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Spatio-Temporal Trends of Urban Heat Island and Surface Temperature in Izmir, Turkey

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Abstract: The distinct characteristics of urban and non-urban land cover usually results with a positive difference in surface temperatures and is referred to as the urban heat island (UHI) phenomenon. This paper assesses the spatio-temporal formation of UHI and land surface temperatures (LSTs) in Izmir, Turkey, situated in a Mediterranean climate region. LSTs were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua and Terra over the period 2000 – 2015. UHI intensity was examined using the temperature differences between urban and non-urban areas and non-parametric Mann-Kendall (M-K) test to identify trends in LSTs and UHI intensity. The results indicate that day-time UHI is higher at Izmir with a seasonal variation. M-K test of LSTs shows increasing trends in nighttime temperatures for both urban and non-urban areas especially for winter and spring.

Keywords: Urban Heat Island, Land Surface Temperature, MODIS

1. Introduction

The ever-growing expanse of urban areas increases anthropogenic impacts on the environment. Some of these impacts are favorable while some have adverse effects to the inhabitants. Among these environmental changes, the urban heat island (UHI) phenomenon is probably one of the more prominent ones. It refers to the positive difference in air and surface temperature between an urban area and its non-urban surroundings [1]. The primary causes of UHI effect are low albedo of the urban fabric, the high thermal admittance of typical urban surfaces, and scarce vegetation cover. Other causes include increased long-wave radiation from the sky due to city air pollution, decreased long-wave radiation loss because of the reduction of the sky view factor, anthropogenic heat sources, decreased evapotranspiration and decreased total turbulent heat transport due to wind speed reduction caused by canyon geometry [2]. UHIs affect the energy consumption [3] and the health of the cities' inhabitants in terms of thermal comfort [4] and therefore, it is crucial to understand the characteristics of air temperature variation of urban and surrounding areas.

UHI studies can generally be divided into two types: the canopy layer UHI and the surface UHI (SUHI). The canopy layer UHI is usually detected by in situ sensors at standard meteorological height while SUHI is measured using land surface temperature (LST) derived from airborne or satellite remote sensing data. Even though the canopy layer UHI is a direct UHI measurement and closer to felt temperature, the meteorological network at the settlements is not always as homogeneously distributed as desired. On the other hand, remote sensing data can provide the spatial distribution of temperature within a large area with consistent and repeatable measurements [5].

There has been a growing number of studies on SUHI however the results vary depending on several physical geography properties. For instance, Bonafoni et al. [6] indicated that the SUHI effect is a noticeable phenomenon throughout the whole diurnal cycle at Milan, Italy and it has a stronger intensity in the daytime. Similar results have been found by Azevedo et al. [7] in Birmingham, UK except the fact that the UHI intensity is higher at nights. On the other hand, some cities may also show negative UHI like Phoenix, USA where urban areas were 2.2°C cooler than surrounding shrubs [8]. Likewise, Rasul et al. [9] indicate that during the daytime, in summer, autumn and winter, densely built-up areas had lower LST acting as negative UHI at the city of Erbil, Iraq. In contrast, at night-time, higher LST experienced at the city than the surroundings and demonstrated a significant SUHI effect. It can therefore be asserted that UHI can be hotter for cities in humid regions and can be negative for cities in arid and semi-arid regions and UHI intensity can vary according to the time of the day.

Quite a few studies have been published on the UHI of Turkey's cities yet most of them used air temperature data. For instance Ezber et al. [10] used statistical and numerical modeling tools to investigate the climatic effects of urbanization in Istanbul using the data from 6 meteorological stations and found a significant warming trend in the atmosphere over the urbanized areas. Likewise, Çiçek and Doğan [11] investigated the effects of urbanization on temperature variation in Ankara using the data from 7 meteorological stations and concluded that there has been a significant increase with the UHI intensity in winters. However, the data collected at meteorological stations in Turkey may not represent non-urban weather conditions, since most of the stations are located or remained in between settlements due to the rapid urbanization. Satellite data, on the other hand, can sort that obstacle out. A more recent study of Benas et al. [12] investigated the nighttime LST and SUHI characteristics and trends in seventeen Mediterranean cities with satellite data for the period 2001– 2012. They determined a SUHI of 0.74°C for Istanbul. Corumluoglu and Asri [13] attempted to determine SUHI from a similar perspective. However, they only used single imagery of Landsat 8 and therefore their study lacks essential information of change in time.

The objective of this paper is to quantify the spatio-temporal formation of the SUHI in Izmir, as a case study of a city with Mediterranean climate. The novel contributions of this paper to the knowledge about the urban climate are the identification of the seasonal and diurnal variation of the patterns of LSTs and UHIs, the analysis of the UHI intensity and how it changes in 15 year period in Izmir.

2. Study Area

The city of Izmir (38° 15' – 38° 30' N and 27° 00' – 27° 10' E) is located in the western extremity of Turkey (Figure 1). It is the third most populous city in Turkey with roughly 3 M residents at the metropolitan area. That area extends along the Gulf of Izmir and surrounded with more rugged terrain to the north, east and south.

Typical Mediterranean climate is observed at Izmir characterized by mild, rainy winters and hot, dry summers [14]. The most explicit properties of Mediterranean climate are significant differences in climate conditions between summer and winters and the inter-annual strong variability of climate components [15].

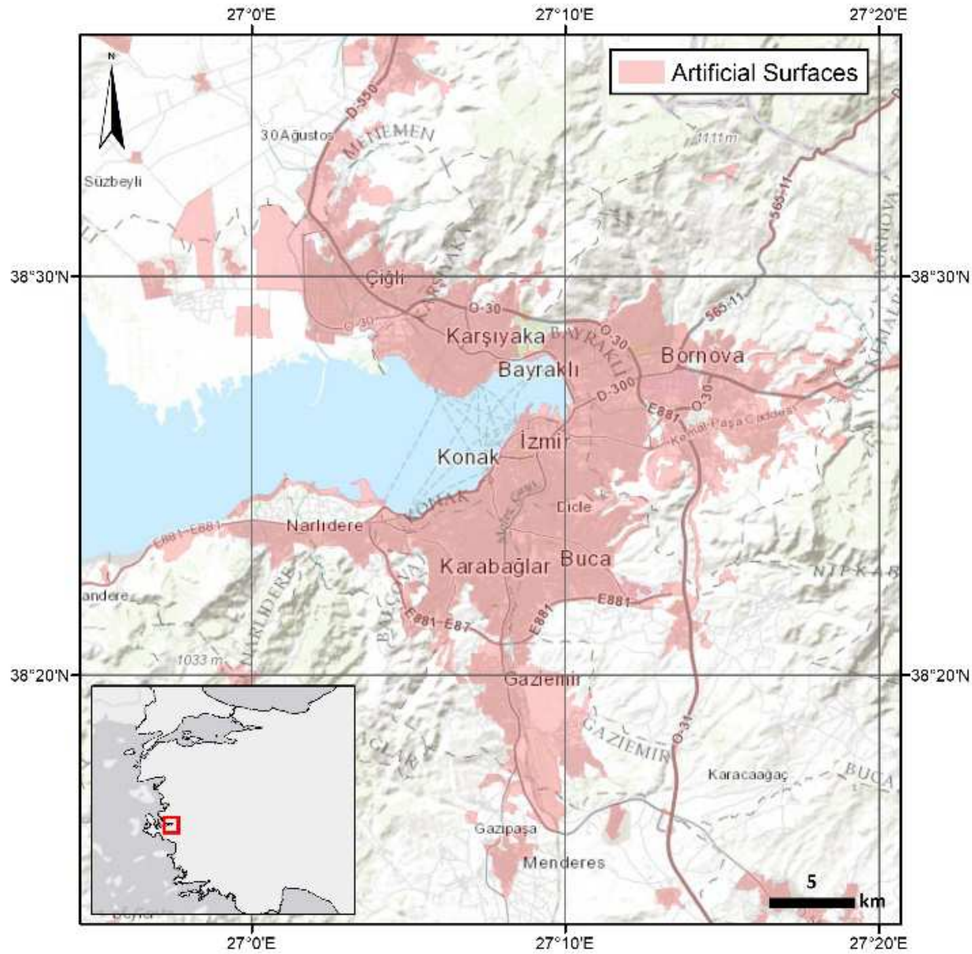

Figure 1. The location map of Izmir.

3. Data

Moderate Resolution Imaging Spectroradiometer (MODIS) LST and Emissivity 8-Day composite products (MOD11A2 and MYD11A2) NASA's Terra and Aqua satellites are used in this study. For MOD11A2, the data is obtained from Terra 2000 – 2015 period was used where MYD11A2 of Aqua was only available for 2003 – 2015 period making a collection of 1378 images. The data were filtered based on the QA flags provided in the quality control layers of the products. Terra satellite images are taken around 10:00 and 23:00, while Aqua satellite passes over the study area at approximately 01:00 and 14:00 local time. MODIS product of land cover data (MCD12Q1) were used to identify the urban and non-urban areas.

4. Methodology

In this study we have examined the UHI intensity using the temperature differences between urban and surrounding non-urban areas ($\Delta T_{u\text{-}r}$). To avoid mixture of urban and non-urban pixels, 1 km buffer zone has been applied to the urban class of MCD12Q1 land cover data. Surrounding non-urban area was defined as 10 km buffer zone.

For determining the seasonal variation, the images are categorized into four seasons: March, April, May for spring; June, July, August for summer; September, October, November for autumn and December, January, February for winter.

All the 8-day product images are converted to Celsius degrees. Average, maximum, minimum LST and standard deviation were calculated for urban and non-urban areas.

We used the non-parametric Mann-Kendall (M-K) test to identify trends in LSTs and UHI intensity (Eq. 1). Two hypotheses were tested using the M-K: the null hypothesis, H_0, that there is no trend in the time series; and the alternative hypothesis, H_a, that there is a statistically significant trend in the series, for a given α significance level. Both the Kendall tau coefficient (τ) and M-K coefficient (S) are used to identify rank correlation. Kendall τ is defined as the actual rating score of correlation divided by the maximum probable score. The M-K coefficient [16] [17] is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

where n is the number of observation values in the series, x_1, x_2, … x_n represent n data points where x_j represents the data point at time j. $Sign_{(xj-xk)}$ is the sign function as:

$$sign\,(x_j - x_k) = \begin{Bmatrix} 1 & x_j > x_k \\ 0 & x_j = x_k \\ -1 & x_k < x_k \end{Bmatrix}$$

The Kendall τ is calculated as:

$$\tau = \frac{S}{0{,}5n(n-1)}$$

A high positive value of τ or S indicates an increasing trend where a low negative value is an indicator of a decreasing trend. However, it is necessary to compute the probability associated with τ or S and the sample size n to statistically quantify the significance of the trend. In this study, significance levels 0.01 and 0.05 were used. For estimating the slope of the trend, Sen's slope estimator [18] is used. We have also used the seasonal Mann-Kendall test to analyze seasonal trends. The seasonal Mann-Kendall test runs a separate M-K trend test on each of number of seasons separately.

5. Results

5.1. Diurnal Variation of LSTs

There is considerable difference of LSTs between the urban and non-urban areas at Izmir. It can be observed that the urban area is warmer than the surrounding non-urban areas (Figure 2) in the observation period. UHI intensity is higher at daytime (Figure 3) whereas there is some seasonal variation (Figure 4). It can be noticed that the intensity of UHI is higher on spring and summer. On the other hand, daytime UHI intensities tend to be higher than night times. Higher UHI intensity was observed on spring and summer day-time Aqua (14:00) averages with an urban – non-urban difference of 2.82°C. However, the lowest UHI intensity occurred on winter night-time Aqua (01:00) averages with a value of 1.07°C.

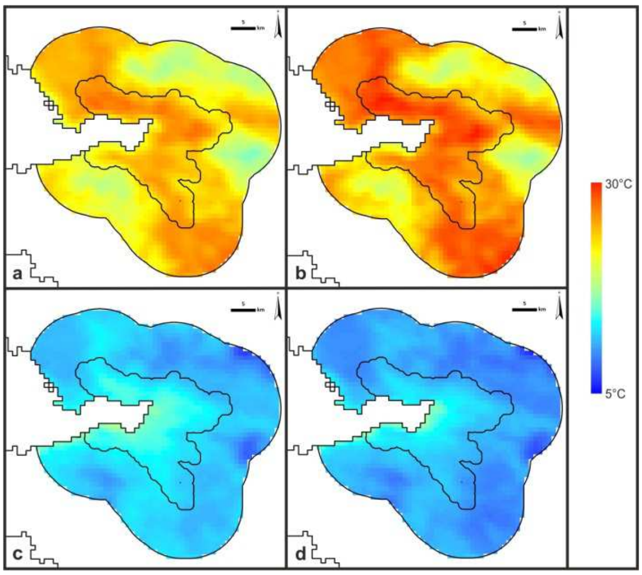

Figure 2. *Average day and night LST of Izmir urban and surrounding non-urban areas from MODIS Aqua and Terra for ~15 years (2000 to 2015 for Terra and 2003 to 2015 for Aqua). (a) 10:00; (b) 14:00; (c) 23:00; (d) 01:00.*

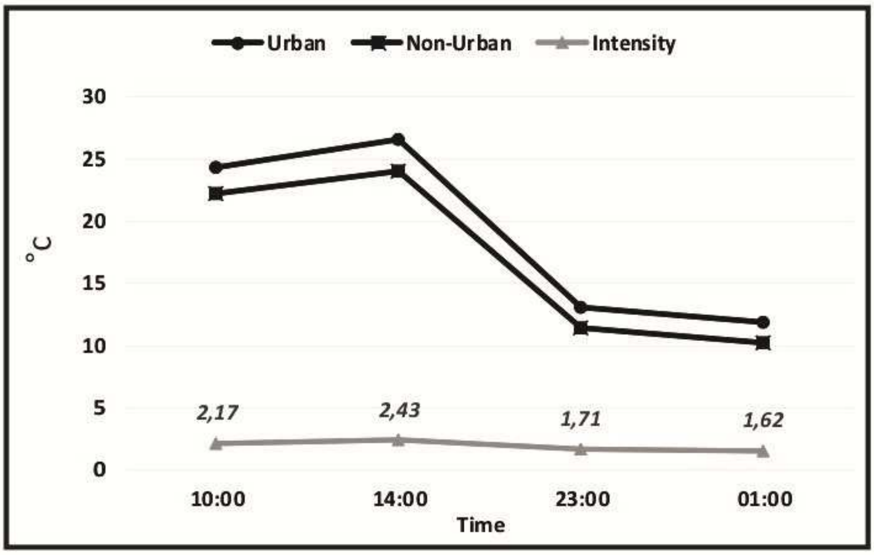

Figure 3. *Average of diurnal urban and non-urban LSTs and UHI intensities at Izmir over the period 2000 – 2015.*

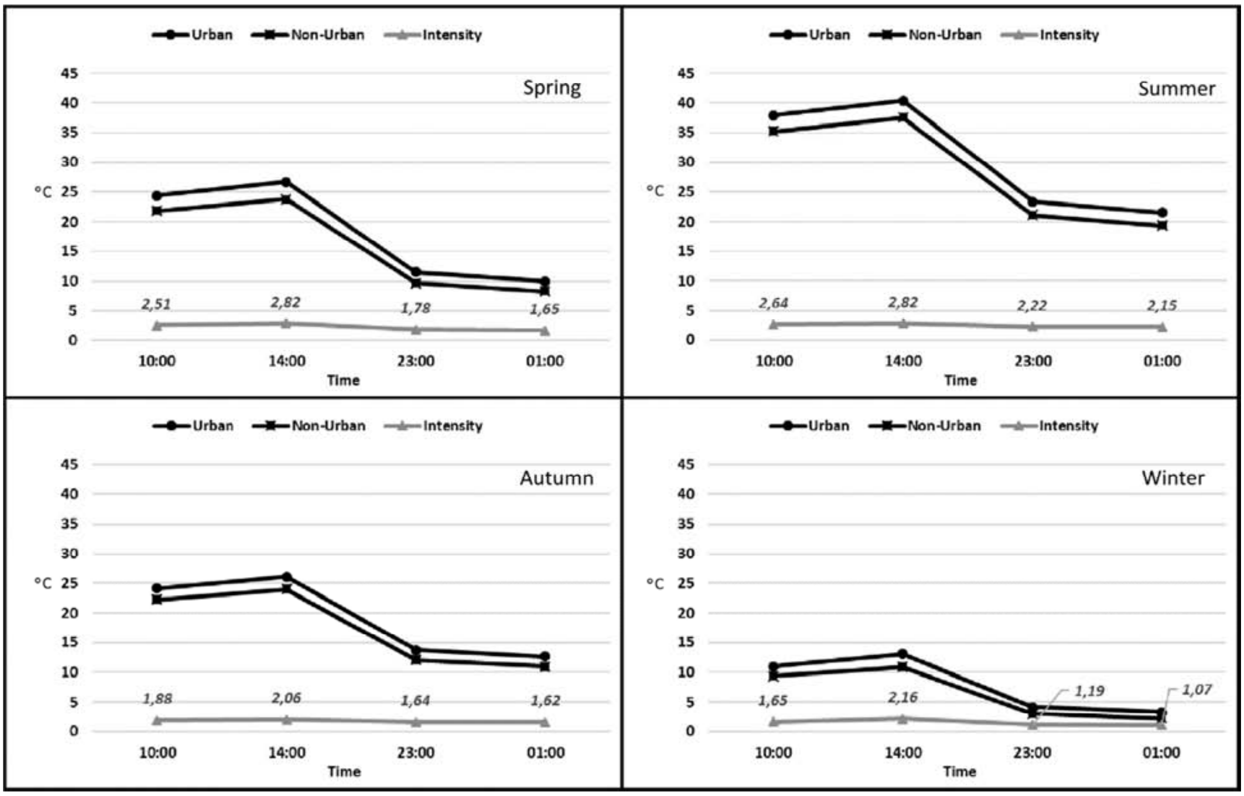

Figure 4. *Seasonal variation of average diurnal urban and non-urban LSTs and UHI intensities at Izmir over the period 2000 – 2015.*

5.2. LST and UHI Intensity Trends

The Mann-Kendall test was applied to the averages of every season separately in the observation period for both day and night images. The results indicate that there is a statistically significant positive trend in winter day and night images (for Aqua) for both urban and non-urban areas (Table 1). However, statistically significant negative trend is observed in summer daytime surface temperatures of urban and non-urban areas (for Terra). We have also applied seasonal Mann-Kendall test to observe the continuous trend in ~15 years (Table 2). The results indicate that night LSTs (both minimum, maximum and average of urban and non-urban pixels) detected with Aqua satellite have a statistically significant positive trend. There is also a statistically significant positive trend in maximum and average of non-urban area LSTs of Terra night images. A notable negative trend has been observed at non-urban areas in Terra day images and the trend in maximum of the non-urban pixels is statistically significant.

Table 1. *Results of the statistical tests for seasonal averages. (* Statistically significant trend at the 5% significance level. ** Statistically significant trend at the 1% significance level.).*

		SprIng		**Summer**		**Autumn**		**WInter**	
		M-K τ	**Sen's Slope**	**M-K τ**	**Sen's Slope**	**M-K τ**	**Sen's Slope**	**M-K τ**	**Sen's Slope**
Terra Day	Urban	-0.17	-0.04	-0.53**	-0.15	-0.02	-0.01	0.25	0.07
	Non-Urban	-0.20	-0.06	-0.53**	-0.16	-0.03	-0.01	0.23	0.08
	UHI intensity	0,23	0.02	0.09	0.01	0.32	0.01	-0.23	-0.01
Aqua Day	Urban	0.16	0.05	-0.41*	-0.12	0.19	0.07	0.52**	0.17
	Non-Urban	0.03	0.01	-0.32	-0.12	0.16	0.07	0.52**	0.18
	UHI intensity	0.34	0.03	0.23	0.01	-0.01	0.00	-0.32	-0.03
Terra NIght	Urban	0.10	0.03	0.10	0.02	0.32	0.07	0.30	0.13
	Non-Urban	0,17	0.04	0.08	0.02	0.32	0.07	0.37	0.15
	UHI intensity	-0.03	0.00	-0.02	0.00	-0.03	0.00	-0.33	-0.02
Aqua NIght	Urban	0.45*	0.10	0.32	0.09	0.32	0.11	0.49*	0.15
	Non-Urban	0.34	0.09	0.38	0.09	0.32	0.12	0.52**	0.16
	UHI intensity	0.12	0.01	-0.23	-0.01	-0.14	-0.01	-0.36	-0.02

Table 2. *Results of the seasonal Mann-Kendall test for LSTs. (* Statistically significant trend at the 5% significance level. ** Statistically significant trend at the 1% significance level.).*

		MIN	**MAX**	**AVG**
Terra Day	Urban	0.00	0.03	-0.12
	Non-Urban	-0.03	-0.30**	-0.13
Aqua Day	Urban	0.35**	0.08	0.10
	Non-Urban	0.11	-0.10	0.10
Terra NIght	Urban	0.20	0.16	0.20
	Non-Urban	0.23	0,29**	0.23*
Aqua NIght	Urban	0.43**	0.27**	0.40**
	Non-Urban	0.42**	0.24**	0.39**

6. Conclusions

The results presented here demonstrate the existence and the intensity of UHI in the Mediterranean climate of Izmir. The day-time UHI is higher in all seasons at the study area. The seasonal variation of the UHI indicates that day-time UHI is stronger in spring and summer. It should be noted that sea breeze is among the factors affecting the temperatures in Izmir as a Mediterranean climate coastal city. However, the corresponding effects are also expected to be minor for LSTs as mentioned in Benas et al. [12] and Pigeon et al. [19].

The analysis of LST trends shows increasing trends in night time temperatures for both urban and non-urban areas especially for winter and spring. However, there is a decreasing trend in daytime LSTs for summer. No statistically significant trend has been found in UHI intensities implying the urban and non-urban areas tend to act similarly in the meaning of warming/cooling.

Future studies on the LSTs of cities in Mediterranean and semi-arid environments are required to attest the results presented here.

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