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LST change for 16-year period for different land use classes

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Abstract

Problems such as global warming and climate change have been increasing their impact in the world negatively in recent years. With the development of the industry, more factories were established. Thus, more harmful gases were released into the environment with more factories. This ultimately caused environmental pollution and eventually damage to the atmosphere. In pursuit of this, the rays coming to the Earth too much have triggered Global Warming. The earth's surface temperature is severely affected by the energy exchange between the earth and the atmosphere. The surface temperature can be measured by terrestrial measurements, but there are constraints in terms of continuity, time, and cost. In this sense, remote sensing is a technology that is fast, reliable, and provides an advantage over terrestrial measurements in terms of cost. Within the scope of this study, the 16-year process between the land surface temperature maps of Kocaeli Province was examined by remote sensing. In this context, Landsat 8 OLI_TIRS and Landsat 5 TM satellite images were used dated 02.07.2017 and 02.07.2001 respectively. Temperature changes were obtained for the different land uses and evaluated for 16-year period in the GIS environment.

1. Introduction

The data obtained by Meteorology Affairs from the point ground stations is one of the most used data in evaluating the ground surface temperature measurements. There are kilometers of distance between these stations, and the measured value can usually only represent that point and its surroundings. For this reason, obtaining information about each point on the surface is done by interpolation methods, this remains far from representing the real data. Because the earth is not just plains. It consists of high mountains, indented shapes, and mountainous areas. Variation in altitude and changes in land use will also bring about differences in surface temperatures. In this sense, stations representing the data of the surface pointwise are limited in producing continuous data. Images taken from satellites are used for land use map creation, classification, etc. although, they can be used in measuring the ground surface temperature. These images consist of bands. Each band has a reflectance value. The thermal infrared regions are providing data to create temperature distribution of surface. In the last 40 years, many studies have been carried out on the urban heat island to determine the ground surface temperature. In the literature, studies using satellite images and algorithms used for ground surface temperatures show diversity in the scientific field. Dağlıyar et al. [1] conducted a study in 2015 and determine the ground surface temperature of Kahramanmaraş province and its surroundings, using the data they received from the Landsat image. In the study carried out by [2], the relationship between urban heat island density and population in 10 different regions with populations ranging from 1000 to 2 million was investigated and compared their results with previous studies. Ndossi et al. [3] used Aster satellite images in their study. They compared three algorithms for LST. In the study conducted by [4], the spatial effects of urbanization on heat island formation were examined with Remote Sensing Technologies. Landsat-8 OLI-TIRS and Sentinel-2 satellite images were used in the study. In the research, vegetation areas were obtained from Sentinel-2 satellite images, and urban area information was obtained using the normalized building difference index (NDBI). In the study by [5], time-series Landsat (TM and ETM+) satellite data products have been employed to quantify the spatiotemporal LST and Urban Heat Island (UHI) intensity for the years 2000, 2005, 2010, and 2015, respectively. Jain et al. [6] investigated the effect of changing LULC, at a local scale, on various variables-land surface temperature (LST), normalized difference vegetation index (NDVI), emissivity, albedo, evaporation, Bowen ratio, and planetary boundary layer (PBL) height, from 1991–2016. Rosas et al. [7] used 28 Landsat 8 satellite images between April and December 2015 in their study. Şekertekin and Marangoz [8] examine the impact of Land Use Land Cover (LULC) on Land Surface Temperature using Landsat 8 satellite data for Zonguldak metropolitan region. Orhan [9] investigated the effect of urbanization on the surface temperature of the city of Mersin. In this context, the Land Surface Temperature maps of the years 1990-1999-2007-2011-2018 were produced and, CORINE land use/cover data were used to identify urban areas in 1990 and 2018. Land surface temperature is an important parameter that shows or manages the energy balance on the earth and is an important factor that directs the dynamic change of environment and earth resources [10-11].

Different methods could be used for geospatial informations from relevant digital data in many disciplines [12-13]. GIS is a beneficial tool in evaluating the results obtained from satellite images [14]. Remote sensing and GIS technology is one of the essential tools in capturing spatial-temporal data and used for many applications intensively [14-15]. GIS is a tool for mapping and analyzing features and events on earth. Also, temperature changes can be obtained for the different land uses and evaluated in the GIS environment

Various algorithms exist for the determination of earth temperatures. The most widely used algorithm includes Land Surface Temperature – LST. Within the scope of this study, LST maps were created for different periods of different land use within the borders of Kocaeli province by using Landsat-5/8 satellite images. The Landsat data used were to a common day of each year. To reach the near or similar days of satellite images of different years, archive data was searched. The changes in the forest, agriculture, industry-urban, and seawater areas were examined from LST maps produced between 2001-2017.

2. Study Area and Data

The study region has been determined as the provincial border of Kocaeli, whose population and urbanization are increasing day by day due to 14 organized industrial zones and existing job opportunities (Figure 1). Kocaeli is located in the northwest of Turkey between 40.7655° latitude and 29.9407° longitude. In Kocaeli, which has a population of 1,883,270 million people for 2018, there are 521 people per square meter. The climate of the city, due to its special location, is a transitional climate between the Mediterranean climate and the Black Sea climate.

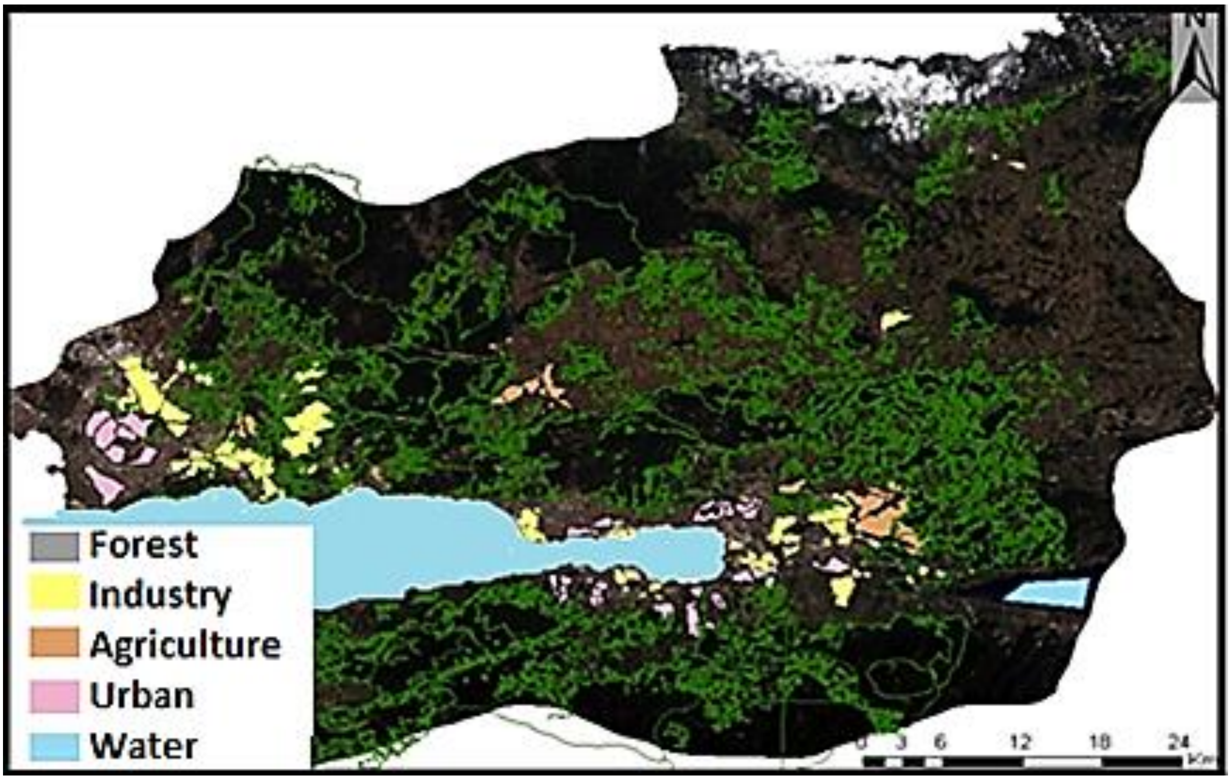

Figure 1. Kocaeli map and land use of the study area

The data used in this study are presented in Table 1. Landsat 5 and Landsat 8 satellite images taken in very recent months were used to determine the land surface temperature. These images were obtained from free satellite images available on the USGS website [16] and [17]. Meteorological data for Kocaeli province for the year 2001-2017 for the day the satellite image was taken were obtained from [18].

Table 1. Data used in the study

Data	Type	Data Used	Band	Spatial Resolution	Date
Meteorological Data	Point Data	Surface Temperature	-	-	2001-2017
Land Use Data	Polygon	Land use	-	-	2013
Remote Sensing Image	Landsat 5 TM	B6 Thermal	10.4-12.50	120x(30)	02.07.2001
	Landsat OLI_TIRS	B10 Thermal	10.60-11.19	100x(30)	02.07.2017

The Landsat-8 satellite image consists of a total of 11 spectral bands and has 2 separate thermal bands ranges from 10.6-11.19 µm, 11.50-12.51 µm. The spatial resolution of the visible and infrared range is 30 m. Bands 10 and 11 form the thermal bands of the satellite and its spatial resolution is 100 m. The satellite has a temporal resolution of 16 days. Landsat-8 satellite offers its products to its users with 16-bit radiometric resolution (Figure 2a). The Landsat-TM satellite image consists of a total of 7 spectral bands and the 6th band, which is in the range of 10.40-12 µm, constitutes the only thermal band of the satellite. The spatial resolution of the bands in the visible and infrared region is 30 m, and the spatial resolution of the 6th band in the thermal range is 120 m. Landsat-5 satellite, which has a temporal resolution of 16 days, offers its user's images with 8-bit radiometric resolution (Figure 2b).

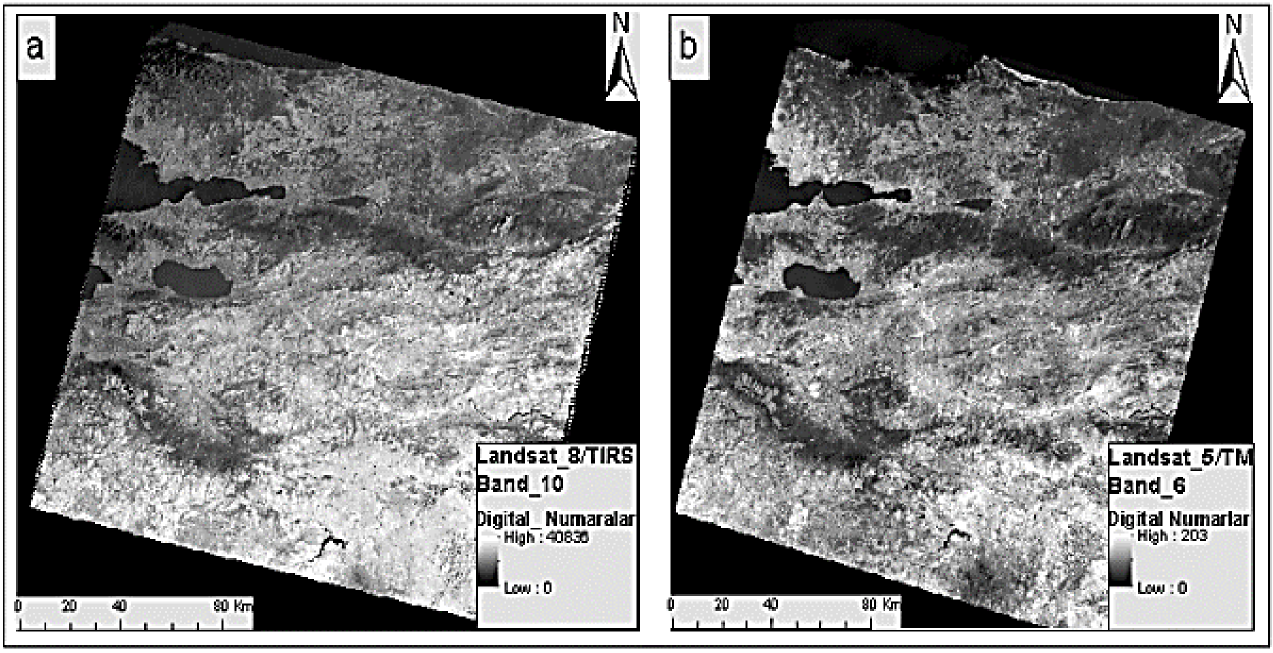

Figure 2. Raw data used in the study of Landsat satellite, **a.** Landsat8 (10th band), **b.** Landsat5 (6th band)

3. Land Surface Temperature (LST) Algorithm

In this study, a continuous surface temperature map of Kocaeli was calculated using the Land Surface Temperature algorithm. Since the radiance values are used while calculating the surface temperatures, the numerical values of the satellite data should be converted to the radiance value. The effect of land cover and topography should be taken into account when interpreting the radiant temperature image [19].

For this purpose, initially by using Equation (1), the pixel values of the thermal band were converted into spectral radiance (L_λ) values. Radiance is the amount of energy reflected from the field at a certain wavelength at a certain angle [1,20-21].

$$L_\lambda = L_{\min} + \left(\frac{L_{\max} - L_{\min}}{Q_{cal}^{\max}}\right) Q_{cal} \tag{1}$$

L_λ- spectral radians, Q_{cal} digital numbers of the relevant band, $L_{max-min}$ values were obtained from the metadata file of the data.

The radiance value consists of the thermal dissipation component, which is formed due to the temperature of the material on the earth's surface being above zero, the radiation when the atmosphere temperature is above absolute zero, the absorption and refraction of the radiation made by the material in the atmosphere and the components that occur as a result of atmospheric events. To correct these, the radiance values for the thermal band (10th band) of the Landsat 8 TM satellite data and the thermal band (6th band) of the Landsat 5 TM satellite data should be converted to luminance temperature values [19].

$$T_R = \frac{K_2}{In(\frac{K_1}{L_\lambda}+1)} \quad (2)$$

T_R luminance temperature value on the sensor (K), K_1 is the first calibration constant, K_2 is the second calibration constant, L_λ is the spectral radiance at the sensor.

Table 2. Calibration Constant

Satellite	K_1	K_2
Landsat 5 TM	607.76	1260.56
Landsat 8 OLI_TIRS	774.8853	1321.0789

Surface temperature; L_λ radiance, T_R: luminance temperature value on the sensor, and the ε surface emissivity value is calculated together [22].

$$LST = \frac{TB}{1 + \left(\lambda * \frac{T}{h * c / s}\right) * In(\varepsilon)} \quad (3)$$

Here, LST is the surface temperature (K), T_B is the blackbody temperature (K), λ is the wavelength of the reflected radiance (μm), α= hc/s (1.438x10-2Mk).

Surface temperature maps were created by applying Equations 1, 2, and 3 to the downloaded satellite images for the study area, respectively, in the information technology environment.

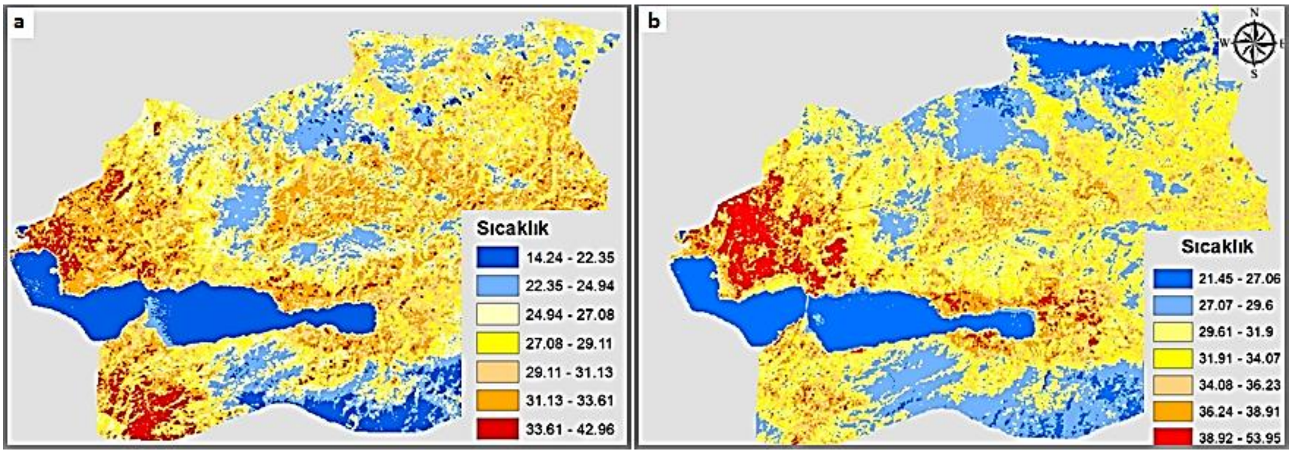

Figure 3. Landsat surface temperature maps, **a.** 02.07.2001 Landsat 5 TM, **b.** 02.07.2017 Landsat 8 OLI_TIRS

The surface temperature map of Kocaeli province is presented in Fig. 3 for 2001 and 2017. It is evident from the observation that the temperature is very high within the city core as well as certain surrounding areas of the city, especially on the northern side. The temperature is comparatively lower on the eastern side of the city than in the western region. Certain peripheral regions, however, show a higher temperature. This can be due to the development taking place in the outer areas of the city and the destruction of vegetation in the outlying parts of the city. In particular, the increase in industry and urban construction can be considered as the cause of the increase in LST. The results were also compared with the meteorological temperature values. The LST values obtained from the satellite image are obtained continuously for the whole area, and it is not very meaningful to compare the continuous data with the data obtained from the point-based meteorological station. However, for the general evaluation, the temperature averages obtained for the LST and meteorological data were compared. Accordingly, the surface temperature values obtained from the satellite and the meteorological temperature values have a temperature difference of 5-6 degrees from each other. The satellite data and the meteorological temperature in 2001 and 2017 increased 5.16 °C and 5.07 °C respectively. Since the temperature values obtained from the satellite image are obtained continuously and within the scope of the entire area, it is considered normal to see this temperature difference between the data obtained pointwise from the meteorological station and not exactly overlap. In addition, the fact that the surface temperature data obtained from satellite images cover the entire region also offers an advantage in terms of detecting the differences between different land-use areas.

4. Discussion

The temperatures in the LST maps obtained from the study were compared temporally for different land use areas. In this context, changes in temperatures in different land uses were observed. For this reason, temperature images and land use maps were overlapped. Sufficient samples were taken from the temperature images for the forest, agriculture, industry and urban, and seawater. The temperature values at the sampling points for the years 2001 and 2017 were assigned to the databases of these random points. For these values, a new column was created on the database and the difference values were obtained by taking the difference of the 2001-2017 temperature values from each other. For each land-use area, the temperature distributions of the same point in different years were created.

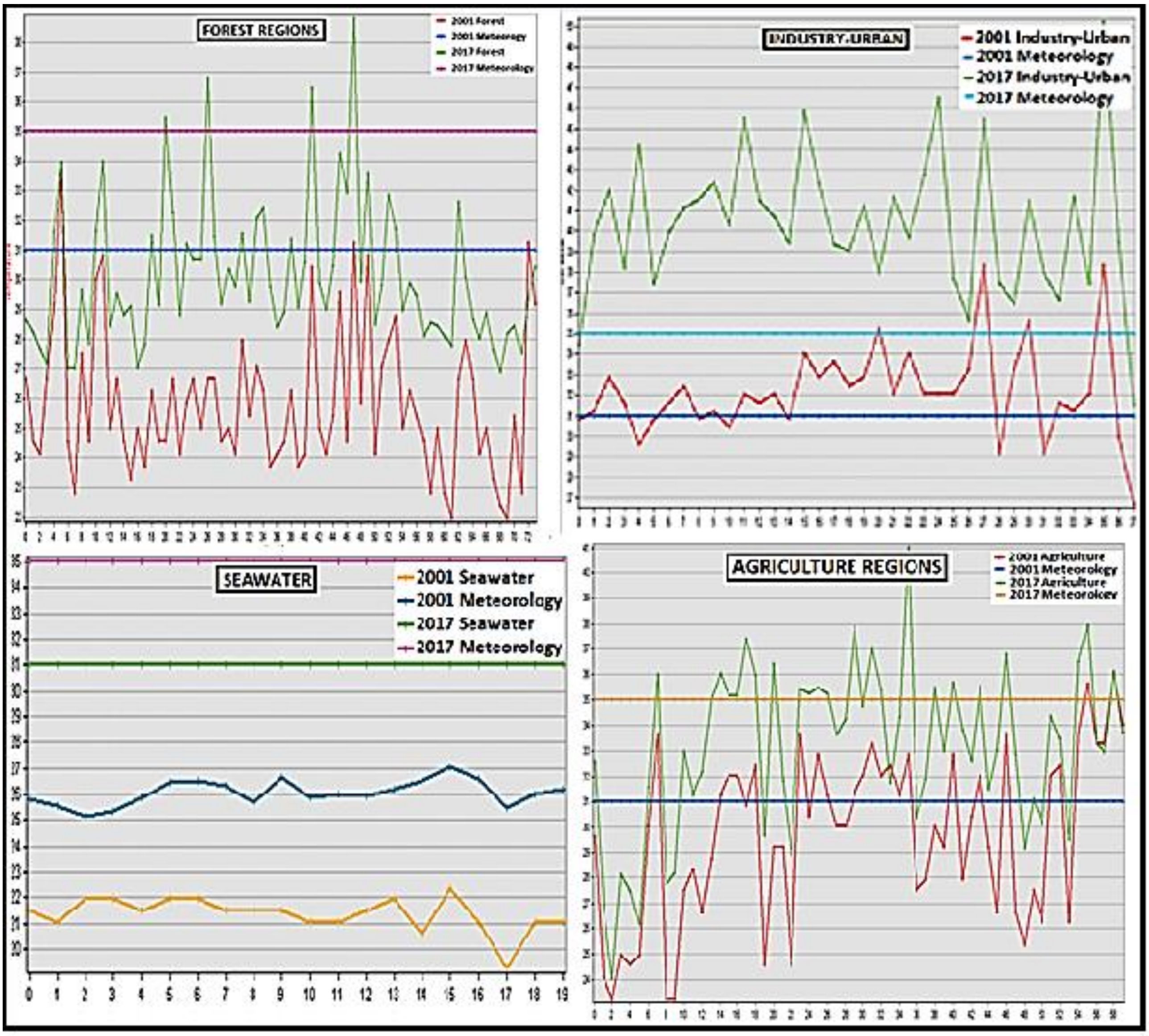

Figure 4. Temperature changes in different land use classes

It was observed that the 2017 and 2001 temperature values for the forest area range between 27 °C to 39 °C and 22 °C to 31°C, respectively. The meteorological temperature for 2017 and 2001 was on average 35⁰C and 31˚C. It was clear that both of the values were increased in 2017 compared to 2001 for forest regions. Similarly, an increase in temperature was observed in other land uses in 2017 compared to 2001. For the agricultural area, 5 °C differences were observed for the maximum temperature values between 2017 and 2001. On the other hand, the temperature difference is quite high for industrial and urban regions. 2017 and 2001 temperature values for the industrial and urban regions range between 50 °C to 31 °C and 39 °C to 27 °C, respectively. As can be seen in the temperature graph for the industrial-urban area, it was observed that the temperature values were higher for 2017 compared to 2001. As can be seen from the temperature graph for the seawater area, it was observed that the temperature values in the sea area were higher for 2017 compared to 2001.

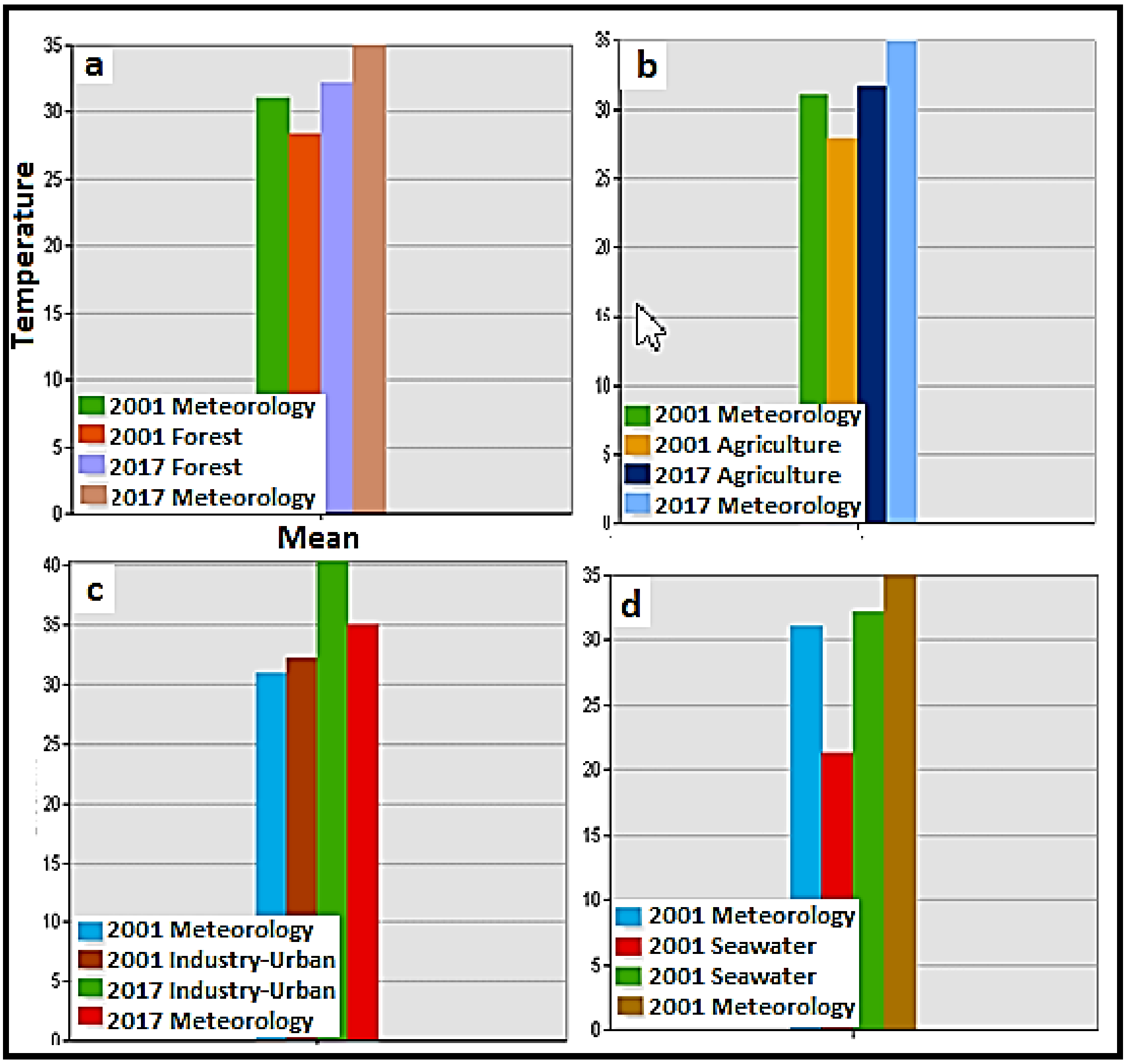

Figure 5. Average temperature changes between 2017 to 2001 for meteorology and different land uses **a.** Forest, **b.** Agriculture, **c.** Industry-Urban, **d.** Seawater

The average temperatures were calculated for the temperature variation differences in the land use areas. While the average was 28 °C in 2001, it was determined to be around 32 °C in 2017 for forest regions. In agricultural areas, the average difference between meteorological stations increased by 5 degrees from 2017 to 2001, while this increase is about 4 degrees according to the points above LST. On the other hand, while the average difference over LST between 2017 and 2001 for industry-urban regions increased by 9 °C, this difference increased by 4 °C in meteorological stations. A similar situation is observed in seawater areas. While the difference in temperature averages over LST in 2017-2001 increased by 10 °C, the increase between the meteorological station averages was 4 °C approximately.

5. Conclusion

Increasing urbanization and industrialization have caused the air temperature to rise due to the pollution of the environment and atmosphere. This change has occurred as an environmental factor that negatively affects the life of living beings. Therefore, remote sensing technology and surface temperature research have made progress in this direction. In the study, the land surface temperature of Kocaeli Province was determined with the help of remote sensing techniques from the Landsat 5 TM image dated 2001/07/02 and the Landsat 8 OLI TIRS image dated 2017/07/02. When the LST maps were examined, it was observed that the temperature increased around the bay in the 16 years. As a result of the study, the comparison of surface temperatures according to 16-year period was made for four different land uses. Accordingly, it was observed that temperature increased from 2017 to 2001 in all land use areas. An average temperature of 4 °C, 5 °C, 9 °C, and 10 °C increased in the forest, agricultural, industrial-urban, and seawater areas in Kocaeli Province.

According to the results, the average temperatures have increased, especially in industrial-urban and seawater areas. This temperature increase may be meaningful with the increase in sea pollution and industrial factories with the increasing population. However, it should not be forgotten that the satellite image reflects the day it was taken and provides information about the weather conditions of that day. People who affect the observed temperature changes need to be more sensitive to the environment and nature and behave carefully. It is recommended not to harm biological activities by reducing all kinds of harmful effects such as vehicle density and exhaust, building density, uncontrolled factory fumes, chemical products, etc., which are harmful to the atmosphere and cause temporal temperature differences, which are defined as global warming. There has been a decrease in forest areas as a result of uncontrolled and rapid construction arising from the increase in migration to settlements. It is recommended that due care and diligence be shown to increase these green areas again.

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Author contributions

Burak Kotan: Investigation, Writing-Original draft preparation, Writing-Reviewing, and Editing. **Suat Kılıç and Abdullah Tatmaz**: Visualization, Investigation, Data curation, Software, Validation. **Arzu Erener:** Conceptualization, Methodology, Investigation, Writing-Original draft preparation, Writing-Reviewing

Conflicts of interest

The authors declare no conflicts of interest.

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