SPATIO-TEMPORAL ANALYSIS OF THE EFFECTS OF URBAN GROWTH ON URBAN HEAT ISLAND: CASE OF KONYA, TURKIYE

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ABSTRACT:

The increase in impermeable surfaces within the urban areas contributes to local and regional-scale climate changes. This phenomenon, called "Urban Heat Island," is observed as the temperature in urban areas is higher than rural areas and natural landscape areas on the urban fringe. In recent years, advances in remote sensing and geographic information system technologies have enabled the urban heat island effect to be determined more quickly, economically, and accurately. In this study, the rapidly increasing urbanization in Konya, Türkiye and the resulting urban heat island effect have been analyzed. The study consists of four steps. In the first step, land surface temperatures for 1990 and 2022 of Konya city center were determined using the thermal band of Landsat-5 TM and Landsat-8 OLI satellite images. Then, satellite images were classified using the maximum likelihood method to determine land use and land cover in Konya. The effects of land use types and urban growth on urban heat island were examined. The Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI) analyses were examined the statistical relationships between land surface temperature. The last step, the urban heat island effects of different types of regions in the city center of Konya were determined based on their urban form, texture, structure, landscape, and planning strategy. As a result of the study, measures that can be taken especially in spatial planning and design policies have been identified to reduce and prevent the urban heat island in Konya.

1. INTRODUCTION

Climate change is one of the most important global issues of our age. The main causes of this change are the increase in carbon emissions in the atmosphere and the increase of impermeable surfaces in rural and urban areas. As the population living in urban areas increases, settlements, industry, and transportation areas are growing, leading to an increase in impermeable surfaces. The increasing impermeable surfaces in urban areas are causing climate change on the local and regional scale. This phenomenon, called "Urban Heat Island (UHI)," is observed as the temperature in urban areas is higher than rural areas and natural landscape areas on the urban fringe (Voogt, 2004).

Urban environments usually experience higher atmospheric and surface temperatures compared to rural areas. The main reason for this is that surfaces in urban areas, such as concrete masses, glass and metal surfaces, asphalt roads, etc., are covered with materials that reflect and have high heat capacity, decrease in natural areas in the urban, and human activities (carbon gases emitted from housing, factory chimneys, and vehicle exhausts, etc.). In addition, urban form, urban texture, building location, and materials also have an impact on the formation of the UHI. The UHI effect causes a decrease in air quality in urban areas, the formation of unfavourable microclimatic conditions, an increase in energy consumption for cooling buildings, and an increase in carbon footprint. In addition, it can cause serious health problems and even deaths in high-risk groups and elderly people, especially during summer months. Therefore, studies should be conducted to determine, monitor, and take necessary precautions against the UHI effect. However, it is observed that comprehensive urban planning, and renewal practices in Türkiye often do not adequately consider microclimatic research. In rapidly developing and renewing cities, determining the microclimatic conditions, and developing planning and design strategies accordingly are of great importance for a sustainable future.

The methods used for modelling UHI and determining their characteristic features in cities can generally be grouped into two. The first group of studies is based on air temperature measurements in urban or rural areas, while the second group relies on land surface temperature (LST) measurements (Streutker, 2003). Studies based on ground-based air temperature measurements are generally derived from meteorological observations, utilizing climate data obtained through meteorological station records or measurements conducted with mobile sensing devices. On the other hand, studies based on LST measurements are carried out using thermal remote sensing data, typically obtained from satellite image. In this case, instead of air temperature, the emitted energy from the city is measured, focusing on surface temperatures. In recent years, significant progress has been made in surface temperature studies with the advancement of remote sensing technologies. The literature includes numerous studies that utilize remote sensing imagery to determine land surface temperature (Anandababu et al., 2018; Dihkan et al., 2018; Erdem et al., 2021).

In this study, the rapid urbanization and resulting UHI effects in Konya, Türkiye were analysed using LST maps from 1990 and 2022. The study investigated the impact of land use and land cover, Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and changes in urban morphology on land surface temperature.

2. CASE OF STUDY: THE METROPOLITAN CITY OF KONYA, TURKIYE

The study area is located within the borders of the Konya province in the central of Türkiye. It is located between 38°05'23"-37°41'18 north latitudes and 32°41'00"-32°20'16" east longitudes in Figure 1. The study area is 84797.80 ha.
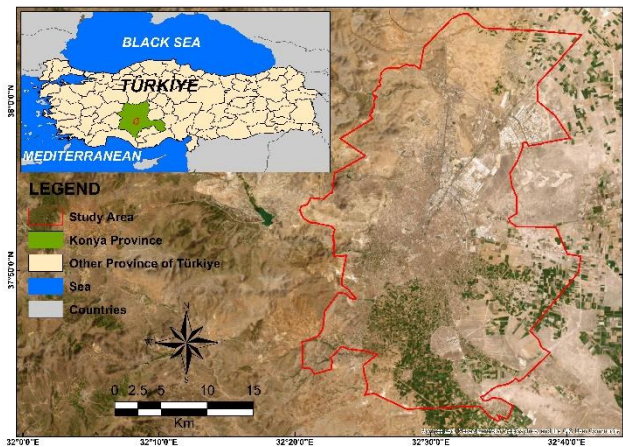
Figure 1. Location of study area.

According to the 2022 census, Konya is the 6th most populous city in Türkiye. According to the census data of 2022, the total population of the study area is 1.409,92. The population of Konya province in 1990 was 584,819. Over a period of 32 years, the population of the city center of Konya has increased by approximately 60%. According to the data from 2022, urban areas constitute 26% of the study area. There are two organized industrial zones in the city center of Konya. The population density analysis of Konya Metropolitan Municipality for 2020 shows that high-density built-up areas are in the city center, while population density decreases at the urban fringe.

3. MATERIALS AND METHODS

3.1 Data Sources

The land surface temperature and land use/land cover (LULC) in the study area were determined using Landsat 5 TM satellite image from 1990 and Landsat 8 OLI satellite image from 2022. The satellite images were obtained from the United States Geological Survey (USGS) data portal. The satellite images were selected for the same season (summer) to minimize the impact of seasonal variations on land surface temperature. Additionally, images were chosen for dates (11/08/1990 and 03/08/2022) when there was no rainfall for at least one week. Many studies in the literature stated that the images of the summer season reflect more appropriate temperature data than the cold seasons, due to the high and negative effects of temperature in the summer season. (Dai et al., 2018). Furthermore, satellite images from the summer days have less cloud cover and atmospheric haze, which is advantageous for obtaining higher quality and higher-resolution remote sensing image. Additionally, during the summer season, the vegetation cover is at its highest level, which can be useful in better understanding the significance of shading effects (Erdem et al., 2021). The analysis of vegetation cover is important because in urban areas, green spaces and water bodies are decreasing, leading to less absorption of heat, and consequently resulting in a higher concentration of the heat effect. All the data were transformed into the Universal Transverse Mercator (UTM) Zone 36 N projection system.

3.2 Method Process

This study aimed to determine the land surface temperature changes in the city center of Konya and examine the relationship between land surface temperature and land use/land cover, NDVI, NDBI, and urban morphology (Figure 2). This study consisted of four steps.

In the first step, satellite images were classified using the maximum likelihood method to determine land use and land cover for 2022. The effects of land use types and urban growth on UHI were examined.

In the second step, LST for 1990 and 2022 of Konya city center were determined using the thermal band of Landsat-5 TM and Landsat-8 OLI satellite images.

In the third step, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI) analyses were examined the statistical relationships between LST.

The last step, the UHI effects of different types of regions in the city center of Konya were determined based on their urban form, texture, structure, landscape, and planning strategy.

3.3 Land Surface Temperature

In this study, the LST method was used to determine the UHI effect in urban areas (Figure 2). The LST was calculated according to the method previously applied by Chen et al. (2014) and Orhan and Yakar (2016).

Initially, radiometric, and atmospheric corrections were applied to the satellite images. Then, all the bands of Landsat 8 satellite images and LULC maps were resampled using the nearest neighbour algorithm to achieve a spatial resolution of 30 m.

In the first stage, the sensor pixel/brightness values (0-255) were converted to the spectral radiance (SR) values using thermal infrared bands (TIR) (band 10 and band 11) (USGS, 2018). Then, the effects of the atmosphere in the thermal region were removed and Top of Atmosphere (TOA) radiance was converted to the surface-leaving radiance.

In the second stage, the spectral radiance values were converted to the reflectance values. The radiance values were then converted to the Brightness Temperature (BT) in °C using the Landsat specific estimate of the Planck curve by assuming the earth's surface is a black body (Coll et al., 2010). The land surface emissivity must be known in order to estimate LST, so NDVI was also calculated to determine vegetation proportion and land surface emissivity (ε). After determining the NDVI values, the Proportion of Vegetation (Pv) is calculated using the vegetation and soil values derived from NDVI. This ratio is determined based on the maximum ($NDVI_{max}$) and minimum ($NDVI_{min}$) values obtained from NDVI. The Pv is used in the calculation of land surface emissivity. The LST, which represents the real surface temperature, was calculated by correcting the land surface emissivity to the sensor brightness temperature value.
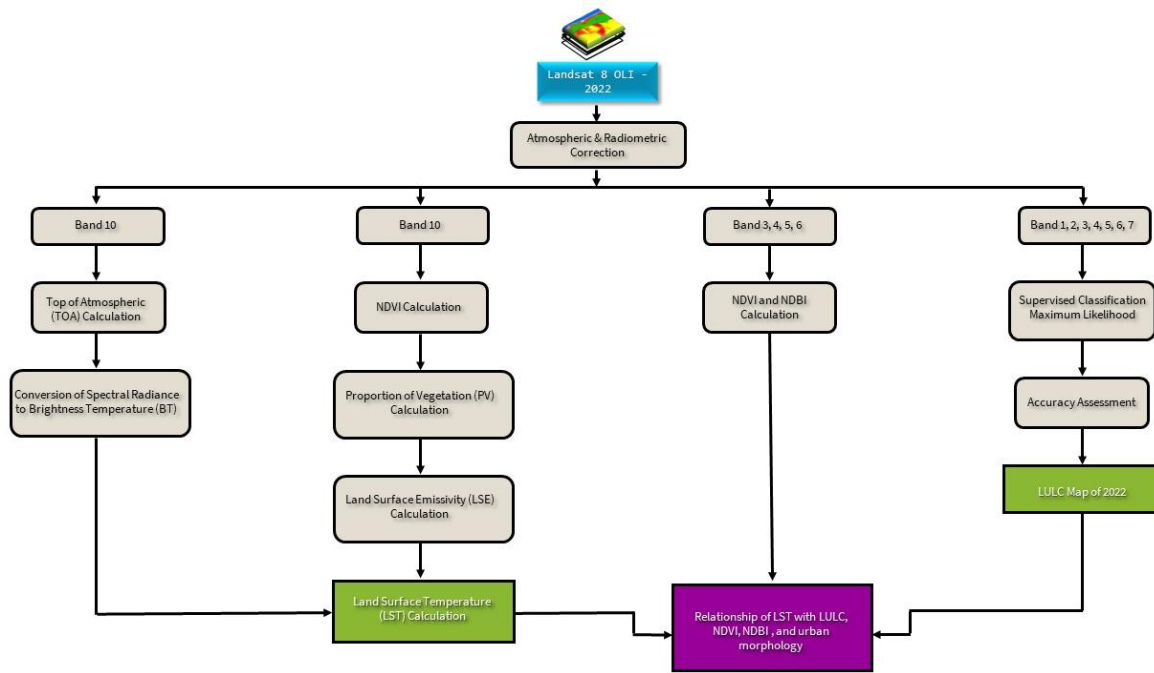
Figure 2. Summarized flowchart of the study showing the land surface temperature method and o image classification.

3.4 Normalized Difference Vegetation Index (NDVI)

NDVI is an index that reveals the density and health status of vegetation in a given area through analysis. This index is derived from near infrared (NIR) and red (Red) bands as in Equation 1 (Rouse et al., 1974).

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

The values obtained as a result of the NDVI analysis range between -1 and +1. High NDVI values indicate dense and healthy vegetation, while low NDVI values indicate low vegetation density or unhealthy vegetation.

3.5 Normalized Difference Built-up Index (NDBI)

NDBI is an index used to determine the extent of built-up areas in urban settings. This index is derived from shortwave infrared (SWIR) and near infrared (NIR) bands as in Equation 2 (Zha et al., 2003).

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \qquad (2)$$

The values obtained as a result of the NDVI analysis range between -1 and +1. A positive NDBI value generally signifies areas with high building density, while a negative NDBI value indicates low or no built-up areas.

3.6 Determination of the LULC Map

The satellite images were classified using maximum likelihood supervised classification method. Six classes were considered for study area, namely built-up, barren land, industrial area, cropland, fallow land, and water body.

The accuracy analysis is a control method based on the statistical comparison of the pixel values determined through classification with the points considered to be reference. The accuracy analysis is performed by utilizing producer's accuracy, user's accuracy,

overall accuracy, and the Kappa coefficient, which are generated from the confusion matrix (Akdeniz et al., 2023). The Kappa coefficient was developed by Cohen (1960) and ranges from 0 to +1. If the kappa value is greater than 0.80, it is determined that the classification is highly acceptable (Landis and Koch, 1977). Accuracy analysis was then carried out by compiling a confusion matrix, where 360 random points were generated over the study area.

4. RESULTS

4.1 LULC classification and accuracy assessment

Figure 3 shows the spatial distribution of the LULC of Konya city center for 2022. The study area is 84797.80 ha. In 2022, 40.20% barren land, 26.01% built-up area, 13.52% cropland and pasture, 13.06% fallow land, 7.20% industrial area, and 0.01% water body.

Table 1 shows the accuracy results. Accordingly, the Kappa coefficient was calculated 0.87. The overall accuracy was calculated 90.00%. The producer's and user's accuracy values regarding the LULC classes ranged from 73.13 to 100% in 2022. These accuracy results demonstrate that the maximum likelihood supervised classification is accurate and reliable.

LULC Classes	2022	
	Producer's accuracy (%)	User's accuracy (%)
Built-up area	100.00	86.66
Barren land	73.13	100.00
Industrial area	100.0	76.66
Water body	100.0	96.66
Cropland and pasture	86.66	86.66
Fallow land and dry farming	90.32	93.33
Overall accuracy (%)	90.00	
Kappa coefficient	0.87	

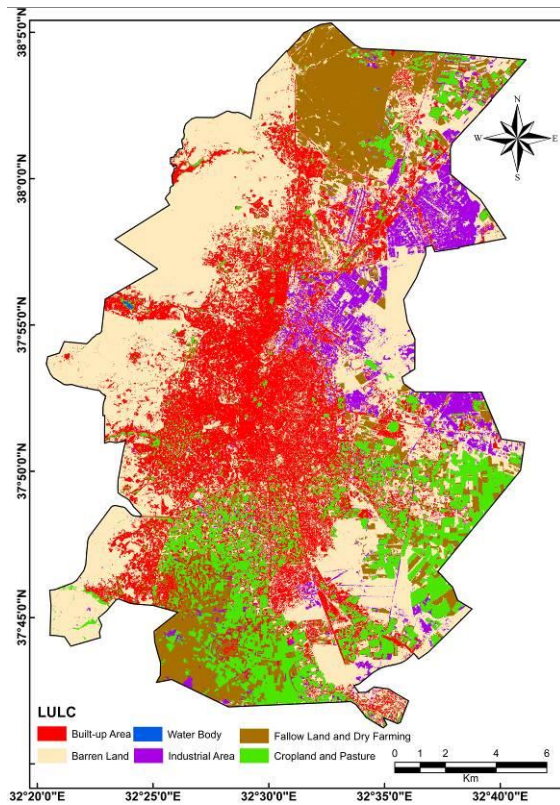**Table 1.** Classification accuracy assessment of LULC map.

Figure 3. LULC map of Konya.

4.2 1990 and 2022 Land Surface Temperature of Konya

The LST maps of the city center of Konya for 1990 and 2022 were produced using thermal bands from Landsat-5 TM and Landsat-8 OLI satellite images, and statistical calculations were performed. Figure 4 shows the LST maps for 1990 and 2022 in Konya city center.

In 1990, the minimum LST in the study area was 18.00 °C, and the maximum LST was 46.30 °C. The average LST was 34.14 °C. The average air temperature measured by the meteorological observation stations of the General Directorate of Meteorology was 30°C. It was determined that the average LST was approximately 4 degrees higher than the average air temperature.

In 2022, the minimum LST in the study area was 21.44 °C, and the maximum LST was 44.39 °C. The average LST was 34.80 °C. The average air temperature measured by the meteorological observation stations of the General Directorate of Meteorology was 33 °C. It was determined that the average LST was higher than average the air temperature.

When comparing the LST values for 1990 and 2022, it was determined that the surface temperatures, especially in the city center, have increased, and there has been an increase in surface temperature in areas experiencing urban growth. Over the 32-year period, it was determined that the average LST of the study area increased by 0.66 °C.

4.3 Relationship between LST and LULC Classes

The relationship between LST and LULC classes for 2022 was examined, and the maximum, minimum, and average LST values

were determined for each class. The LST statistics for each land use class are given in Table 2.

LULC Classes	Maximum LST Value (°C)	Minimum LST Value (°C)	Mean LST Value (°C)
Built-up area	44.39	24.73	33.65
Industrial area	41.65	23.48	33.71
Barren land	44.15	24.26	35.88
Water bodies	31.44	21.44	25.92
Cropland and pasture	41.26	23.48	28.86
Fallow land and dry farming	42.24	25.65	35.39

Table 2. The maximum, minimum and average LST values for each LULC class.

The highest LST values were determined for the built-up area (44.39 °C) and barren land (44.15 °C), while the lowest LST values were determined for water bodies (21.44 °C) and cropland and pasture (23.48 °C). When examining the average LST values of land use classes, it was determined that the class with the highest surface temperature was barren land (35.88 °C), followed by fallow land (35.39 °C), industrial area (33.71 °C), built-up area (33.65 °C), cropland and pasture (28.86 °C), and water bodies (25.92 °C). Considering the average air temperature of 33 °C, it was determined that particularly the barren land and fallow land LULC classes were approximately 3 °C warmer than the average air temperature.

4.4 Relationship between LST and Spectral Indices (NDVI, NDBI)

The relationship between LST and NDVI, NDBI index for 1990 and 2022 was investigated. The spatial distribution of LST, NDVI, and NDBI in the study area is shown in Figure 5. The NDVI and NDBI analyses were performed using the formulas shown in equations (1) and (2) to generate the index maps. Then, a regression analysis was used to examine the relationship between LST, NDVI, and NDBI values obtained from 250 randomly selected points within the study area. These 250 random points were selected in a way that they would cover the entire study area without creating excessive density (i.e., not being too close to each other).

When examining the NDVI map for 1990, NDVI values ranged from -0.41 to 0.70. In the NDVI and NDBI maps for 2022, the NDVI values ranged from -0.14 to 0.63, while the NDBI values ranged from -0.56 to 0.38. When analyzing both maps together, it was observed that NDVI values, particularly within the city center, experienced a negative change, while areas on the urban fringe with high NDVI values showed a decrease.

The relationship between LST and NDVI/NDBI index was investigated through regression analysis. The results of the regression analyses indicated a negative correlation between LST and NDVI for both time periods. A correlation of 75% was determined between LST and NDVI values for 1990, while a correlation of 89% was determined for 2022.
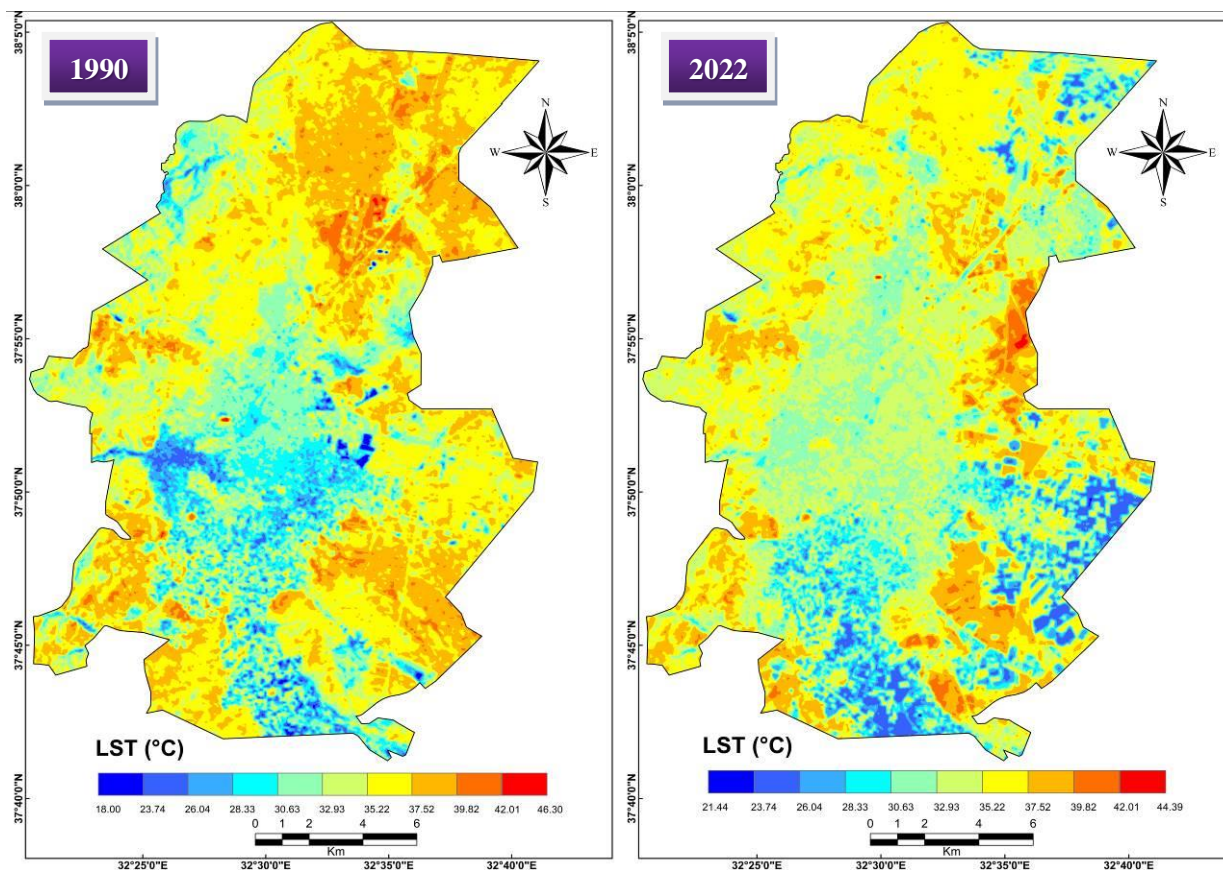
Figure 4. 1990 and 2022 LST maps of Konya.

A positive correlation was observed between LST and NDBI. A correlation of 86% was determined between LST and NDBI values for 2022. The results obtained for the city center of Konya are similar to findings from studies conducted in different geographical locations (Ning et al., 2018; Malik et al., 2019). In summary, as vegetation density increases, land surface temperature decreases. This is because vegetation increases evapotranspiration, leading to cooling of the surfaces. On the other hand, as impermeability increases, the proportion and mass of covering materials that cause heating and heat retention also increase, resulting in higher surface temperatures.
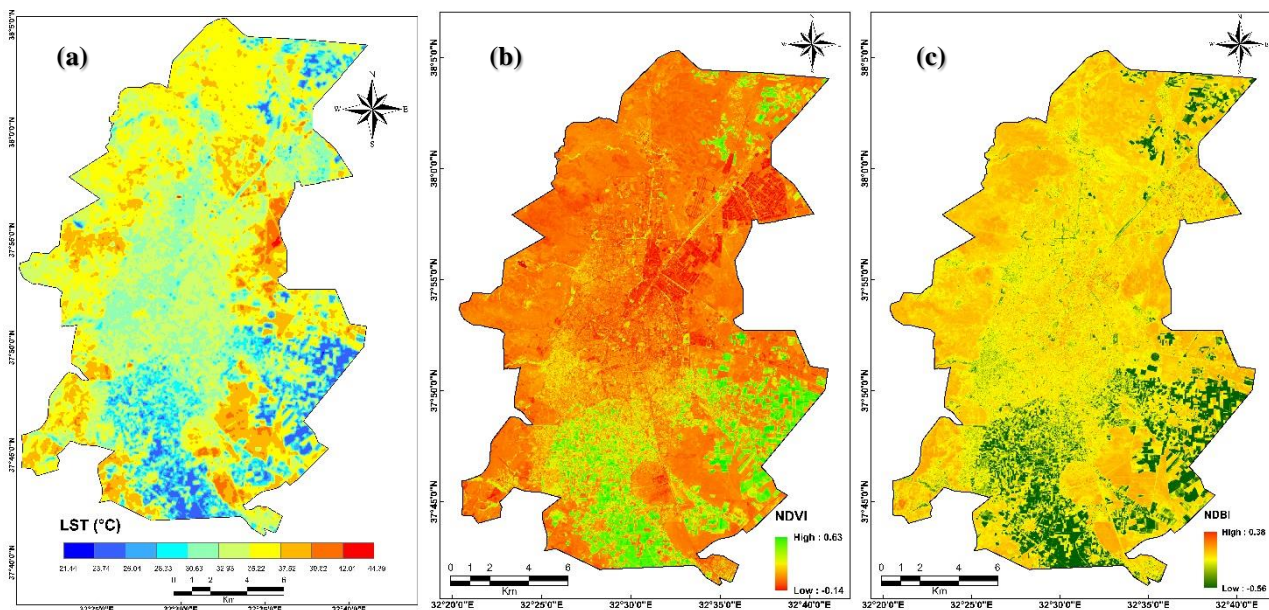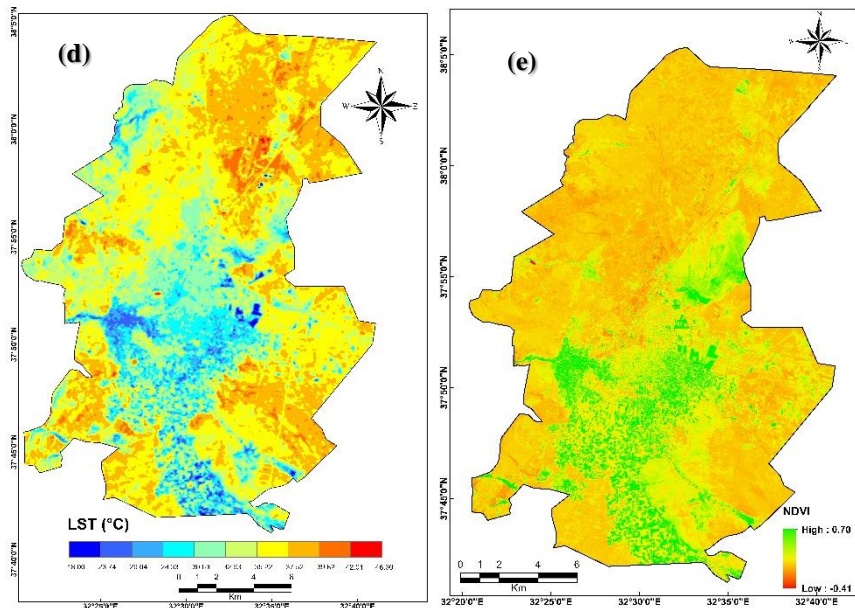
Figure 5. 2022 LST (a), NDVI (b), NDBI (c) and 1990 LST (d), NDVI (e) maps of Konya.

4.5 Impact of Urban Morphology on LST

The land surface temperatures in different types of areas in the city center of Konya were examined based on urban form, texture, pattern, and structural characteristics. Three distinct regions with the highest LST values in the 2022 were analyzed. These regions are shown in Figure 6.

Zone A is a shopping center located in dense urban development within the city. The average LST is 43.65°C in this zone. Zone A has an approximately 10°C higher LST compared to the average LST in the study area. The cause of this temperature difference was determined as the construction material of the shopping center and the large open concrete parking area (Figure 6).
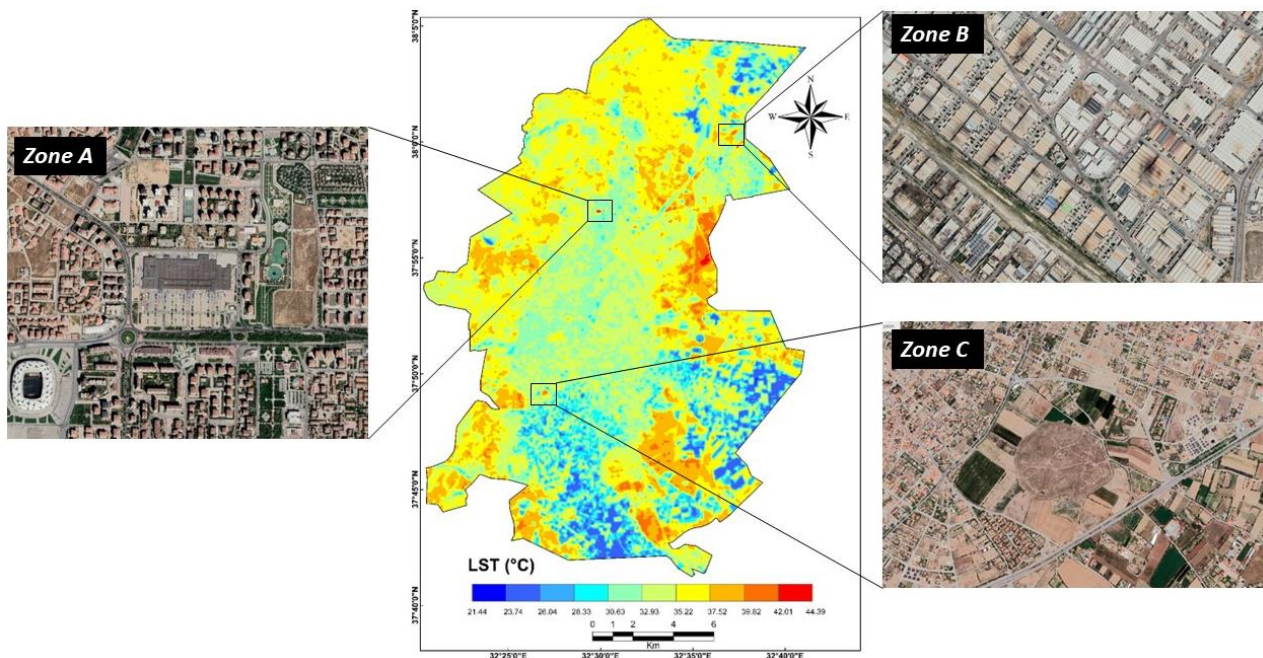

Figure 6. UHI effects of different types of regions in the city center of Konya.

The Zone B represents the industrial zone of the city where industrial facilities are concentrated. The average LST is 40.90°C in this zone. The reason for the above-average LST in this zone is attributed to the roofs of the buildings being covered with metal materials and the thermal energy emitted from the production activities. These contribute to the urban heat island effect.

The Zone C represents the open and barren areas in the urban center and urban fringe. The average LST is 42.25°C in this zone. This zone isn't covered with vegetation. It is observed that such areas, including barren mountainous, gizzard, and rocky terrains under state-owned lands, as well as protected areas, maximize the urban heat island effect.

5. CONCLUSION AND DISCUSSION

The urban heat island is the local manifestation of global climate change, and like global climate change, it has negative impacts on human and other living beings' health, quality of life, energy consumption, carbon footprint, and more. In order to address this problem that extends from local to global scales, spatial strategies should be developed, and action plans should be prepared from lower to upper scales (Yüksel and Yılmaz, 2008). First of all, it is of great importance to identify the problems that cause the UHI effect. Each city differs in terms of its unique geographical features, urban morphology, LULC, socio-economic structure, and urban dynamics. Therefore, the dimensions of this problem and proposed solutions differ in each city.

The LST, as a reflection of surface temperatures, is considered the most fundamental indicator of the urban heat island phenomenon. In this study, the UHI effect in Konya, which is one of Turkey's rapidly urbanizing cities with excessive population growth, was determined through LST analyses.

It was determined that the average surface temperatures in built-up areas, industrial areas, and barren land are between 1 and 3 ℃ warmer than the average air temperature. When examining LST maps, the highest temperature was determined in the parking area of the shopping center within the city, while the lowest temperature was determined in the cultivated agricultural area. In both periods, it was determined that vegetation within urban areas reduced the UHI effect. The NDVI and NDBI analyses revealed a negative correlation between LST and vegetation density, and a positive correlation with urban/building density. In the study area, land surface temperatures were lower in regions with high vegetation density, and higher in artificial/urban areas and barren land.

It is widely accepted that increasing vegetation density is a simple and effective way to reduce the UHI effect and the adverse effects of urban climate change. According to Farina (2012), a 10% increase in vegetation cover in urban areas can lower temperatures by approximately 4°C. Quattrochi and Luvall (1997) found that the forest area was approximately 15.5 °C cooler than adjacent open parking lots. Spronken-Smith and Oke (1998) stated that park/vegetation areas in the city were approximately 2°C cooler than the surrounding residential/structural areas. These temperature differences vary depending on factors such as size, type, etc. of vegetation. The results of this study are similar to the literature.

In the regions where urban heat islands are determined, it is necessary to determine the degree of influence of the factors affecting this formation and to reduce them by taking precautions. This is important both for the reduction of energy consumption and for the health and comfort requirements of habitants in these living spaces. Measures that can be taken to reduce or prevent the UHI effect have been developed to encompass global scales, starting from scale of the city of Konya.

Shopping malls increase the UHI effect in that area due to their building materials, large open parking lots, and impermeable surfaces. Therefore, cool coating materials should be used in parking lots and afforestation should be done. The barren lands located within and on the periphery of the urban, such as state-owned lands, mountains, rocky areas, and natural protected areas should be forested. It was determined that the vegetation within built-up areas reduces the UHI effect. Therefore, green areas within the city should be protected, and median planting, road afforestation and the amount of open green space must be increased. It is recommended to surround industrial areas with green belt buffers and to implement green roof to reduce urban heat island effects to acceptable levels. The LST studies enable urban planners, policymakers, and decision-makers to find the best solutions for spatial planning and design strategies aimed at reducing and preventing the UHI effect. n mega cities around the world, it is essential to establish an information system that continuously monitors the latest developments related to urban climate using remote sensing and geographic information systems.

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