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Calculation of daily land surface temperature values using Google Earth Engine

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Abstract

In parallel with urbanization, the temperature in dense residential areas is observed to be higher than in rural areas around the city. Urban areas being warmer than the surrounding natural areas is defined as an urban heat island. With the use of thermal bands in remote sensing platforms, the determination of Land Surface Temperatures (LST) and the spatial distribution of related parameters have begun to be represented better than the old methods. This data, obtained from the images detected by satellites, has enabled them to be used as a data source in a wide variety of applications due to its accessibility and coverage of large areas. In this study, LST maps and temperature tables within the provincial borders of Şanlıurfa were created by using the thermal band of a total of 9 Landsat 8 satellite images belonging to September of each year between 2013 and 2021. Finally, Normalized Difference Vegetation Index (NDVI) images were created from the satellite images and the correlation between them was examined.

1. Introduction

In parallel with urbanization, the temperature in dense residential areas is observed to be higher than in rural areas around the city. The materials that make up the buildings, asphalt and concrete roads, roofing materials and pavements absorb more energy from the sun than other natural surfaces.

The phenomenon of urban settlements having higher temperatures than the surrounding natural areas; it is defined as an urban heat island (Oke 1982; Gerçek and Bayraktar 2014). The vertical development of cities creates urban canyons by increasing the amount of energy reaching the earth and increases the urban heat island effect. Due to these urban canyons, cities show different climatic characteristics according to their surroundings (Yılmaz 2015).

Land Surface Temperature (LST) can be defined as the temperature emitted by the earth's surface. The main source of this heat is the sun. The heat energy reaching the earth from the sun heats the objects. The materials used in urbanization and construction absorb the energy reaching the earth by not reflecting it back, thus causing an increase in LST. LST is shown as an important factor that has an impact on various kinds of events on earth. LST data is a frequently preferred data type in plant change analysis, land use and land cover change analysis, global warming studies and meteorological studies (Parker and Warner 1973; Zhang et al. 2006; Li et al. 2013; Ndossi and Avdan 2016; Yıldız et al. 2017).

With the use of thermal images in remote sensing platforms, the determination of surface temperatures and spatial distributions of related parameters have begun to be better represented. The data obtained from the images detected by satellites has enabled them to be used as a data source in various applications due to its low cost and coverage of large areas. The Landsat 8 remote sensing platform was launched into space in 2013 by the National Aeronautics and Space Administration (NASA). It provides data to users with its nine spectral and two thermal bands.

It is of great importance that the data be used quickly and effectively in the studies carried out. Considering the importance of remote sensing and geographic information systems, the use of developing technologies is increasing. In parallel with this, geographic information system software is also developing. Advances in remote sensing and geographic information systems have enabled detailed investigations using high-resolution data. These developments also enabled the data to be obtained numerically and to reach the user quickly and to use the data effectively.

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The use of data obtained from satellites and geographic information systems provide fast, comparable, and updatable information about the changes that have occurred on the earth from past to present. In line with these developments, Google Earth Engine, which offers the opportunity to conduct research by combining large satellite images and data obtained from satellites, has provided a great advantage to users in recent years.

2. Method

The most widely used remote sensing platform for determining the LST is the Landsat 8 satellite, operated by NASA. The Landsat 8 platform has an altitude of 705 km, a temporal resolution of 16 days, and a sun-synchronous orbit that can orbit the earth in 98.9 minutes. The Landsat 8 platform contains two different sensor systems. The first of these is the Operational Location Imager (OLI). In addition to the bands included in previous Landsat sensors, the OLI system has 3 new bands for deep blue (Band 1) for coastal/aerosol applications, short wave infrared (Band 9) for analysis and detection of cirrus clouds, and band quality assessment. The second sensing system is the Thermal Infrared Sensor (TIRS). The TIRS system includes 100 m spatial (30 m resampling), 16-bit radiometric resolution, two bands of 10.6 – 12.51 µm electromagnetic spectrum thermal wavelength. The Landsat 8 (OLI&TIRS) sensor has a narrower spectral bandwidth and stronger signal-to-noise characteristics than Landsat 7 ETM+ and Landsat 5 TM sensors (USGS 2019).

In order to determine the surface temperatures in large areas on the earth, the temperature values in the study area cannot be fully represented by point-based local measurements. Thanks to remote sensing satellites, it has become possible to determine high-resolution temperature data on the earth's surface and has found the opportunity to be used in study areas such as ice thickness, phytosanitary, forest fires and determination of geothermal areas. The workflow of the study are given in Figure 1.

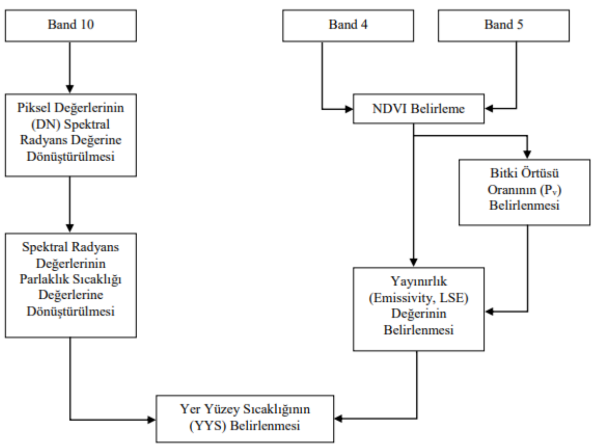

Figure 1. Workflow of the study

2.1. Study area

Şanlıurfa has an area of approximately 19,242 km^2 and is located between latitude 36,314 - 38,343 N and longitude 37,595 - 40,458 E. It has an average altitude of 518 m above sea level. The city has an extremely hot and dry climate in summers and cool and humid winters. It is the 8th most populous city in Turkey with a population of over 2 million.

2.2. Google Earth Engine (GEE) system

Depending on the developing technology, UA-GIS software is also developing. With this developing technology, software can be used over the internet, access to big data is provided and this data can be processed on the internet again.

While obtaining tabular data with UA-GIS integration, presenting spatial data to the user provides convenience in data analysis. UA-GIS systems are important in terms of more conscious use of the ecosystem we are in, increasing sensitivity, conscious use of energy resources and providing opportunities for use in many areas. Google Earth Engine is a platform developed by Google for the analysis of geoscience and data. Google Earth Engine provides visualization on maps by combining large satellite images and data with analysis.

Google Earth Engine is a platform that creates resources for many analyzes with algorithms developed on satellite images. The factors used in the study were quickly obtained by time series analysis of the developed algorithms.

2.3. Conversion of Pixel Values (DN) to Spectral Radiance Values

Spectral radiance value transformation is applied to the thermal image band values (DN: Digital Number) that will be used to determine the LST, with the help of the parameters in the metadata file of the satellite image. Spectral radiance value is defined as the amount of energy reflected or transmitted from a certain angle and region at a certain wavelength. Equation (1) is used for this transformation;

$$L\lambda = ML * Qcal + AL \tag{1}$$

where

Lλ = Calculated Radiance value (W/(m2 * sr * µm))

ML = Radians multiplicative scaling factor (from Satellite metadata)

Qcal = Pixel value (DN) of the satellite image

AL = Radians represents the additional scaling factor (from Satellite metadata).

2.4. Conversion of spectral radiance values to luminosity temperature values

Luminosity Temperature is the luminosity value of microwave emission traveling upwards from the highest point of the earth's atmosphere (T: Luminous Temperature). The second step is to convert the spectral radiance values obtained from the pixel values (DN) with Equation (1) to the luminance temperature (T). This transformation is calculated by equation (2).

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} - 273.15 \qquad (2)$$

where
T = Luminosity temperature (C0)
Lλ = Calculated Radiance value (W/(m2 * sr * µm))
K1 and K2 = Defines the conversion constants for the Thermal Band found in the satellite metadata.

2.5 Determination of Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) must be calculated in order to determine the ground surface emissivity and Vegetation Ratio. In determining the LST, NDVI values should be obtained from reflectance values, not DN values. The NDVI value is calculated by equation (3) using the reflectance values of the near infrared and red bands.

$$\mathrm{NDVI} = \frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}} \qquad (3)$$

On the Landsat 8 platform, the 5th band represents the near infrared and the 4th band represents the red band. The condition of the vegetation can be determined by taking the ratio of these two bands shown in Equation (3).

2.6 Determination of Vegetation Rate (Pv)

After the NDVI values of the study area are determined, the Vegetation Rate (Pv) is determined by using the plant and soil values of the NDVI. This ratio is determined using the maximum (NDVImax) and minimum (NDVImin) values over NDVI. Vegetation Rate (Pv); It is calculated by equation (4) (Sobrino et al. 2004). This ratio is used to calculate the earth emissivity (radiance) value (ε).

$$P_v = \left(\frac{\mathrm{NDVI}-\mathrm{NDVI}_{min}}{\mathrm{NDVI}_{max}-\mathrm{NDVI}_{min}}\right)^2 \qquad (4)$$

2.7 Determination of Emissions Values

The emissivity (ε) value is an important parameter used in the calculation of ground surface temperatures. Many methods have been developed to determine the emissivity value. However, in this study, the method based on NDVI values was used. In this method, the NDVI values were thresholded as soil and plant values, and the emissivity values of the study area were calculated. As threshold values, the values used globally in the literature are 0.2 for soil and 0.5 for plants (Sobrino and Raissouni 2000). It is calculated by the equation ελ (5).

$$\varepsilon\lambda = \begin{cases} \varepsilon_{s\lambda}, & NDVI < NDVI_s \\ \varepsilon_{v\lambda} P_v + \varepsilon_{s\lambda}(1-P_v) + C, & NDVI_s \le \mathrm{NDVI} \le NDVI_v \\ \varepsilon_{s\lambda} + C, & \mathrm{NDVI} > NDVI_v \end{cases} \qquad (5)$$

2.8 Determination of Land Surface Temperature (LST) Values

After the emissivity value is determined by calculating, the last step is to determine the ground surface temperature value. For this, ground surface emissivity correction should be made to the sensor temperature value calculated in the previous steps. Equation (6) is used for this correction.

$$LST = \frac{T}{\left(1+\left(\frac{w.T}{\rho}\right)*\ln(\varepsilon)\right)} \qquad (6)$$

Here, T represents the temperature values calculated in the previous stages, w represents the average wavelength value of the thermal band used (10.9 µm), and ε represents the emissivity value. The value of ρ is a constant value and is calculated by equation (7).

$$\rho = h * {}^{c}/_{s} = 1.438 \times 10 - 2\ \mathrm{mK} \qquad (7)$$

h: Planck's constant (6.626 * 10-34 Js),
s: Boltzmann constant (1.38 * 10-23 J/K),
c: speed of light (2.998 * 108 m/s) .

3. Results

The maximum, minimum and average temperature values of Şanlıurfa province calculated between 2013-2021 are given in Table 1. In addition, the changes in daily average temperature values are given in Figure 2. When Table 1 is examined, a difference of 0.8 °C is seen between the years 2017-2018. The increase in global warming and urbanization affects the sudden changes in annual average daily temperatures.

Table 1. Maximum, minimum and average temperatures in 2013-2021

Year	Max	Min	Average
2013	39.5	30.5	35
2014	36.5	32.3	34.4
2015	36.3	32.1	34.2
2016	36.5	34.5	35.5
2017	37.4	34	35.7
2018	36.6	36.4	36.5
2019	38.1	34.5	36.3
2020	36.95	36.35	36.65
2021	36.25	34.05	35.15

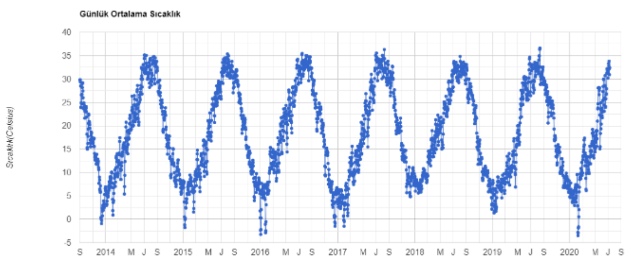

Figure 2. Average daily temperatures

4. Conclusion

In the study, the change in the LST of Şanlıurfa province in September between 2013 and 2021 was examined by using Geographical Information Systems and Remote Sensing techniques.

Within the scope of the study, the LST from Şanlıurfa global warming was examined and the criteria that could affect these temperatures were analyzed and evaluated by means of Google Earth Engine datasets and code editor. Within the scope of the study, NDVI, land surface temperature data between 2013-2021 were calculated and graphics were revealed. The effect of NDVI, temperature independent variables on the dependent variable LST was investigated. When the regression results are examined, it is observed that the effects of global warming, temperature and population data on forest losses are high.

In the study, revealing the temporal change of LST is of great importance in terms of future planning. Along with monitoring the temporal changes of LST, the causative factors should also be investigated. It is also very important in terms of making predictions for future plans with the determinations to be made.

The rapid and effective use of the data that will form the basis for the planning to be made is possible with geographic information systems. Especially in recent years, the increasing ground surface temperature emphasizes its importance. It is of great importance to follow the increase in urban areas in the protection of the natural environment. Considering all these criteria affecting the LST in the study, it is of great importance to control these negativities for a livable nature. In the study, an increase is observed in the ground surface temperature for Şanlıurfa Province between the years 2013-2021 as the vegetation density decreases, as the evaporation caused is less. For this reason, because the amount of energy lost is low on surfaces with less vegetation and sparse vegetation, it causes warming. It was determined by the index values that the ground surface temperature was inversely proportional to the plant density and directly proportional to the urban building density. Future plans should be made with precision, taking into account the findings revealed in the light of all the data used.

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