Thermal Band Analysis of Different Land Uses in Urban Spaces and its Effects

Nalan Demircioglu YILDIZ¹, University of Ataturk (Turkey)
Uğur AVDAN, University of Anadolu (Eskisehir/Turkey)
Sevgi YILMAZ, University of Ataturk (Turkey)
Ayşe DAĞLIYAR, Mineral Research Exploration General Directorate, Remoting Sensing and GIS(Ankara/Turkey)
Andreas MATZARAKIS, Albert-Ludwigs-University of Freiburg (Germany)

ABSTRACT

In this research, remote sensing technology was used to evaluate urban development and its thermal characteristics through mapping of impervious surfaces and evaluating thermal infrared images.

As a result of rapid changes in urban areas, urban ecosystems and quality of life are deteriorated and decreased. In the presence of increased building density, for the comfortable living of people natural and cultural resources should be analyzed in detail. For that reason, optimal land use planning should be made in cities. In this study, Thermal Band analysis is applied in Erzurum city center with the aim of identifying of the different land uses. In this context, temperature map is produced with surface temperature analysis made on Landsat 5 Tematic Mapper (TM) satellite image. Landsat images were used to calculate the variation in urban impervious surfaces to 2010. PET values of the different urban areas are calculated. The obtained results are important because they create data bases for sustainable urban planning and provide a direction for urban planners and city administration.

Thermal bands were processed to obtain land surface temperatures for investigating the urban heat island effect associated with increasing impervious surfaces both spatially and temporally. This study has shown that different urban development intensities, have significant effects on LST.

Introduction

The surface temperature is of prime importance to the study of urban climatology (Vooght and Oke, 2003, Becker and Li, 1995). The thermal environment in urban areas is characterized by the heat island phenomenon affected energy demand, human health and environmental conditions (Van, 2005). Land surface temperature (LST) is an important factor for a wide variety of applications such as: hydrological, agricultural, biogeochemical and climate change LST is strongly influenced by the ability of the surface emission. Therefore, calculating LST with the high accuracy has been one of the biggest preoccupations of scientists. Thermal infrared remote sensing potentially measures the earth surface radiation for retrieving surface temperature values in the whole study area by pixel. (Van and Bao, 2008). To estimate the thermal condition of land surface by satellite, it is necessary to find the relationship between the surface temperature and land cover type (Takemata et al., 2004). Land use has always changed in response to changing human needs, driven by gradual trends and abrupt changes in the economy, society, technology, governance structures, and environmental conditions such as the climate and soil degradation (Ostwald and Chen, 2006; Rounsevell and Reay, 2009).

Land covers, as the biophysical state of the earth’s surface and immediate subsurface, are sources and sinks for most of the material and energy movements and interactions between the geosphere and biosphere (Weng, 2001). Surface temperature can be

¹ Corresponding Author: [nalandemircioglu25@hotmail.com]
estimated daily using thermal bands of NOAA/AVHRR (Kidder and Wu 1987, Balling and Brazell 1988, Roth et al. 1989, Gallo et al. 1993). Urban development, as the major type of human activities leading to land cover change, has a great impact on the environment. In the process of urbanization, natural vegetation cover is largely replaced by impervious surfaces such as buildings, roads, parking lots, sidewalks and other built surfaces (Van and Bao, 2008).

The integration of remote sensing and geographic information systems (GIS) has been widely applied and been recognized tool in detecting urban land use and land cover change (Harris and Ventura 1995; Stathopoulou et al. 2009).

TM thermal infrared data was used to evaluate urban microclimate change associated with urbanization (Carlson and Sanchez-Azofeifa 1999) while in another study (Carnahan and Larson 1990) to monitor urban vs. rural temperature differences in Indianapolis. Nichol (1994) such data for the observation of microclimate around housing estates in Singapore and Quattrochi et al. (2000) used thermal remote sensing in a GIS framework to assess urban heat islands. Lam (1990) compared the fractal dimension of three land-cover types in the coastal Louisiana. Weng (2001) examined the surface temperature pattern and its relationship with land cover in urban clusters in the Zhujiang Delta, China. Xiao and Weng (2007) studied the impact of land use and land cover changes on land surface temperature in a karst area of China. Weng and Wei, (2003); Weng, (2003) studied satellite images have been used extensively to study temporal changes in LULC in China. De Cola (1989) applied fractal analysis to describe the complexity of eight land-cover types in northwest Vermont while Emerson et al. (1999) studied the Normalized Difference Vegetation Index (NDVI) images derived from Landsat and examined the effect of changing pixel size on land use. Qiu et al., (1999) used two images of the Los Angeles area to compare the image complexity across the full spectral range of the hyperspectral images.

Thermal infrared remote sensing proved its capability in monitoring temperature field. The purpose of this study is to evaluate the use of Landsat 5 TM data for indicating temperature differences in urban areas and compare the relationships between urban surface temperature and land cover types. The urban temperature distribution map and the analyses of thermal-land cover relationships can be used as the reference for urban planning and the solution to the reduction of heat island effect. This research aims to evaluate the use of Landsat ETM+ data for indicating temperature differences in urban areas, to analyze and compare the relationship between urban surface temperature and land cover types.

**Material and methods**

The city of Erzurum is located in the northeastern part of Turkey at an elevation of 1850 m and 39.90 N, 41.27 E. It has a surface area of 25,066 km², being the 4th largest city and covering 3.2% of the country’s whole area. The Landsat satellite image of the study area for the year of 2010(08-15-2010, Path/Row:172/32) is shown in the Figure 1.
The study area boundary is determined in Landsat Satellite image (RGB/ 4 3 2). For the study area, the Landsat satellite image, provided from USGS Earth Explorer website http://glovis.usgs.gov/.

Land-use map is prepared with the data obtained from Provincial Directorate of Agriculture in 20. The land use database for Erzurum in vector format is utilized in this study in an effort to link more effectively land cover and surface emissivity. Corine land cover (CLC) is a geographic land cover/ land use database for a pan-European region. It is produced by the European Environment Agency and provides consistent information on land cover across Europe using a nomenclature of 44 standard classes which are organized in 5 levels of detail (European Commission, 1993). The CLC database for Uzundere in vector format is utilized in this study in an effort to link more effectively land cover and surface emissivity. For this purpose, the original 44 classes of Corine were grouped into only 5 ones: “open area”, “settlement area”, “meadow area”, “dry farming area”; “irrigated area” thus, a new land cover polygon map for each city was produced.

The LST were derived from the Landsat TM Thermal Infrared band (10.45-12.42 μm). In order to convert the digital number (DN) of Landsat TM TIR band into spectral radiance ($L_\lambda$) can be used as equations (Chander ve ark., 2007; Barsi ve ark., 2007).

\[ L_\lambda = \left( \frac{L_{MAX,\lambda} - L_{MIN,\lambda}}{Q_{cal,\text{max}} - Q_{cal,\text{min}}} \right) (Q_{cal} - Q_{cal,\text{min}}) + L_{MIN,\lambda} \]

($L_\lambda$ = Spectral radiance at the sensor's aperture (W/ (m² sr μm)), $Q_{cal}$ = Quantized calibrated pixel value (DN), $Q_{cal,\text{max}}$ = Minimum quantized calibrated pixel value corresponding to $L_{MIN,\lambda}$ (DN=0), $Q_{cal,\text{min}}$ = Maximum quantized calibrated pixel value corresponding to $L_{MAX,\lambda}$ (DN=255), $L_{MIN,\lambda}$ = Maximum at-sensor spectral radiance that is scaled to $Q_{cal,\text{min}}$ (W/(m² sr μm)), $L_{MAX,\lambda}$ = Minimum at-sensor spectral radiance that is scaled to $Q_{cal,\text{max}}$ (W/(m² sr μm))).
The next step is to convert the spectral radiance \( L_{\lambda} \) to at-sensor brightness temperature \( T_B \). For Landsat Data, to convert the spectral radiance into at-sensor brightness temperature can be used as following Equation (NASA 2004; Chander and Markham 2003).

\[
T_B = \frac{K_2}{\ln \left( 1 + K_1/L_{\lambda} \right)}
\]

\( T_B \) = Effective at-sensor brightness temperature (K), \( K_1 \) = Calibration constant 1 (W/(m\(^2\) sr μm)), \( K_2 \) = Calibration constant 2 (K), \( L_{\lambda} \) = Spectral radiance at the sensor’s aperture (W/(m\(^2\) sr μm)), \( \ln \) = Natural algorithm

The temperature values were obtained and referenced to a black body. Therefore, corrections for spectral emissivity (\( \varepsilon \)) became necessary according to the nature of land cover (Weng ve ark, 2004; Li ve ark, 2012). Emissivity of an object is the ratio of energy radiated by an object at a given temperature. The emissivity of natural surface can vary significantly difference in vegetation characteristics. The emissivity calculated from NDVI (Sobrino ve ark. 2004; Vandegriend ve Owe 1993).

After the Calculation of brightness temperature \( T_B \) and Emissivity \( \varepsilon \) images, the final Land Surface Temperature (LST) image was computed as Equation (Artis ve Carnahan 1982).

\[
T = \frac{T_B}{1 + (\lambda/T_B/\alpha) \times \ln\varepsilon}
\]

\( T \) = Surface radiant temperature (K), \( T_B \) = The blackbody temperature (K), \( \lambda \) = Wavelength of emitted radiance (\( \lambda = 11.435 \) μm), \( \alpha \) =hc/K (1.438 x 10\(^{-2}\) mK), \( h \) = Planck’s constant (6.26 x 10\(^{-34}\) J/s), \( c \) = Velocity of light (2.998×10\(^{8}\) m/s), \( K \) = Boltzman constant (1.38 x 10\(^{-23}\) J/K), \( \varepsilon \) = Surface emissivity

**Results**

The finding of classification of land-use and land-cover maps, are displayed in Table 1 and Figure 2.

Land-use map is prepared with the data obtained from Provincial Directorate of Agriculture. On the land-use map, while red color shows settlement area, light green ones show meadow area and pink color demonstrate open areas (Fig. 2)
In this study, LST is analyzed on non-vegetated mountainous open areas (M), meadow area (C), irrigated area (S), and dry farming area (K) on city plain. Surface temperatures and analysis results for these five different land uses are given in Figure 2. Surface temperatures of different land-uses show different values between 32.2°C and 2.4°C (Figure 3).

Temperature map of study area which is produced through thermal band analysis is given in Figure 4. When the LST and land use maps are overlapped, the open areas in the application field cover 287.42 km², the irrigated areas cover 231.35 km², meadow area 109.06 km², dry farming area 196.50 km² and settlement area cover 68.02 km² (Table 1).

While the maximum temperature in dry farming area raised up to 25.1°C, it was 22.6°C in the open areas. In the basin, the irrigated area mean temperature is 19.5°C, the temperature in meadow area is 18.6°C and the temperature in settlement area is 20.7°C (Table 1; Figure 5). As the maximum temperature is measured in non-vegetated open areas (31.7°C), minimum temperature is measured as 4.8°C in settlement areas (Figure 5).
Table 1. Mean temperatures in the study area

<table>
<thead>
<tr>
<th>Land use</th>
<th>AREA (km²)</th>
<th>MIN (°C)</th>
<th>MAX (°C)</th>
<th>RANGE</th>
<th>MEAN (°C)</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (Irrigated area)</td>
<td>231.35</td>
<td>11.5</td>
<td>28.8</td>
<td>17.3</td>
<td>19.5</td>
<td>2.2</td>
</tr>
<tr>
<td>M (open area)</td>
<td>287.42</td>
<td>9.6</td>
<td>31.8</td>
<td>22.2</td>
<td>22.7</td>
<td>3.5</td>
</tr>
<tr>
<td>C (meadow area)</td>
<td>109.06</td>
<td>11.0</td>
<td>29.8</td>
<td>18.8</td>
<td>18.7</td>
<td>2.4</td>
</tr>
<tr>
<td>K (dry farming area)</td>
<td>196.50</td>
<td>14.2</td>
<td>31.5</td>
<td>17.2</td>
<td>25.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Settlement area</td>
<td>68.02</td>
<td>4.8</td>
<td>27.6</td>
<td>22.8</td>
<td>20.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Figure 4. Land use & LST Maps Overlay

Figure 5. Mean temperatures in the study area
Discussion

Matson et al. (1978) defined that the difference between urban and rural areas differs from 2.6°C to 6.5°C. Dry farming area and open areas are defined hot places, and the green areas (irrigated area, meadow area) are cold places. Tran et al., (2006), Zhang et al., (2009) and Weng, (2009) have been reported the relationship between LST and green space composition the temperature of green space is lower than its surrounding areas. Upmanis et al. (1998) also tried to understand the effects of green areas to their surroundings by conducting studies in parks. In a field of 1500 m, these green areas reduce air temperature by 3°C. Trees and other plants help cool the environment, making green space a simple and effective way to reduce urban temperature (Hamada and Ohta, 2010 ). Yilmaz et al. (2008) that the heat difference between asphalt and grass was 11.8°C. Increasing the green space by planting more trees has been emphasized in urban planning (Zhou et al., 2011).

Settlement areas were found to be 20.7°C. Reduction of green and evaporation surfaces and increase of impervious surfaces and structures may cause variations in meteorological parameters and thus climate at regional and local levels. Metropolitan areas turn out to be the areas exhibiting their own climates. Such climatic variations are called urban heat islands (Yüksel, 2005).

Urban heat islands are metropolitan areas which are warmer than their surrounding caused by human activities and where temperature differences reach up to 5°C (Yu and Hien 2006; Ca et al. 1998). Yu and Hien (2006) found temperature over concrete surfaces to be 40.7°C while 32.9°C in tree planted areas. Ca et al. (1998) found a temperature difference over concrete surface to be 55°C and 40.3°C over turf surface. Demircioğlu et al (2003) determined temperature over 4.8°C between 100-1000 m altitude in the valley of Çoruh. Avdan et al. (2014), found temperature over water surfaces to be 12.0°C while 20.6°C in tree planted areas.

The reason that the temperature measured in the city centre of Erzurum is lower than its surrounding may result from narrow streets and the time of satellite image which is 10:00 LST in the morning.

Conclusion

Temperature is an important meteorological factor in the process of forming the climate. The urban development and expansion lead to increase of LST. The changes in Land use have resulted in changes in LST, especially in the urban areas. In this paper we applied thermal remote sensing to study the LST distribution in Erzurum. This study will be useful to making better decisions about land use planning.

References


