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# Impact Assessment of Urban Development Patterns on Land Surface Temperature and Urban Heat Islands Using Remote Sensing Techniques – A Case Study of Prishtina, Kosovo

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## ABSTRACT

The swift expansion of urban areas worldwide has triggered significant environmental shifts, notably impacting land surface temperature (LST) and fostering the development of urban heat islands (UHIs). This study examines the impact of urban development patterns on LST and UHIs, focusing on Prishtina, Kosovo. As urbanization accelerates, the global population migrates to cities, increasing energy consumption, greenhouse gas emissions, and altering land cover. The purpose of this research is to utilize remote sensing techniques, including land use/land cover (LU/LC) classification, satellite data analysis in conjunction with official LST data, measured from local institutions to identify whether urbanization has an impact on LST in Prishtina and therefore UHIs. The study, conducted over the years 2000 to 2018, reveals a substantial increase in urban settlements by two-fold in Prishtina municipality, accompanied by a reduction in vegetation cover. Utilizing LU/LC maps, a detailed analysis illustrates the correlation between LST and urban parameters: a positive association between LST and built-up areas, signifying their contribution to heightened urban temperatures, and a negative correlation between green spaces and LST, indicating a cooling effect. Statistical analyses through multiple-line regression and correlation demonstrate the significant impact of urbanization on LST, emphasizing the necessity of incorporating additional urban parameters for more comprehensive precision in future assessments. The findings underscore the critical role of urban planning interventions in mitigating UHI effects, preserving green spaces, and managing urban growth for sustainable and climate-resilient cities. This research provides valuable insights into the relationship between urban development, land surface temperature, and UHIs, offering a basis for informed urban planning and environmental management strategies to address rising temperatures in rapidly urbanizing areas like Prishtina.

**Keywords:** urbanization; land surface temperature; urban heat islands; remote sensing; land use/land cover analysis.

## INTRODUCTION

The global population is growing rapidly, with more people moving to cities, leading to extensive urban development. According to World Bank statistics, 56% of the world's population resides in urban areas, a figure expected to more than double by 2050 (The World Bank, 2023). 50% of the population in Kosovo were living in urban areas by 2018, with an expected increase in the following years (Institute for Spatial Planning, 2010). While cities drive significant economic growth, contributing around 60% of global GDP, they also consume over 60% of energy and generate nearly 70% of greenhouse gasses (GHGs) (Farid et al., 2022).

Over recent decades, urban green spaces have markedly diminished worldwide, despite their crucial role in balancing LST within urban environments. The loss of vegetation due to urban expansion triggers extensive changes, elevating LST and resulting in various environmental challenges, such as land degradation, disruptions to ecosystems, heatwaves, flash floods, increased precipitation, and temperatures in urban areas. Such swift expansion exerts substantial environmental pressures globally, affecting food security, regional climate patterns, hydrology, and biodiversity. Urban areas' surfaces tend to have higher temperatures compared to vegetated and water-covered areas, and the expanding urban landscape drives an increase in temperature values (Abd-Elmabod et al., 2022; Farid et al., 2022; Fonseka et al., 2019; Stewart and Mills, 2021; Zhou and Chen, 2018).

The changes in ecosystems, vegetation, and land cover in urban areas ensure that there is a difference in the temperature measured in the urban area versus the surrounding non-urbanized areas, meaning that the urban areas are warmer. This is the UHI effect. The impacts of the UHI effect include increased energy consumption for cooling buildings, increased emissions of GHGs and air pollutants, decreased water quality, changes to natural ecosystems, and compromised human comfort and health, in addition to facilitating weather events such as heat waves of acid rain (Abd-Elmabod et al., 2022; Han et al., 2023; Musco, 2016; Stewart and Mills, 2021). When population density is considered, Kosovo has among the highest densities in Europe at 220 inhabitants per square meter. The highest densities are observed in urban areas, especially in the capital city of Prishtina, where the population density is as high as 900 inhabitants per square meter. The capital city houses more than a quarter of the overall population of the country. Urban growth has quadrupled from 1980 until 2020, and it is expected to increase even more (Institute for Spatial Planning, 2010). UHI effect can be determined either by using satellite-derived temperature or atmospheric temperature. Remote sensing has been used before as a tool to compute LST and has been shown to be very accurate when identifying and monitoring the UHI effect (de Almeida et al., 2021; Farhan et al., 2022; Wang et al., 2019).

Kosovo used to be a country with a continental climate of harsh winters with snow, and hot summers. Over the last years, drastic changes in climate patterns have been observed, with winters being warmer and shorter, with a lack of snow, and summers getting longer. The impact of this shift has been noticeable in all fields of the environment, but especially in the water sector and water supply (Institute for Spatial Planning, 2010). The purpose of this research is to determine whether there is a connection between the percentage of urbanization (determined via LU/LC changes) and the increase in average yearly LST in Prishtina. The type of connection or possible correlation between these two values will help determine the impact of LU/LC changes in the formation of UHIs and overall increase of average temperatures in Prishtina. With urbanization and UHI having a strong influence in this field, this research provides valuable insights into the relationship between urban development, land surface temperature, and UHIs, offering a basis for informed urban planning and environmental management strategies to address rising temperatures in rapidly urbanizing areas like Prishtina.

## MATERIALS AND METHODS

For the conduct of this study, the methodology included collection of satellite data, preparation of land use and land cover maps, retrieval of LST data from the official Hydrometeorological Institute of Kosovo, and relationship assessment between LST and the LU/LC. The study was conducted in 2023–2024 period.

### Study area

Prishtina has been selected as a study area for this research. It is located in the central-eastern part of Kosovo. The area lies approximately at latitude and longitude 42°40 N 21°10 E. Prishtina has been chosen because it stands out as the city undergoing the most significant changes over the past decade. According to Kosovo Agency of Statistics, Prishtina has experienced significant changes since 2000, but we lack statistical data since 2011. Currently, population registration is taking place throughout the entire state of Kosovo, and final results are expected to be published by the end of 2024.

### Data collection

The data that we used for LU/LC are from CLC. CLC is the data monitored by Copernicus, which is the European Union's Earth Observation Programme. Until the 1980s, regarding land cover, all countries had data only for their own state. However, this made it difficult to harmonize their data and control it within the framework of Europe. So, in the 80s, the European Commission began to harmonize this data across the entire territory of Europe, as well as make it accessible in order to facilitate their monitoring. The CLC classification system consists of three hierarchical levels. At Level 1, there are five primary land cover/use categories: Artificial surfaces, Agriculture, Forests and seminatural areas, Wetlands, and Water. Level 2 further refines these categories into 15 classes, while Level 3 provides a detailed classification into 44 thematic categories. In terms of geometric detail, it's important to note that the product has a minimum mapping unit (MMU) of 25 hectares (ha) for area-based phenomena and a minimum width of 100 meters for linear phenomena. This means that any land cover feature or area smaller than 25 hectares and any linear feature narrower than 100 meters might not be shown accurately on the map.

The corine land cover datasets for different years used different satellite sensors for data acquisition. Specifically, CLC 2000 relied solely on Landsat-7 ETM imagery, captured during a single date. In contrast, CLC 2006 integrated data from SPOT-4/5 and IRS P6 LISS III satellites, acquired across dual dates. For CLC 2012, satellite data were obtained from IRS P6 LISS III and RapidEye, also acquired over dual dates. Notably, CLC 2018 benefited from the advanced capabilities of Sentinel-2 and Landsat-8 satellites, acquired over dual dates, with Landsat-8 utilized for gap filling purposes.

Regarding geometric accuracy, the satellite data for all CLC datasets maintain a high level of precision, typically ≤ 25 meters. However, an exceptional enhancement is observed in CLC 2018, where the geometric accuracy achieves an impressive ≤ 10 meters, for Sentinel-2 imagery (European Environment Agency, 2021).

## STATISTICAL ANALYSIS

Statistical analyses, including multiple linear regression and correlation analysis, were conducted to determine whether there is a positive association between LST and built-up areas, signifying their contribution to heightened urban temperatures, and a negative correlation between green spaces and LST, indicating a cooling effect. Statistical analyses demonstrate the significant impact of urbanization on LST, emphasizing the necessity of incorporating additional urban parameters for more comprehensive precision in future assessments.

## RESULTS AND DISCUSSION

### LU/LC

The land cover maps for the four different years within the study area of Prishtina are shown in Figure 1. The detailed breakdown of land cover categories within the study area is provided in Table 2. The total area of the Prishtina is 54.32 km². Details of each land cover type in square kilometers are listed in the table. While the corine land cover (CLC) dataset comprises 44 classifications, only 13 classes are included for the Prishtina area. Not all classes are the same every year. Two classes – construction sites and dump sites - were not present in 2000, while only dump sites were missing in 2006. However, all 13 classes are covered in both 2012 and 2018, shown in Table 1.

The following table shows the land coverage in hectares in Pristina for the 4 years for which we have the data. The result from the land cover classification analysis, as shown in the table, indicates the most increase in urban areas. With an urban coverage of 35.87% in 2000, the urban landscape surged to 49.58% by 2018, marking a significant growth of 38.22% over the study period. There has also been a large increase in Industrial or commercial units. From the year 2000, we have a 150% increase in 2018. While there has been a decrease particularly in cultivation and forested regions, notable reductions are observed in non-irrigated arable land (-40% in 2018) and complex cultivation patterns (-50% since 2000). The most significant decline is evident in transitional woodlands, experiencing a 57% decrease from 2000 to 2018.

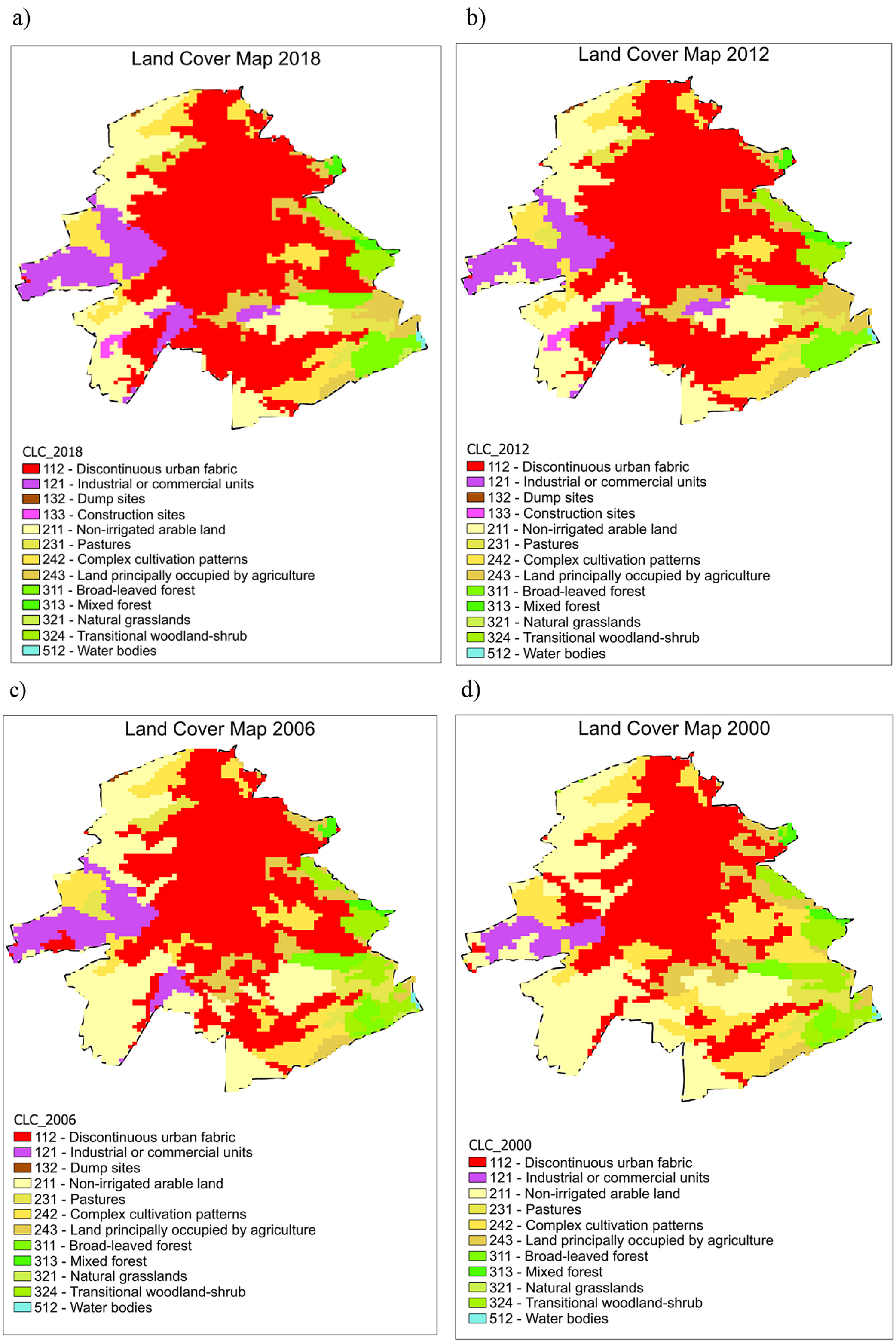


**Figure 1.** Land cover map across the study area: (a) 2018, (b) 2012, (c) 2006, (d) 2000

For monitoring LU/LC change, it is necessary to have at least data from two time periods for comparison. We have 4 years of data, and each year's data is compared between. The remote sensing method involves using satellite images from different dates to track changes in land use and land cover over time. In this study, we have used data from CLC, and we do not need processing, since these data are pre-processed; therefore, no radiometric calibrations and atmospheric

**Table 1.** CORINE land cover nomenclature

| CORINE land cover nomenclature | | | |
|---|---|---|---|
| CLC_CODE | LEVEL 1 | LEVEL 2 | LEVEL 3 |
| 112 | Artificial surfaces | Urban fabric | Discontinuous urban fabric |
| 121 | Artificial surfaces | Industrial, commercial and transport units | Industrial or commercial units |
| 132 | Artificial surfaces | Mine, dump and construction sites | Dump sites |
| 133 | Artificial surfaces | Mine, dump and construction sites | Construction sites |
| 211 | Agricultural areas | Arable land | Non-irrigated arable land |
| 231 | Agricultural areas | Pastures | Pastures |
| 242 | Agricultural areas | Heterogeneous agricultural areas | Complex cultivation patterns |
| 243 | Agricultural areas | Heterogeneous agricultural areas | Land principally occupied by agriculture, with significant areas of natural vegetation |
| 311 | Forest and semi natural areas | Forests | Broad-leaved forest |
| 313 | Forest and semi natural areas | Forests | Mixed forest |
| 321 | Forest and semi natural areas | Scrub and/or herbaceous vegetation associations | Natural grasslands |
| 324 | Forest and semi natural areas | Scrub and/or herbaceous vegetation associations | Transitional woodland-shrub |
| 512 | Water bodies | Inland waters | Water bodies |

**Table 2.** Land cover analysis from 2000–2018, presented in square kilometers and percentage

| CLC code | 2000 | | 2006 | | 2012 | | 2018 | |
|---|---|---|---|---|---|---|---|---|
| | Area Ha | % | Area Ha | % | Area Ha | % | Area Ha | % |
| 112 | 1950 | 35.87 | 2369 | 43.56 | 2654 | 48.78 | 2691 | 49.58 |
| 121 | 201 | 3.70 | 401 | 7.37 | 470 | 8.64 | 501 | 9.23 |
| 132 | 0 | 0 | 3 | 0.06 | 3 | 0.06 | 2 | 0.04 |
| 133 | 0 | 0 | 0 | 0 | 25 | 0.46 | 24 | 0.44 |
| 211 | 1475 | 27.13 | 1239 | 22.78 | 961 | 17.66 | 891 | 16.41 |
| 231 | 110 | 2.02 | 202 | 3.71 | 184 | 3.38 | 160 | 2.95 |
| 242 | 915 | 16.83 | 519 | 9.54 | 440 | 8.09 | 461 | 8.49 |
| 243 | 356 | 6.55 | 283 | 5.20 | 332 | 6.1 | 325 | 5.99 |
| 311 | 85 | 1.56 | 119 | 2.19 | 198 | 3.64 | 197 | 3.63 |
| 313 | 34 | 0.63 | 36 | 0.66 | 38 | 0.7 | 34 | 0.63 |
| 321 | 6 | 0.11 | 6 | 0.11 | 6 | 0.11 | 8 | 0.15 |
| 324 | 299 | 5.50 | 256 | 4.71 | 126 | 2.32 | 128 | 2.36 |
| 512 | 5 | 0.09 | 5 | 0.09 | 4 | 0.07 | 6 | 0.11 |

corrections were applied. The analysis was done by the QGIS 3.36.1 software to interpret land cover changes that occurred in the period 2000–2018 in Prishtina. First, we received CLC data for each year, and we calculated the changes between these products. We also received layers of changes (CHA) from Corine Land Cover; CHA06 (00–06), CHA12 (06–12), and CHA18 (12–18). The CLC-Change product includes the real changes that happened on the ground directly, with a visual control and with a minimum mapping unit (MMU) of 5 ha, which means a higher resolution and they do not include any technical distortions brought about by incorrect mapping or changed production methods. On the other hand, two generalized datasets with a lesser resolution of 25 ha are provided by the CLC changes from difference (intersect) product.

Based on our research and the Copernicus Land Monitoring Service's recommendation in the Corine Land Cover User Manual, we used only the CHA product for Prishtina. The manual advises against using the difference (intersection) between two consecutive status layers and

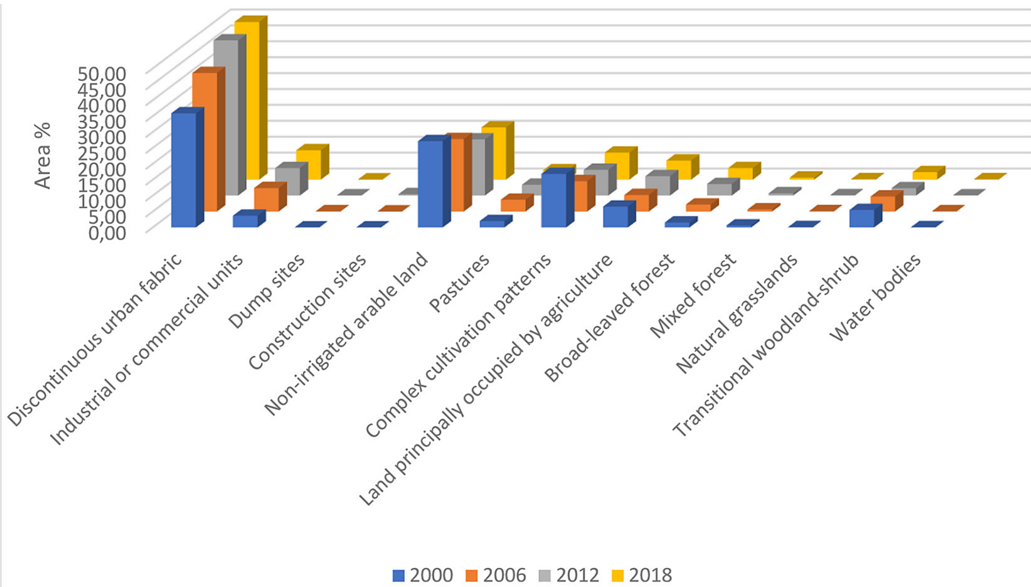


**Figure 2.** Area under different land use and land cover classes (2000–2018)

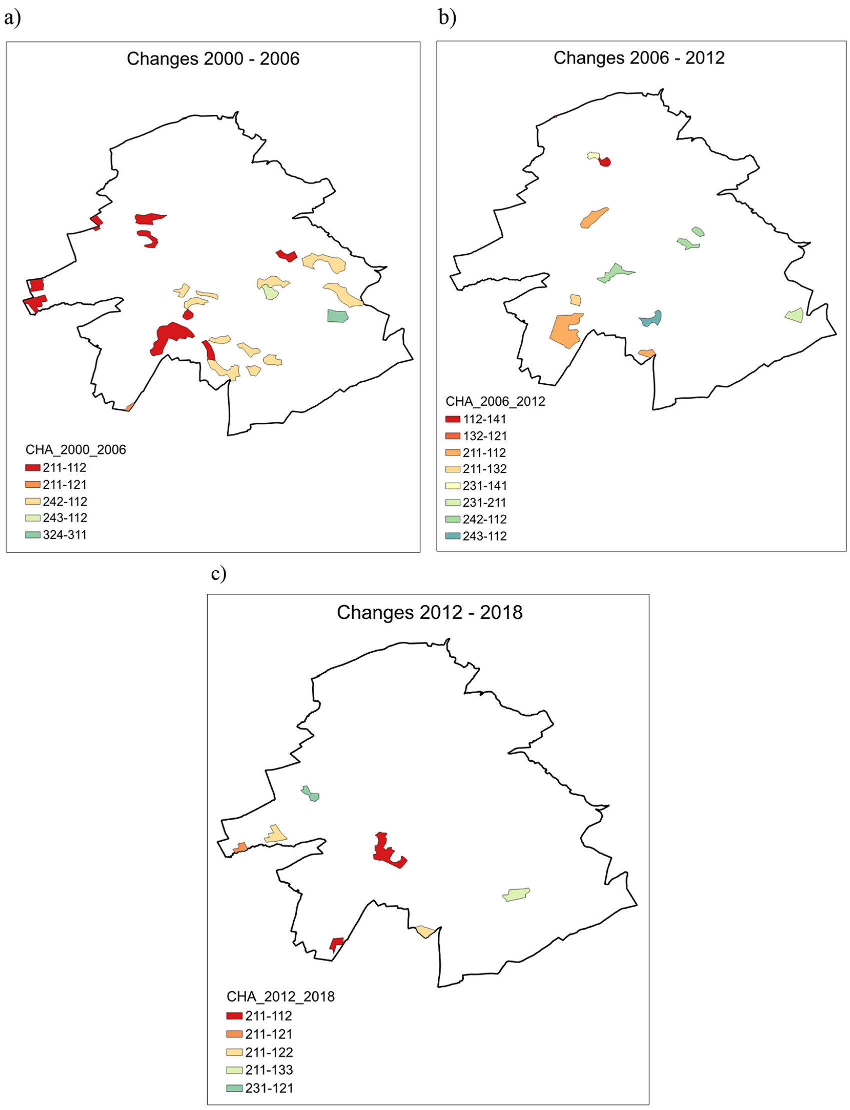


**Figure 3.** Location of changing areas in CLC between: a) 2000–2006, b) 2006–2012, c) 2012–2018

Table 3. Land cover change analysis between research years

| Change 2000–2006 | | | |
|---|---|---|---|
| Change | Code 2006 | Code 2012 | Area, ha |
| 242-112 | 242 | 112 | 7.60 |
| 324-311 | 324 | 311 | 16.48 |
| 211-121 | 211 | 121 | 27.63 |
| 243-112 | 243 | 112 | 11.48 |
| 211-112 | 211 | 112 | 9.91 |
| Change 2006–2012 | | | |
| Change | Code 2006 | Code 2012 | Area, ha |
| 242-112 | 242 | 112 | 17.03 |
| 112-141 | 112 | 141 | 6.34 |
| 132-121 | 132 | 121 | 5.36 |
| 211-132 | 211 | 132 | 7.48 |
| 231-141 | 231 | 141 | 5.23 |
| 243-112 | 243 | 112 | 12.86 |
| 211-112 | 211 | 112 | 7.15 |
| 231-211 | 231 | 211 | 12.82 |
| Change 2012–2018 | | | |
| Change | Code 2012 | Code 2018 | Area, ha |
| 211-122 | 211 | 122 | 19.43 |
| 211-133 | 211 | 133 | 14.76 |
| 231-121 | 231 | 121 | 8.12 |
| 211-112 | 211 | 112 | 7.13 |
| 211-121 | 211 | 121 | 7.04 |

suggests on the CLC Change product from Corine Land Cover instead. This decision is in accordance with the reasons previously mentioned.

We have used vector Corine Change data, and the differences between the years 2000–2006, 2006–2012, and 2012–2018 are presented in Figure 3. The details of the area and the percentage are given in Table 3. A change of less than 5 hectares is not considered. Initially, based on the table, we noticed that a new class was added in the changes layer, which had not been present in the land cover data for all different years. This addition happened for a specific reason; as we know before, the MMU is 25 ha for mapping CLC status layers. This means that polygons smaller than 25 ha are not individually represented but rather generalized into neighboring features. In contrast, the MMU for mapping CLC change status layers is reduced to 5 hectares, resulting in a much more detailed depiction of changes over time. This difference in MMU has made the CLC-Change layers much more detailed than the CLC status layers. As a result, we have a new class to our CLC changes map. From 2000 to 2006, the biggest changes were from non-irrigated arable land to industrial or commercial units. We also have a change in forests, but the transition from one type of forest to another, such as transitional woodland-shrub to broad-leaved forest. Those that have a big impact are the transition of agricultural land, such as land principally occupied by agriculture in discontinuous urban fabric. During the years 2006 to 2012, even from the analyzes and statistics, it can be seen that we have a large urbanization in the territory of Prishtina. All the changes are almost related to the urban planning part. The biggest changes are those of complex cultivation patterns to the discontinuous urban fabric, or the land mainly occupied by agriculture, into discontinuous urban fabric. Additionally, there was a discernible shift from pasturelands to non-irrigated arable land during this period.

A positive thing that is observed during this change is that, in addition to urbanism, we now have a new class appearing, indicating that there has been some progress made from discontinuous urban fabric to green urban areas. We do not know how much green space there is behind according to the land cover maps, since the polygon is smaller than 5 ha in the CHA.

Unfortunately, even during the years 2012 to 2018, the biggest changes belong to the infrastructure. Generally, the transformation of non-irrigated arable land into urban areas is distinguished. Any change presented during these years from a non-urbanized part passes to the urbanized part.

## Land surface temperature

LST data was obtained from the official databases and reports of the Hydrometeorological Institute of Kosovo. The maximal, minimal, and average temperatures for all months of the year, as well as a yearly average, were obtained from the Prishtina area and are presented in the Table 4 for the years 2000, 2006, 2012, and 2018.

Analysis shows that the average LST in Prishtina has increased by 1.46 ºC from year 2000 to 2018. The increase in temperature is less significant between 2000 and 2006, and more significant from 2006 to 2012, and 2012 to 2018. Likewise, the urbanized area has increased by 38% from year 2000 to 2018, followed by a significant decrease of arable land and transitional woodland-shrub areas. A graphical representation of LST change during the research period 2000–2018 is shown in Figure 4.

**Table 4.** LST data for the research period 2000–2018

| 2000 | | | | | | | | | | | | | Yearly average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| $T_{max}$ | 6.5 | 7 | 15.2 | 14.7 | 21.4 | 23.5 | 27.3 | 28.8 | 20.2 | 20.1 | 8.6 | -2.8 | |
| $T_{min}$ | 0.8 | 1.5 | 7.2 | 4.7 | 10.5 | 10.4 | 13.8 | 10.4 | 9.8 | 4.8 | 0.4 | -8.4 | |
| $T_{ave}$ | 2.7 | 2.8 | 10.3 | 9.3 | 16.5 | 18.2 | 21.9 | 22.6 | 8.1 | 13.2 | 4.4 | -5.7 | 10.36 |
| 2006 | | | | | | | | | | | | | Yearly average |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| $T_{max}$ | 4.8 | 2.4 | 10.3 | 16.2 | 21.6 | 23.7 | 27.3 | 25.8 | 22.5 | 17.1 | 9.4 | 5.3 | |
| $T_{min}$ | -4 | -6.7 | -1.1 | 4.1 | 9.5 | 10.8 | 13.9 | 13.9 | 11.5 | 5.3 | -0.3 | -0.9 | |
| $T_{ave}$ | 0 | -2.2 | 4.6 | 10.1 | 15.8 | 17.8 | 21.1 | 19.6 | 16.8 | 11 | 4.2 | 1.8 | 10.05 |
| 2012 | | | | | | | | | | | | | Yearly average |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| $T_{max}$ | 2.4 | 0 | 13.6 | 16.8 | 20.7 | 28.5 | 31.7 | 31.8 | 27.7 | 21.6 | 14.1 | 3 | |
| $T_{min}$ | -5.2 | -7.9 | 1.1 | 4.9 | 9.4 | 13.7 | 16.6 | 15 | 12.1 | 7.5 | 4.7 | -3.1 | |
| $T_{ave}$ | -1.9 | -4.9 | 7 | 11.3 | 14.8 | 21.6 | 24.4 | 24 | 19.8 | 13.4 | 9 | -1.1 | 11.45 |
| 2018 | | | | | | | | | | | | | Yearly average |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| $T_{max}$ | 6.4 | 6.3 | 11.8 | 22.8 | 24.9 | 25.6 | 27.5 | 29.8 | 25.7 | 21.6 | 13.2 | 4.8 | |
| $T_{min}$ | -2.7 | -0.7 | 1.9 | 8.4 | 11.1 | 13.7 | 15.2 | 14.6 | 9.7 | 6.4 | 2.2 | -3 | |
| $T_{ave}$ | 1.3 | 2 | 6.3 | 15.6 | 17.9 | 19.4 | 20.7 | 21.7 | 17.2 | 13.1 | 6.5 | 0.1 | 11.82 |

**Note:** Source – Hydrometeorological Institute of Kosovo (2019).

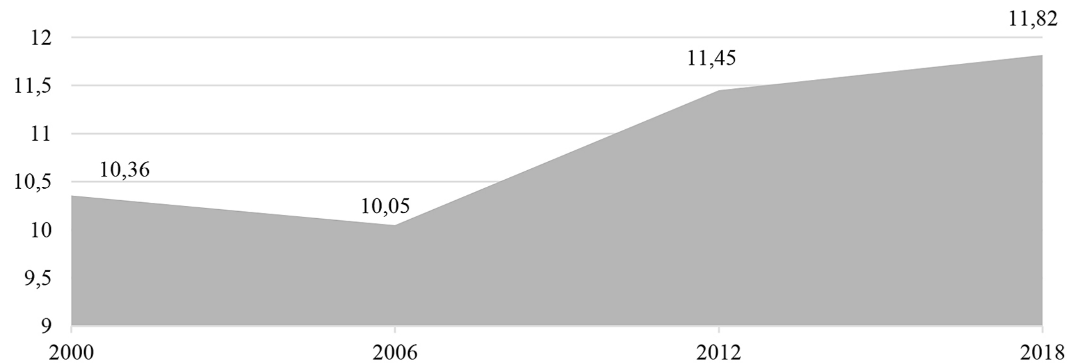


**Figure 4.** Increase in average yearly LST during 2000–2018 period

**Table 5.** Summary of data used for the regression and correlation analysis

| Year | Average yearly LST (ºC) | Urban cover (ha) | Vegetation (ha) |
|---|---|---|---|
| 2000 | 10.36 | 2151 | 3280 |
| 2006 | 10.05 | 2770 | 2660 |
| 2012 | 11.45 | 3124 | 2285 |
| 2018 | 11.82 | 3192 | 2204 |

**Table 6.** Summary of data obtained by multiple regression analysis

| Regression Statistics | | | |
|---|---|---|---|
| Multiple R | 0.98165578 | Adjusted R square | 0.890944212 |
| R Square | 0.963648071 | Standard error | 0.280038277 |

## RESULTS

Correlation analysis shows a positive correlation of 0.75 for temperature and urban growth, and a negative correlation of -0.77 for temperature and vegetation which is a strong correlation in both cases. Values for the average LST, urban cover and vegetation are shown in the Table 5.

The regression analysis shows a high multiple R and $R^2$ above 0.96. The table below shows the detailed analysis data.

## CONCLUSIONS

This research highlights the impact of urbanization on LST in Prishtina, Kosovo, over the period from 2000 to 2018. The findings demonstrate a significant correlation between the increase in urban areas and the rise in LST, with urban coverage growing by 38.22% and average LST increasing by 1.46 °C. The reduction in vegetative cover, particularly non-irrigated arable land and transitional woodlands, underscores the environmental consequences of urban expansion, contributing to the UHI effect.

The statistical analyses, including multiple linear regression and correlation, confirm strong positive correlations between urban growth and temperature rise, as well as strong negative correlations between vegetation and temperature. These relationships emphasize the importance of green spaces in mitigating urban heat effects. The study's use of satellite-derived data and corine land cover datasets has provided a comprehensive overview of LU/LC changes, reinforcing the reliability of remote sensing in environmental monitoring.

The research shows that there is an increasing need for integrated urban planning and environmental management strategies in rapidly urbanizing areas like Prishtina. To combat the adverse effects of the UHI, it is crucial to incorporate sustainable practices such as enhancing urban green spaces, promoting energy-efficient building designs, and implementing policies to control urban sprawl. These measures will not only help in reducing LST but also improve the overall quality of life for urban residents.

Future research should focus on long-term monitoring and assessment of urbanization impacts on local climates, incorporating more granular data and exploring the effectiveness of different mitigation strategies. By adopting a proactive approach, urban planners and policymakers can better manage the challenges posed by urban growth and climate change, ensuring a sustainable and resilient urban environment.

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