

MONITORING THE SURFACE HEAT ISLAND (SHI) EFFECTS OF INDUSTRIAL ENTERPRISES

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ABSTRACT:

The aim of this study is to present the effects of industrial enterprises on Land Surface Temperature (LST) and to retrieve Surface Heat Island (SHI) maps of these regions. SHI is one of the types of Urban Heat Island (UHI) and as the urban areas grow in a city, UHI effect becomes bigger. The city centre of Zonguldak was chosen as study area and Landsat 5 satellite data were used as materials. Zonguldak has important industrial enterprises like thermal power plants and iron and steel plant. ERDEMIR is the biggest iron and steel plant in Turkey and it is one of the biggest ones in Europe, as well. There are three operating thermal power plants in the region namely CATES, ZETES1 and ZETES2. In order to investigate these industrial regions, Landsat 5 satellite data were processed using mono-window algorithm to retrieve LST and they were acquired on 11.09.1987, 18.09.2007 and 29.09.2011, respectively. The obtained results revealed that from 1987 to 2011, spatial and temporal variability in LST in industrial enterprises became higher than the surroundings. Besides, the sizes of SHIs in 2011 are bigger than the ones in 1987. For the countries and governments, having industrial enterprises is crucial for the development and it is also important to present the community better conditions in life. Thus, decision makers should consider mitigating the effects of these regions on LST.

1. INTRODUCTION

The rise in temperature of Earth's surface has been accelerating since the last century. Thus, it is of great importance to study on Land Surface Temperature (LST) as a climate parameter for the scientists. Satellite images are widely used by the scientists in order to investigate and visualize the effects of global warming by means of remote sensing technologies.

LST is a crucial climate parameter and it is great importance of analysing the UHIs and local climate changes (Voogt & Oke, 2003; Kaya et al., 2012). Split-window algorithm (Sobrino et al., 1996), temperature/emissivity separation method (Gillespie et al., 1998), mono-window algorithm (Qin et al., 2001) and single channel method (Jimenez-Munoz & Sobrino, 2003) are the most commonly used LST retrieval algorithms. Radiative transfer equation method, single channel method and mono-window algorithm are generally used LST retrieval methods for Landsat data. Radiative transfer equation method is not applicable because during the satellite pass, atmospheric parameters must be measured in-situ. Thus, single channel method and mono-window algorithms are preferred to obtain LST maps using Landsat data and they both present satisfying results. However, mono-window algorithm can be implemented

simply and practically because of using simulated linear transformation equations for some parameters in the algorithm.

The UHI is the phenomenon that the cities or urban areas have more temperature values than its surrounding (rural areas). SHI is one of the types of UHI and it can be observed by airborne aircrafts, satellites etc. The aim of this study is to extract Surface Heat Island (SHI) maps of the industrial regions on the basis of LST and to analyse the effects of industrial enterprises on LST.

2. STUDY AREA

The industrial enterprises are located in the city of Zonguldak and it is on the coast of Western Black Sea region of Turkey (Figure 1). Three thermal power plants (ÇATES, ZETES 1, ZETES 2) and one iron and steel plant (ERDEMIR) are operating in the study area right now. ERDEMIR is one of the biggest iron and steel plants in Europe and the thermal power plants are some of the important ones in Turkey. The city Zonguldak is one of the most forested cities in Turkey. However, with the exploitation of the coal reserves, progressive deforestation, and massive loss of wetlands followed on (Sekertekin et al., 2016). This study was examined in order to investigate whether the industrial enterprises have impact on LST and SHI or not.

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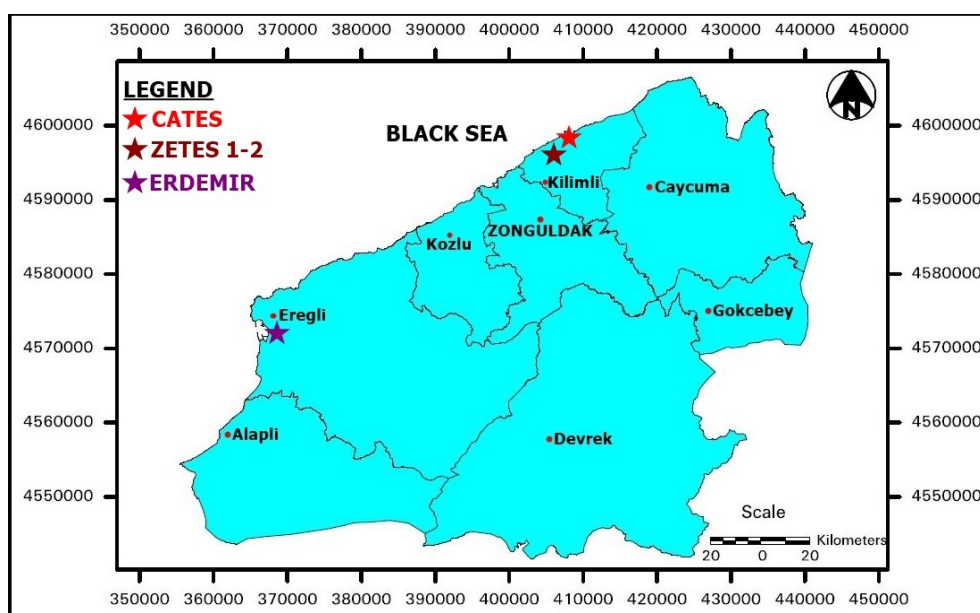


Figure 1. The distribution of the industrial enterprises in the study area

3. MATERIAL AND METHOD

In this research, Landsat 5 TM images acquired on 11.09.1987, 18.09.2007 and 29.09.2011 were used to retrieve LST. In addition to satellite data, meteorological data such as humidity and temperature obtained from the local meteorological stations were used in the algorithm.

Radiative transfer equation method, mono-window algorithm and single-channel algorithm are the most common LST retrieval methods using Landsat data. Radiative transfer equation method reveals the best results, but it requires in-situ radiosonde measurement of the atmospheric parameters during the satellite passes. Mono-window algorithm is also an effective method which provides satisfying values of root mean square deviation (Sobrino et al., 2004). Therefore, mono-window algorithm was chosen in this research.

Mono-window algorithm, developed by Qin et al. (2001), is recommended for LST retrieval of the images with one thermal band. The method includes three main parameters, namely emissivity, atmospheric transmittance and effective mean atmospheric temperature (Qin et al., 2001). In order to apply mono-window algorithm, seven steps written below were utilized.

- Converting Digital Numbers (DNs) To Spectral Radiance Values
- Converting Spectral Radiance to Reflectance Values
- Converting Spectral Radiance to Brightness Temperature Values
- Estimation of Emissivity Values (Depends on Normalized Difference Vegetation Index (NDVI))
- Estimation of Atmospheric Transmittance (Depends on water vapour content)
- Calculation of Mean Atmospheric Temperature
- Calculation of LST

Before implementing these steps, pre-processing of satellite data were performed. The images were resampled and clipped as including the study area. The first two steps of the algorithm are

radiometric corrections. After radiometric corrections of the images, spectral radiance values of thermal bands were converted to brightness temperature by means of equation (1).

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (1)$$

where T = effective at-satellite temperature in Kelvin
 L_λ = spectral radiance at the sensor's aperture
 K_1, K_2 = calibration constants

The next step is the estimation of Land Surface Emissivity (LSE) by using NDVI. A detailed estimation of LSE from NDVI was proposed by Zhang et al. (2006a).

After that, the estimation of mean atmospheric temperature (T_a) via near surface temperature (T_o) was proposed by Qin et al. (2001). Estimation of the last parameter, atmospheric transmittance (τ_i), could be estimated from water vapor content (w_i) as demonstrated in Table 1 (Qin et al., 2001). Water vapor content can be obtained from the meteorological stations or can be calculated using near surface temperature and relative humidity.

Profiles	Water Vapor (w_i)(g/c m ²)	Transmittance estimation equation (τ_i)	Squared correlation	Standard Error
High Air Temperature	0.4-1.6	0.974290-0.08007× w_i	0.99611	0.002368
	1.6-3.0	1.031412-0.11536× w_i	0.99827	0.002539
Low Air Temperature	0.4-1.6	0.982007-0.09611× w_i	0.99563	0.003340
	1.6-3.0	1.053710-0.14142× w_i	0.99899	0.002375

Table 1. Estimation of atmospheric transmittance from water vapour

Finally LST values could be obtained from equation (2), the equation of mono-window algorithm.

$$T_s = [a \cdot (1 - C \cdot D) + [b \cdot (1 - C \cdot D) + C \cdot D] \cdot T_i - D \cdot T_a] / C \quad (2)$$

where $a = -67.355351$
 $b = 0.458606$
 $C = \epsilon_i \times \tau_i$
 $D = (1 - \tau_i)[1 + (1 - \epsilon_i) \times \tau_i]$
 $T_s =$ LST in Kelvin
 $T_i =$ brightness temperature in Kelvin
 $T_a =$ effective mean atmospheric temperature
 $\tau_i =$ atmospheric transmittance
 $\epsilon_i =$ land surface emissivity
 $a, b =$ algorithm constants

Urban Thermal Field Variance Index (UTFVI) was used to evaluate the SHI effect (Zhang et al., 2006b). UTFVI can be calculated using the equation (3) as below:

$$UTFVI = \frac{T_s}{T_s - T_{MEAN}} \quad (3)$$

where $T_s =$ LST in Kelvin
 $T_{MEAN} =$ the mean LST value of the whole study area in Kelvin

The threshold values for the ecological evaluation index related to UTFVI are presented in Table 2.

Urban Thermal Field Variance Index	Urban Heat Island phenomenon	Ecological Evaluation Index
<0	None	Excellent
0.000-0.005	Weak	Good
0.005-0.010	Middle	Normal
0.010-0.015	Strong	Bad
0.015-0.020	Stronger	Worse
>0.020	Strongest	Worst

Table 2. The threshold values for the ecological evaluation index related to UTFVI

4. RESULTS

A model of the mono-window algorithm is illustrated in Figure 2. The whole process in this figure is programmed in Erdas Imagine Spatial Modeler for processing the data automatically. After obtaining LST, the images were classified using threshold method (Figure 3).

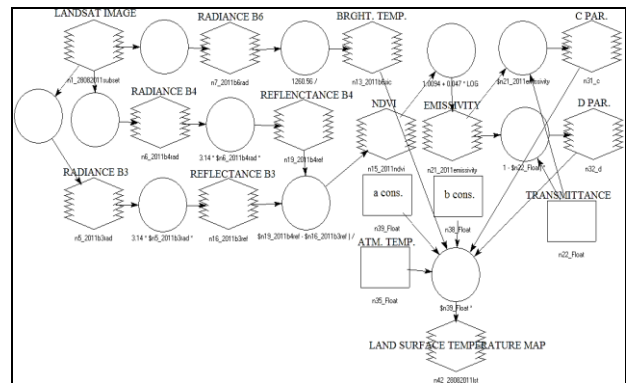


Figure 2. LST image model created in Erdas Imagine Spatial Modeler

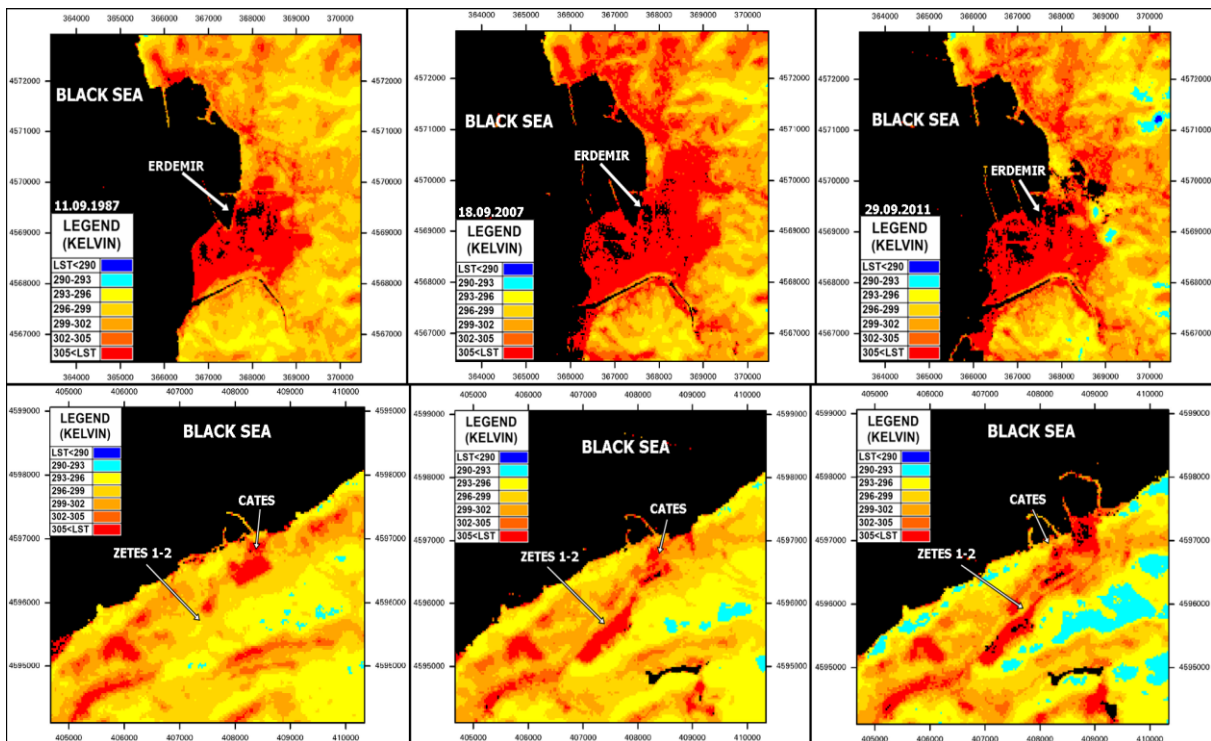


Figure 3. Classified LST images of the industrial enterprises in the study area

Accuracy assessment of LST image was conducted using the linear correlation coefficient between the radiance and LST values. In general, the temperature values of LST image and local meteorological stations are compared for this evaluation. Because there is only one meteorological station in Zonguldak, the radiance and LST values were compared with each other for the accuracy assessment and the results from 1987 to 2011 were 88%, 92% and 90%, respectively.

YEAR	ERDEMIR REGION			POWER PLANTS' REGION		
	Min. LST	Max. LST	Mean LST	Min. LST	Max. LST	Mean LST
1987	292.7	336.0	300.7	292.3	319.7	298.2
2007	292.2	338.3	301.5	291.8	335.0	299.6
2011	288.8	341.1	303.3	289.6	338.4	301.2

Table 2. LST statistics for the Landsat images

In this study, industrial regions in the city of Zonguldak were evaluated with regard to LST and SHI. As a result of the analyses, the surface temperature around some places in thermal power plants' region Catalagzi is about 5 °C higher than the city centre. Three thermal power plants (ÇATES, ZETES 1 and ZETES 2) have high LST values compared to the other land cover types. Max., min., and mean LST values for the industrial regions are presented in Table 2. The acquisition month of the satellite images is September. Although 2011 image was acquired at the end of September, mean LST values for this image are higher than the others. In the satellite images some places seem wet; hence, LST values for these places could not be calculated in the algorithm due to just presenting land cover.

Classified UTFVI for the study sites were presented in Figure 4. As understood from Figure 4, SHIs' sizes have enlarged year by year for the industrial enterprises and their surroundings due to the expansion of the facilities in the regions. In particular, after constructions of ZETES' power plant (after 2005) heat island effect can be observed in the region clearly.

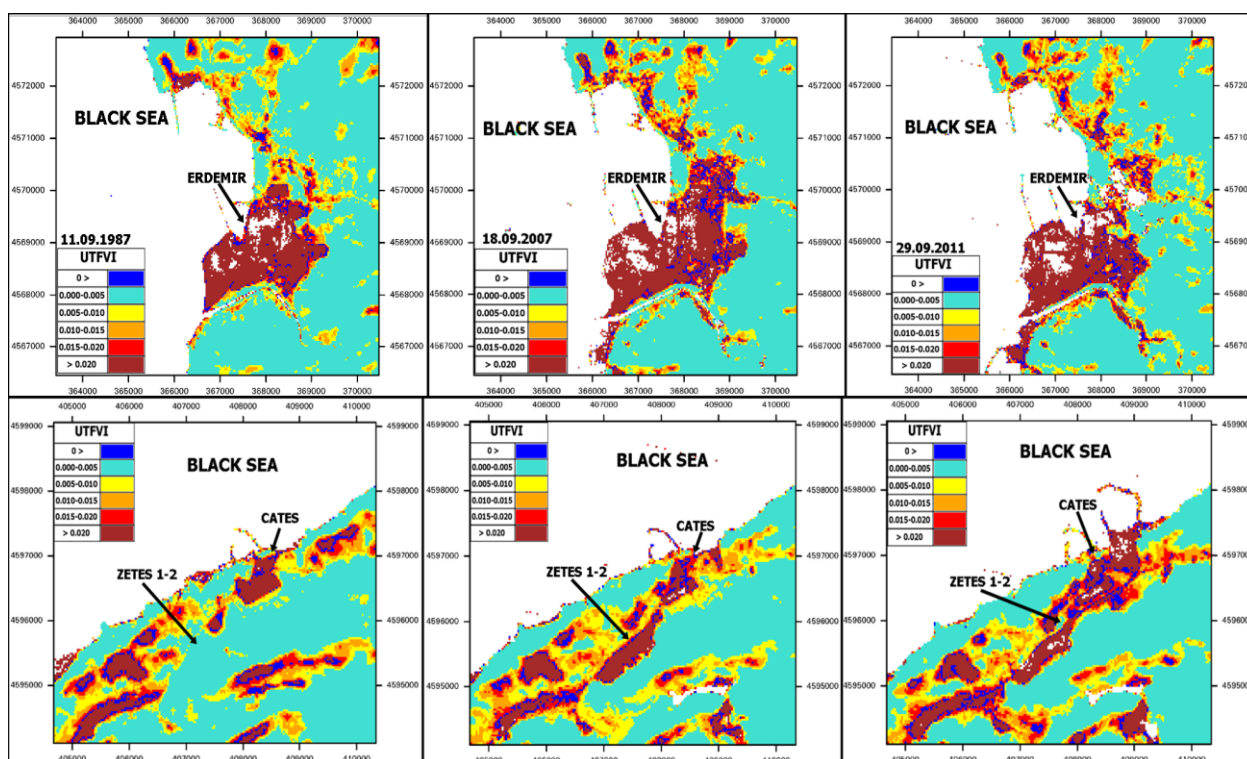


Figure 4. Classified UTFVI images of the study sites

5. CONCLUSION

Heat island effect has an important role for regional climate change studies. Thus, variations in air and surface temperatures for any region are considered by lots of scientists. In this context, satellite imagery is an effective method to retrieve LST thanks to presenting large areas. In this study, LST variations in industrial regions were evaluated and SHIs were extracted using LST images. ERDEMIR is in the centre of the city and thus it should be investigated by some different disciplines together whether it has negative effects on people and environment or not. The expansion in the industrial enterprises' facilities causes rise in the surface temperature. Therefore, it should be considered to increase woodland and vegetative areas while

constructing concrete structures. The decision makers should control the construction works and consider using materials that do not absorb sun radiation so much in the industrial enterprises.

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