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Measuring changes in spatio-temporal LST variations and evaluating their relationship between greenhouses and their surroundings

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Abstract

Thermal infrared (TIR), frequently used in remote sensing studies, allows the analysis, modeling, collection, and evaluation of environmental parameters. Land surface temperature (LST) algorithms are used to detect urban heat islands and, accordingly, to identify concrete indicators of global warming resulting from urban heat islands. In this study, the land surface temperature change in agricultural land use where greenhouses occupy a dense area was determined in a time-dependent manner. To provide a suitable growing environment for the development of plants in greenhouses, the environment inside the greenhouse is kept warmer than its surroundings, especially in the winter. The investigation of the effect of this internal temperature on the external surface temperature constituted the motivation for this study. For this purpose, the determination and analysis of the land surface temperature change were carried out in the relevant region. The study material consists of agricultural fields containing greenhouses in the Kumluca district of Antalya province obtained from Landsat 8 satellite images between 2013-2019. LST analyzes were performed on images taken at 3-year intervals, and the results were compared. The results demonstrated that the surface temperatures of the greenhouses increased by about 1°C in the relevant period. Moreover, similar temperature increases were observed in other land cover classes. As a result, it has been concluded that while the surface temperatures of the greenhouses were generally lower than the building surface temperatures, they were higher than the green cover surface temperatures.

1. Introduction

Land surface temperature (LST) is of fundamental importance for ecological and climatic studies (Liu and Wang 2018). LST values are an important indicator for monitoring vegetation condition, and evaluating ecological demands of agricultural areas in line with the information obtained from them (Rashid et al. 2021). LST measurements made with remote sensing can provide a wealth of regional and global data based on a variety of available temporal and spatial resolutions available (Yu et al. 2018). With the use of data in agricultural areas, information about the plant's existence, diversity, and health can be obtained (Ardahanlıoğlu et al. 2017; Maroni et al. 2021; Selim et al. 2022).

In addition, the land surface temperature increase also affects the relevant region's air temperature (Yang et al. 2021). An area covered with vegetation has a lower surface temperature than the surrounding artificial structures since it can absorb radiation from the sun (Deng et al. 2018; Tan et al. 2021). Similarly, agricultural products grown in open fields have a cooling effect on the air temperature of that region (Aram et al. 2019; Karakuş and Selim 2022; Yu et al. 2020). However, this situation differs in indoor agricultural applications, namely in greenhouses (Kim et al. 2022). Greenhouses play an essential role in producing high-yield foods, as they control various climatic parameters such as temperature, humidity, CO_2 concentration, and light (Amani et al. 2021). Temperature of the greenhouses are critical to growing quality crops and increasing yield, especially during the off-season (Tang et al. 2020). Materials used for greenhouse covers, such as glass, nylon, and the like, are expected to keep the internal temperature balanced by preventing heat loss inside (Papadakis et al. 2000). In order to provide a suitable growing environment for four seasons in the greenhouse interior, artificial heating and cooling are often necessary. Furthermore, due to economic reasons and to ensure optimum energy use, greenhouse cover materials are expected to interact

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well with solar radiation (Kim et al. 2018). In addition, they should be in a structure that allows the sun's radiation to pass through and be capable of trapping the heat inside (Teitel et al. 2019; Yan et al. 2020). In this context, it has been expected that the surrounding land cover surface temperature is likely to be different from the greenhouse surface temperature.

Current technological developments in remote sensing and Geographical Information Systems (GIS) make it possible to determine the surface temperatures of the land cover with LST analyses (Çoşlu et al. 2021). This technology is an important source of data for possible applications such as monitoring the relevant region's Spatio-temporal land surface temperature changes (Shen et al. 2020) and planning residential (Ardahanlıoğlu et al. 2020) and agricultural areas (Ghosh et al. 2019). This study aims to monitor the temporal variation of land surface temperatures of greenhouse areas, to determine the variations in these temperatures, and to evaluate their relationship with the surrounding land uses in Kumluca district, which is one of the important greenhouse cultivation centers of Antalya and even Turkey. Between 2013 and 2019, the change in surface temperature in greenhouses in the study area and adjacent land covers at 3-year intervals was analyzed with remote sensing and GIS technologies. It is anticipated that the results obtained can guide local and central governments in the planning of greenhouses and their surroundings.

2. Method

The study consists of the primary stages of obtaining data, performing data preprocessing, performing LST analyses, and finally interpreting the findings. The main material of the study is the sample area in Antalya province Kumluca district where greenhouses are densely located.

2.1. Study area

The study area is located in the southwest of Turkey at 36°19'56.65"N and 30°18'1.54"E coordinates (Fig. 1). The surface coverage of the greenhouses within the relevant land boundaries is mainly made of plastic material. Greenhouses are built adjacent to each other, with an average width of 5-10 m and various lengths, which can reach up to 200 m in length.

Figure 1. Aerial photograph of the study area

2.2. Data sets

The basic data set of the study consists of Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite images of December for the years of 2013-2016 and 2019. For LST analysis, Band 4 (Red) and Band 5 (Near Infrared) with 30 m spatial resolution and Band 10 (Thermal Infrared 1) with 100 m spatial resolution of Landsat 8 were used.

2.2.1. Pre-processing and LST analysis

Satellite images covering the study area for the relevant years were obtained from the official and free website of USGS Earth Explorer (https://earthexplorer.usgs.gov/). Atmospheric corrections were performed using QGIS software to remove the images' noise. Then, the LST analysis, whose 6-step formula is given below, was carried out in ArcGIS 10.4.1 software using Landsat 8's red (Band 4), near-infrared (Band 5), and thermal bands (Band 10).

Calculation of TOA (Top of Atmosrefic) (1)

TOA(L): $M_L * Q_{cal} + A_L$

Convert radiance into BT in Celcius (2)

$$BT = \left(\frac{K2}{\ln\left(\frac{K1}{L}\right)+1}\right) - 273.15$$

Calculation of NDVI (3)

$$NDVI_i = \left(\frac{Band\ 5 - Band\ 4}{\text{Band 5 + Band 4}}\right)$$

Calculation of proportion of vegetation (4)

P_V= Square (($NDVI$-$NDVI_{MIN}$) / ($NDVI_{MAX}$-$NDVI_{MIN}$))

Calculation of emissivity (5)

ε= 0.004 * P_V + 0.986

Calculation of LST (6)

LST = (BT/ (1+(0.00115 * BT /1.4388) * Ln(ε)))
M_L = Band − spesific multiplicative rescaling factor
Q_{CAL}= Corresponds to Thermal Band
A_L = Band − spesific additive rescaling factor
K1= Band specific thermal conversion constant 1 (774,8853)
K2= Band specific thermal conversion constant 2 (1321.0789)
L = TOA

Following these processes, on the LST maps, points are assigned randomly to the areas of greenhouses and its surroundings. Then, the obtained LST value of corresponding to each point were carried over to the table. In this context, the temperature values on the greenhouse surface and the land surfaces adjacent to the greenhouses were evaluated in line with the international literature and suggestions were developed.

3. Results

In this study carried out in Kumluca/Antalya, which has a very dense land use cover in terms of greenhouses, the difference between the surface temperatures of the greenhouse surfaces and other land covers and the time-dependent variation of the temperatures of these surfaces were determined. LST maps produced for the years 2013, 2016, 2019 confirm that the surface temperatures differ spatio-temporally (Fig. 2).

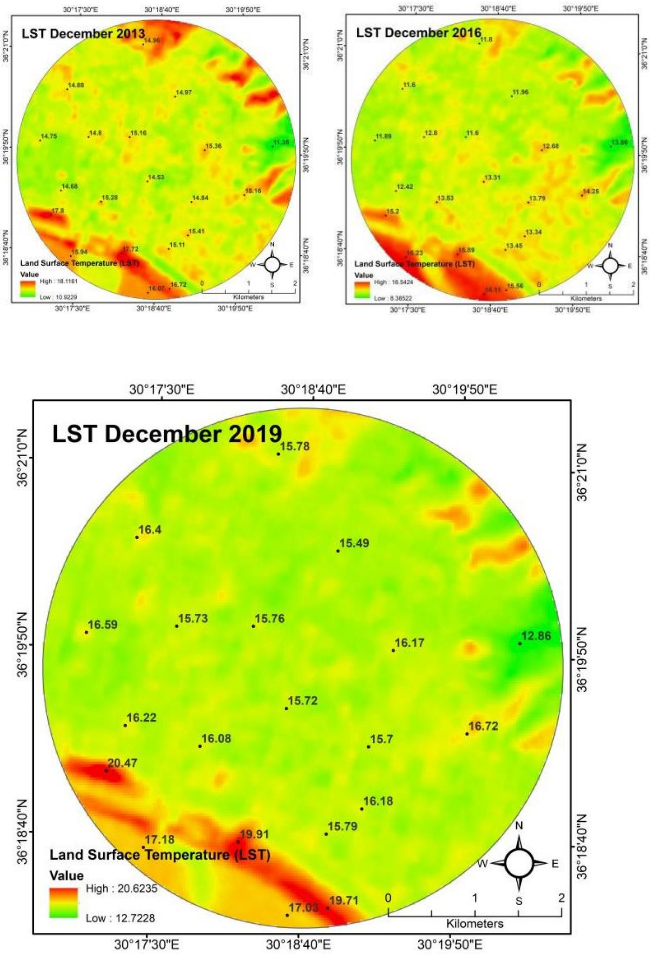

Figure 2. LST Maps of the relevant years

According to the findings obtained from the 2013 LST values, the average greenhouse surface temperature is 14.98 °C. In the same year, the average surface temperature for green areas is 13.15 °C, water is 16.00 °C, the building is 15.01 °C, and non-vegetation is 17.40 °C. In 2016, it was observed that the average greenhouse surface temperature decreased to 13.62 °C. Similarly, there was a temperature decrease in other land covers except for the water surface. In 2019, the average surface temperature of greenhouses increased significantly and reached 15.94 °C. Likewise, the mean surface temperatures increased for all other land covers. The data for 2019 shows that the highest surface temperature is in non-vegetation, which is followed by water, building, greenhouse and vegetation cover surfaces, respectively. According to the findings, in 2013, the highest surface temperature was measured at 17.80 °C in non-vegetation areas. Similarly, the highest value was measured again in non-vegetation in 2019. However, in 2016, it was obtained from the water surface. In all three years, the lowest temperature values were measured in green areas. On the other hand, water surface temperature was found to be the highest in all three years compared to other land cover classes.

4. Discussion and Conclusion

For the relevant years, the surface temperature values in the greenhouses increased by about 1 °C depending on the micro climatic conditions. This surface temperature increase was similarly measured in other land covers. As seen in Table 1, all land cover surface temperatures partially decreased in 2016 but increased in 2019, depending on the micro climatic climate data.

Table 1. Average LST values of land covers

Land_cover_type	LST_2013	LST_2016	LST_2019
Ave. water temperature (C°)	16.00	16.17	17.01
Ave. non_vegetation temperature (C°)	17.40	15.54	17.18
Ave. building temperature (C°)	15.01	12.91	16.56
Ave. vegetation temperature (C°)	13.15	12.82	14.31
Ave. temperature of greenhouses (C°)	14.98	13,62	15.94

In parallel with the related studies in the literature, the green areas showed a cooling effect on the surface temperatures (Song et al. 2018). The same situation was partially observed on water surfaces (Yang et al. 2021). Although greenhouses are artificial structures like buildings, their external surface temperatures were measured 1-2 °C higher than the buildings surface temperatures due to their internal temperature values (Saberian, and Sajadiye, 2019). On the other hand, the reason why the surface temperature values of greenhouses are lower than the surface temperature value of non-vegetation areas is thought to be due to the fact that greenhouses absorb some of the radiation and reflect the radiation less (Bonachela et al. 2020). It is also estimated that the increase in the surface temperature in greenhouses is due to global warming and micro climatic events (Haque et al. 2019), like the increase in other land cover surface temperatures.

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