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ANALYSIS OF THE URBAN HEAT ISLAND OF THE CITY OF TREBINJE USING REMOTE SENSING PRODUCTS

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Abstract: The phenomenon of urban heat islands is becoming increasingly pronounced and is one of the main reasons for the increase in air temperature in cities. The thermal regime of urban areas is different from peri-urban and rural areas, and is reflected in faster daytime heating and slower nighttime cooling. There are two main approaches to the study of urban heat islands - direct measurements of air temperature in the field and readings of temperatures from remote sensing products. The paper will analyze remote sensing products from the Landsat 8 satellite in order to determine differences in thermal characteristics of specific types of land use in the territory of the city of Trebinje. For the purposes of the analysis, a buffer zone was defined within a radius of 10 km from the central point of the city (geographical coordinates: 42.7112° N, 18.3436° E), which enabled the inclusion of urban, rural and natural areas. A total of 12 satellite images were collected and a time frame covering the summer months of 2024 (June 1 to August 31) was used. Given the sensitivity of thermal data to the presence of clouds, a cloud filter (CLOUD_COVER < 20%) was applied to ensure the quality of the input data. Additionally, a cloud mask and cloud shadows were implemented using the QA_PIXEL layer to remove contaminated pixels. The research results show that built-up areas have higher temperatures compared to other land use classes by more than 2°C. All analyses were conducted using open source software packages. The research results can be useful for various sectors such as public health, spatial planning, energy, water management, forestry and similar areas. In addition, the research results may contribute to future detailed studies aimed at defining local climate zones and thermal variations within them.

Keywords: Urban heat island, Land surface temperature, Remote sensing, Landsat 8, Land use, Thermal regime, Urban-rural gradient, Spatial analysis, Local climate zones, Trebinje.

1. INTRODUCTION

Urbanization and climate change are two very important phenomena, which are interconnected and which will significantly affect the human population [1,2,3]. It is expected that 6.3 billion people (about 68% of the world's population) will live in urban areas by 2050 [4]. The built-up area of urban settlements is increasing faster than the population in urban areas, which significantly affects land use patterns, the environment, biodiversity, the hydrological cycle and climate at local, regional and even global levels [5, 6]. According to Hopkins et al., urban areas emit up to 70% of global anthropogenic greenhouse gases that negatively affect global climate change [7]. The effects of climate change, to a greater or lesser extent, are evident in all urban areas, regardless of their size [8]. Urban areas, or built-up areas, with their characteristics affect the local energy balance and create urban heat islands. Although a large number of factors influence the creation of urban heat islands, it can be said that the greatest influence is exerted by different land uses, urban morphology, and the materials from which infrastructure and building structures are built [9, 10]. The above factors create specific thermal characteristics of urban areas, which differ from the thermal characteristics of rural areas in the surrounding area [11, 12, 13]. In addition, reduced evapotranspiration in combination with a large share of built-up areas affects heat accumulation and heat radiation, which ultimately results in increased air temperature [14, 15]. Urban heat islands negatively affect energy consumption, thermal comfort, public health and certain outdoor activities [16, 17]. Two approaches are most commonly used to study urban heat islands. The first approach refers to direct measurements of air temperature, while the second approach refers to the use of remote sensing products, more precisely thermal images from which the thermal footprint of the substrate is read [18, 19, 20]. The use of remote sensing products has certain advantages, primarily if the spatial coverage of certain images is taken into account, the analysis of which can determine patterns of urban heat islands [21].Ранија истраживања су показала да постоји висок степен корелације између температура ваздуха мерених директним путем и температура подлоге које су мерене методама даљинске детекције, али са извесним разликама у зависности од начина коришћења земљишта, односно подлоге [22, 23]. За истраживање термалних карактеристика подлоге, користе се различити сензори постављени на сателитске платформе. Најпознатији сензори за наведене намене су спектрорадиометар средње резолуције МОДИС (Moderate Resolution Imaging Spectroradiometer – MODIS), Ландсат (Landsat TM, ETM+, OLI/TIRS) и АСТЕР [24, 25, 26].

The phenomenon of urban heat islands in larger urban areas on the territory of the Republic of Srpska is in the initial phase of research and has been conducted only in the largest city - Banja Luka. Research into bioclimatic conditions and thermal characteristics of the urban part of the city of Banja Luka was conducted using methods of direct air temperature measurements with mobile and stationary sensors in daytime and nighttime conditions [27, 28, 29]. The results of the research for the City of Banja Luka indicate different thermal characteristics within the urban area itself during the summer, where differences in air temperature of 5-6°C were recorded between the densely built-up city center and the main city park. The phenomenon of the urban heat island was analyzed using remote sensing methods for the cities of Mostar [30], Sarajevo [31, 32] and Banja Luka [33]. In all three cases, the difference in ground temperatures for the built-up urban area and the rural environment was analyzed. During the summer, significantly higher ground temperatures were recorded in urban areas compared to the surrounding area, and a larger temperature amplitude was recorded in Mostar.

This paper aims to provide insight into the thermal characteristics of different land uses in the territory of the city of Trebinje, using remote sensing products. For the purposes of the work, 12 satellite images from the Landsat 8 platform were collected and analyzed, and a time frame covering the summer months from June 1 to August 31, 2024 was used. The research results may be useful in the process of spatial and urban planning, and in defining mitigation and adaptation measures to climate change in the sectors of public health, housing, civil protection, agriculture, water management, and landscape architecture.

2. MATERIALS AND METHODS

Research Area

The research was conducted in the city of Trebinje, located in the southeastern part of the Republic of Srpska. For the purposes of the analysis, a buffer zone was defined within a radius of 10 km from the central point of the city (geographic coordinates: 42.7112° N, 18.3436° E), which enabled the inclusion of urban, rural and natural areas.

Satellite Data

For the purposes of estimating land surface temperature (LST), optical and thermal data from the Landsat 8 satellite (Operational Land Imager – OLI and Thermal Infrared Sensor – TIRS) were used. They were downloaded from the LANDSAT/LC08/C02/T1_L2 collection (Collection 2, Level 2) via the

Google Earth Engine (GEE) platform. The time frame used was the summer months of 2024 (from June 1 to August 31). Considering the sensitivity of the thermal data to the presence of clouds, a cloudiness filter (CLOUD_COVER < 20%) was applied to ensure the quality of the input data. Additionally, a cloud and cloud shadow mask was implemented using the QA_PIXEL layer to remove contaminated pixels.

Data processing and LST calculation

The calculation of land surface temperature (LST) is based on a single-channel method, using the thermal channel ST_B10 (thermal infrared radiation). The calculation was carried out through the following steps:

1. Radiometric calibration: ST_B10 was scaled using a factor of 0.00341802 and an offset of 149.0 to obtain the brightness temperature in Kelvin.
2. Calculation of NDVI (Normalized Difference Vegetation Index): By combining the spectral channels SR_B5 (NIR) and SR_B4 (RED), NDVI was calculated as an indicator of vegetation coverage.
3. Surface emissivity estimation: Emissivity was determined based on NDVI values, using the NDVI Thresholds method in the range $NDVI \in [0.2, 0.5]$.
4. Calculation of LST: The final surface temperature expressed in degrees Celsius was obtained by applying the Planck equation adapted for Landsat 8 and thermal channel B10, with correction for surface emissivity.

Data Analysis and Export

For each Landsat scene that met the cloud cover and time frame criteria:

– The LST and NDVI values were calculated for each pixel.

– The results were visualized and exported as GeoTIFF files at a spatial resolution of 30 meters in the WGS 84 coordinate system.

Software Tools

All data processing was performed in the Google Earth Engine environment (JavaScript API), which allows access to large temporal-spatial archives of satellite data and parallel processing on a server infrastructure. Export of results and post-processing were realized using the open source software package QGIS.

3. RESULTS AND DISCUSSION

For the purposes of the research, a detailed map of land use in the analyzed area was made. A digital orthophoto from 30.08.2024 was used as a ba-

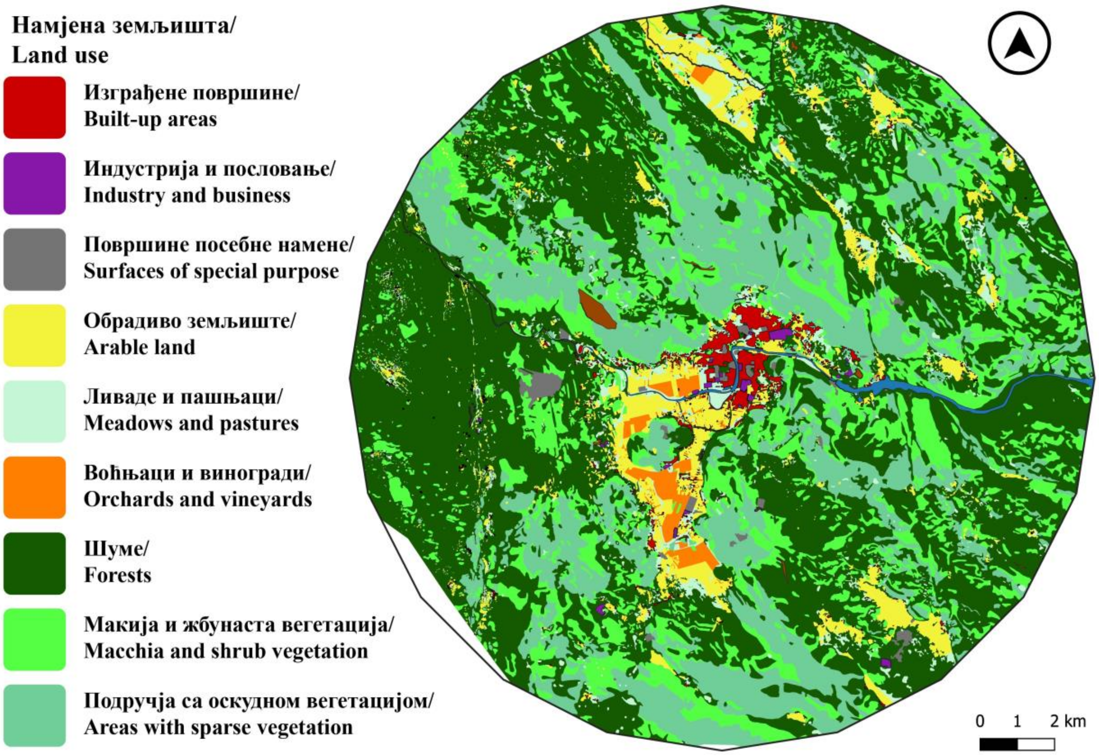


Figure 1. *Structure of land use in the research area*

sis for land use. The areas were digitized in the open source software package QGIS 3.28.14. Due to the large number of different land uses, a generalization was made and a total of 9 classes were distinguished: built-up areas, industry and business, special-purpose areas, arable land, meadows and pastures, orchards and vineyards, forests, maquis and woody vegetation, and areas with sparse vegetation.

Given the spatial size of the studied area, it was determined that the morphological characteristics of the terrain are diverse and that the altitude variable should be included in the analysis of the thermal characteristics of certain land use classes. As is known, a change in altitude changes the temperature of the air and the substrate.

Data on altitudes were obtained by analyzing a digital terrain model with a resolution of 5 meters. The mentioned digital terrain model is a product of the Republic Administration for Geodetic and Property-Legal Affairs of the Republic of Srpska. The entire area was separated into three altitude, or hypsometric, zones by reclassifying the raster in the GRASS GIS software package, using the “r.reclass” option. The first altitude zone refers to areas up to 300 meters above sea level and occupies 60.6 km2. The altitude zone, which covers areas between 300 and 500 meters, covers 64 km2. The third zone covers areas between 500 and 700 meters, is the largest territorially and covers 126.8 km2. The fourth zone covers areas between 700 and 900 meters and has an area of 48.3 km2. The fifth zone covers a relatively small area (from 900 to 11,000 meters) and covers an area of 6.6 km2, while the smallest zone covers an area of 0.3 km2 (above 1,100 meters).

To calculate the thermal characteristics of the substrate, the products of the Landsat 8 mission were used. The products, or images, were downloaded from the geoportal “Earth Explorer” of the US Geological Survey (earthexplorer.usgs.gov). A total of 12 images, L1 processing level, from 2024 were downloaded.

Landsat 8 has one panchromatic channel with a spatial resolution of 15 meters and eight multispectral channels with a spatial resolution of 30 meters. In addition, Landsat 8 also has all the thermal channels with a spatial resolution of 100 meters, the data of which are downscaled to a resolution of 30 meters [34].Термалне карактеристике подлоге израчунате су на основу НДВИ индекса (NDVI – Normalized Difference Vegetation Index) и коефицијента емисивности подлоге (LSE – Land Surface Emissivity) [35].

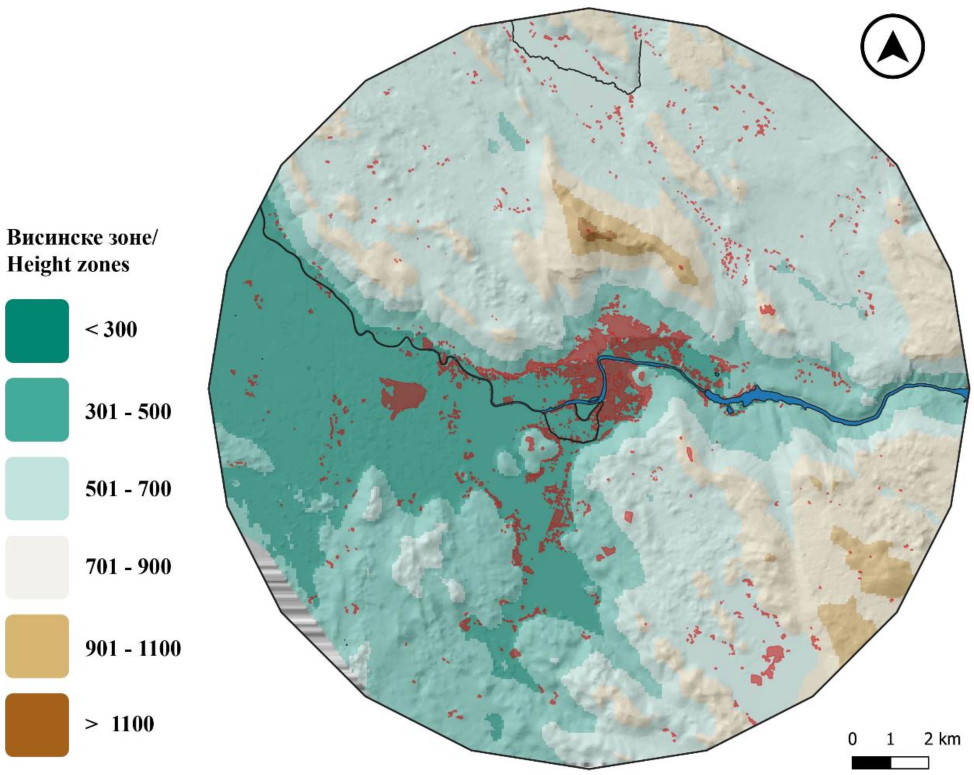


Figure 2. *Elevation zones in the study area*

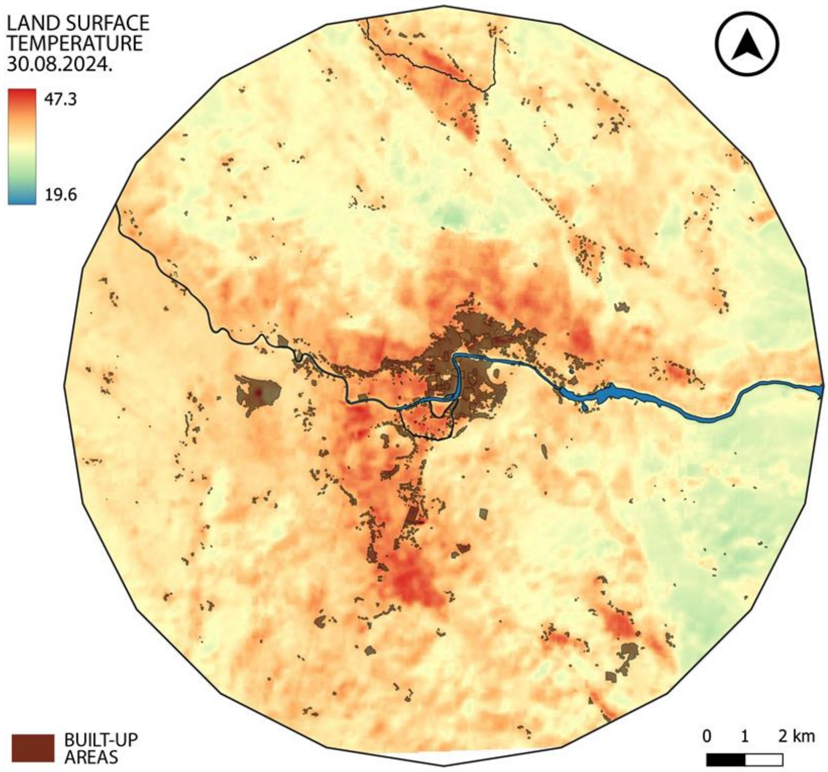


Figure 3. *Surface temperatures (in °C) in the observed area, August 30, 2024 - with built-up areas*

The QGIS 3.28.14 software package was used to calculate the thermal characteristics of the substrate. Within the aforementioned software package, the Semi-Automatic Classification (SCP) plugin was also used, primarily for preliminary processing of the source images, i.e. for atmospheric corrections of the images.

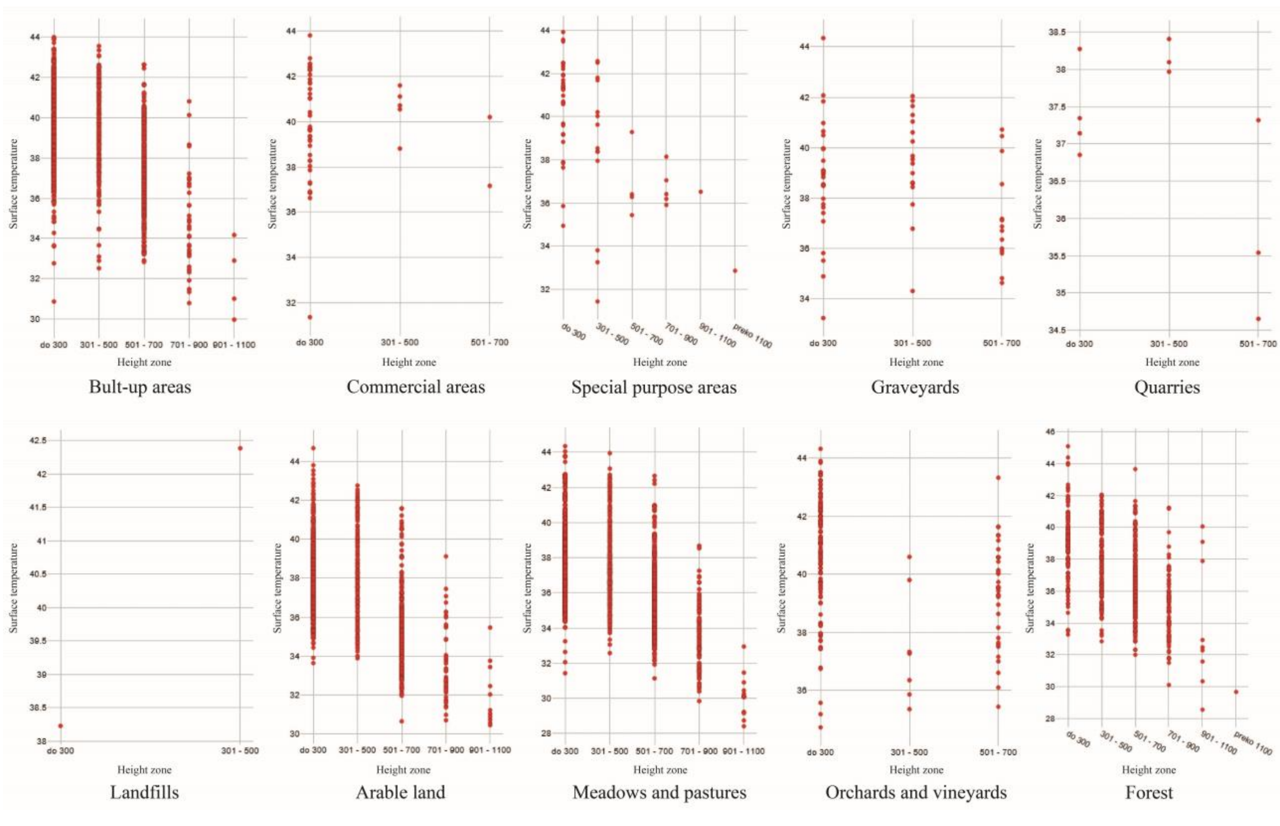
The first altitude zone (up to 300 meters) contains the city's inner urban area and most of the built-up areas. The listed built-up areas include zones of family and individual housing of various storeys, business and housing, business and production, and the central city zone. On average, the surface temperature on August 30, 2024 for built-up areas was 40.01°C. A slightly lower average value was recorded in the polygons of urban greenery and water bodies and watercourses (37.21°C). The reason for the small difference in surface temperatures between built-up areas and urban greenery is the high share of greenery on plots where individual housing is located and the significant areas of greenery along roads that are associated with built-up areas due to the level of detail. Other barren areas (cemeteries, warehouses of loose construction materials, etc.) had an average temperature of 38.75°C.

Agricultural areas in the first altitude zone emitted an average of 37.97°C, while forests and forest land had an average temperature of 38.03°C. The lowest temperature in the first altitude zone was observed in watercourses and water surfaces (35.45°C). On average, the thermal footprint of the solid waste landfill was 38.23°C. It is important to emphasize that the highest temperature in the first altitude zone was 47.3°C, and was recorded in the pixel corresponding to the built-up areas. The lowest temperature value in the first altitude zone was recorded in water surfaces and was 35.45°C. A relatively large range between the minimum and maximum surface temperatures was also recorded in the studies conducted for Mostar, Sarajevo and Banja Luka.

In the second altitude zone (from 300 to 500 meters above sea level), similar values were recorded. Built-up areas emitted an average temperature of 39.45°C, while urban greenery had an average of 38.5°C. On other barren surfaces, an average temperature of 38°C was recorded, while agricultural areas had an average substrate temperature of 37.5°C. Lower average temperatures were recorded in the zone covered by maquis and shrub vegetation (36.81°C). The highest temperature in the second altitude zone

Table 1. *Surface temperatures by purpose and altitude zones (30.08.2024.)*

Category	***Average surface temperature***					
	< 300	301 - 500	501 - 700	701 - 900	901 – 1100	> 1100
Building land	39.42	39.45	37.25	34.9	32.01	-
Industry and business	39.87	40.55	38.68	-	-	-
Special purpose	40.59	38.58	36.85	36.73	36.52	32.85
Cemeteries	38.75	39.45	37.21	-	-	-
Quarries	37.24	38.09	35.54	-	-	-
Solid waste landfills	38.23	42.38	-	-	-	-
Arable land	37.97	38.1	35.2	33.54	32.01	-
Meadows and pastures	37.14	37.29	34.93	33.40	30.10	-
Orchards and vineyards	41.14	37.50	39.53	-	-	-
Forests	39.07	38.08	36.28	34.87	32.46	29.65
Macchia and shrub vegetation	37.03	36.81	34.83	33.79	32.56	-
Areas with sparse vegetation	38.32	37.93	35.80	34.62	33.38	-
Bare rocks	37.23	38.03	35.70	37.41	33.53	-
Watercourses and water bodies	35.45	35.45	35.45	-	-	-



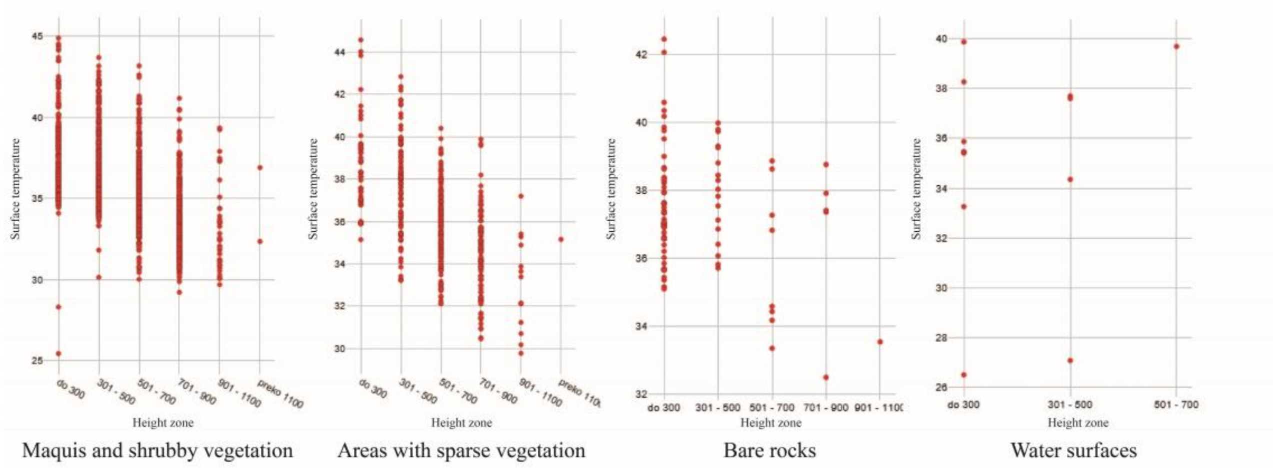


Figure 4. *Surface temperatures by purpose and altitude zones (30.08.2024.)*

was recorded at the location of the solid waste landfill and was 42.38°C, while the lowest temperature was recorded on and water surfaces (35.4°C).

The third altitude zone has less pronounced differences between the thermal footprints of different uses. The highest average temperature was recorded in the vineyard zone (39.5°C), and in built-up areas where the temperature was 38.68°C. In the forest and urban green areas, the average temperature was recorded at 36.2°C. In the water surface class, the temperature was the same as in the previous two zones (35.4°C).

Taken together, the average temperature of the first (38.36°C) and second altitudinal zones (38.40°C) is almost identical, while in the third altitudinal zone the average temperature is somewhat lower (36.4°C). The average temperature amplitude between different land uses in the first altitudinal zone was 7°C, while in the highest zone (above 1100 meters) the amplitude was only 3°C. From the above, it can be concluded that each land use class has its own unique thermal footprint and that it has higher values where different buildings are located. Also, the influence of altitude on the thermal characteristics of all analyzed land use classes is evident.

3. CONCLUSION

Urban heat islands are a phenomenon that is present in medium and large cities. The study of the aforementioned phenomenon is of great importance for various sectors, of which we particularly highlight: public health, housing, water supply, agriculture, civil protection and landscape architecture. In general, there are two approaches to studying the thermal characteristics of urban environments. The first approach refers to direct measurements of air temperatures, while the second approach uses remote sensing products to read surface temperatures. In this paper, the products of the Landsat 8 mission were used to determine the thermal characteristics of certain surface uses. Analysis of the image from the summer of 2024 revealed that there are clear differences in the thermal footprint of different surface uses in the wider urban area of Trebinje. The highest average temperatures were recorded in built-up areas (40.59°C), orchards and vineyards (41.14°C), forests (39.07°C) and areas with sparse vegetation (38.32°C). Somewhat lower temperatures were recorded in watercourses and water ponds (35.45°C). It is important to emphasize that the highest temperature in the first altitude zone was 47.3°S, and it was recorded on the pixel corresponding to built-up areas. The lowest temperature value in the first altitude zone was recorded on the forest surface and was 19.6°S. Apart from the thermal characteristics of specific surface uses, the influence of altitude on temperatures was also analyzed. It was found that the average temperature was lower by 1°S for every 100 meters above sea level. This research can be the starting point for further more detailed research that focuses on determining local microclimate zones and that investigates temperature differences within certain classes of surface uses in more detail.

4. ACKNOWLEDGEMENTS

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АНАЛИЗА УРБАНОГ ТОПЛОТНОГ ОСТРВА ГРАДА ТРЕБИЊА КОРИШЋЕЊЕМ ПРОИЗВОДА ДАЉИНСКЕ ДЕТЕКЦИЈЕ

Сажетак: Феномен урбаних топлотних острва постаје све израженији и један је од главних разлога повећања температуре ваздуха у градовима. Термички режим урбаних подручја је другачији од периурбаних и руралних простора, и огледа се у бржем дневном загријавању и споријем ноћном хлађењу. У истраживању урбаних топлотних острва постоје два главна приступа - директна мјерења температуре ваздуха на терену и очитавање температура са производа даљинске детекције. У раду ће бити анализирани производи даљинске детекције са сателита Landsat 8 како би се утврдиле разлике у термичким карактеристикама специфичних типова коришћења земљишта на територији града Требиња. За потребе анализе дефинисана је тампон зона у радијусу од 10 km од централне тачке града (географске координате: 42.7112° N, 18.3436° E), што је омогућило обухватање урбаних, руралних и природних површина. Прикупљено је укупно 12 сателитска снимка и коришћен је временски оквир који обухвата љетне мјесеце 2024. године (од 1. јуна до 31. августа). С обзиром на осјетљивост термалних података на присуство облака, примијењен је филтер облачности (CLOUD_COVER < 20%) како би се осигурао квалитет улазних података. Додатно је имплементирана маска облака и сјене облака кориштењем *QA_ПИХЕЛ* слоја ради уклањања контаминираних пиксела. Резултати истраживања показују да изграђена подручја имају више температуре у поређењу са другим класама коришћења земљишта за преко2°C. Све анализе су спроведене коришћењем софтверских пакета отвореног кода. Резултати истраживања могу бити корисни за различите секторе као што су јавно здравље просторно планирање, енергетика, водопривреда, шумарство и сличне области. Поред тога, резултати истраживања могу допринијети будућим детаљним студијама усмјереним на дефинисање локалних климатских зона и термичких варијација унутар њих.

Кључне ријечи: Урбана топлотна острва, температура површине земљишта, даљинско осматрање, Landsat 8, намјена земљишта, термални режим, урбано-сеоски градијент, просторна анализа, локалне климатске зоне, Требиње.

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