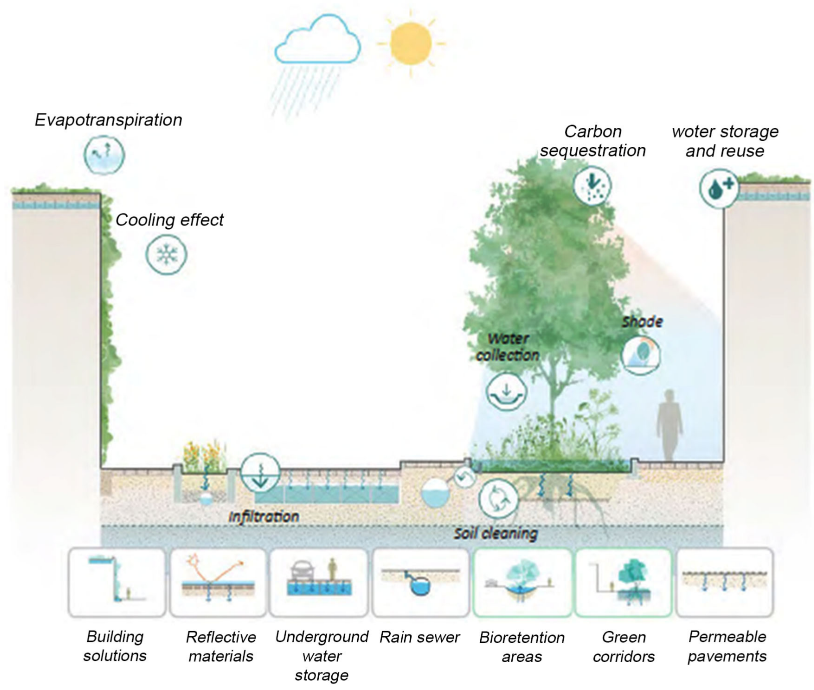


Figure 18. Building designs guidelines (Graphic attachments of "A Nature-Based Solution").

[10]Source: https://naturebasedsolutions.org. The Global Program on (NBS) for Climate Resilience has been developed by the UN-World Bank Group with a mission to increase investments in solutions that integrate and strengthen natural systems across regions and sectors. Nature-based solutions are approaches that use nature and natural processes for delivering infrastructure, services, and integrative solutions to meet the rising challenge of Healthy city—climate change and urban planning of green cities, in order to reduce three-atomic gases and urban heat islands (UHI). (Ozment *et al.* 2019 Sudmeier-Rieux *et al.* 2021).

Urban concept "Varoš na Vodi" as a case study, was analyzed and compared without and with prediction green façades and rooftops and without and with a street tree line as proposed by the Detailed Urban Plan, for any given parcel. This state-of-the-art methodology was applied to the optimized prediction concept of vegetation resources. Newly created model corresponds with reflected wavelengths of the vegetation depending on the evaporation potential incorporated into this urban plan that affects the microclimate of the built-up area. Such natural cooling influence was measured and showed that could be achieved potential UHI emissions decrease in the urban areas. The goal of this urban plan was to carry out urban remediation on parcels that generate UHI. The result of the created comparative model is in favor of the reduction of the average temperatures by 1.16˚C in the prediction model area. The concept of urban "green" remediation—Urban Modeling[11], has been proposed along with new urban planning tools—green corridors, green façades, and green roofs, followed by the change of the shape and the volume of buildings and energy efficiency (**Figure 18**)[12]. Enormous urban pollution necessitates "a healthy city" as a *Conditio sine qua non*[13].

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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[12] Graphic attachments of "A Nature-Based Solution". Source: https://naturebasedsolutions.org.

[13] A Latin legal phrase meaning: "An indispensable and essential condition".

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