Investigation of Urban Temperature Changes using Multitemporal Thermal Infrared Images

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Abstract: The aim of this study is to explore the thermal condition and temperature changes in Ulaanbaatar city, Mongolia using multitemporal satellite thermal infrared images. For this purpose, Landsat TM band 6 of 09 October 1990, ASTER bands 13 and 14 of 31 May 2001 and Landsat ETM+ bands 61 and 62 of 31 August 2001 are used. In order to estimate the temperatures from the thermal infrared images of the Landsat, initially, the thermal infrared band values expressed in digital numbers are converted to the radiance values. Then, the temperature values are derived using the inverse of the Planck function.
Keywords: Urban temperature change, Thermal condition, Ulaanbaatar city.

1. Introduction

Optical satellite data sets have been widely used for the Earth's surface temperature studies since the launch of Landsat (5) TM in 1984. It is well known that the Landsat TM had 7 spectral bands in visible, near infrared, middle infrared and thermal infrared ranges (TIR) of the electro-magnetic spectrum and the thermal band could sense the surface temperature within a resolution cell of 120m [1]. The Landsat (7) ETM+ and ASTER launched in 1999 put satellite TIR remote sensing (RS) in more advanced stage, because the thermal sensor of the first had an improved spatial resolution (ie, 60m), whereas the second had 5 thermal bands that acquire the surface temperature data within a resolution cell of 90m. Moreover, it is known that band 6 of Landsat ETM+ is always acquired in low (L) and high (H) gain states. Band 6L provides an expanded dynamic range and lower radiometric sensitivity and can measure the temperatures in between -70ºC and +90ºC, whereas band 6H has higher radiometric sensitivity (although it has a more restricted dynamic range) and can measure the temperatures in between -30ºC and +60ºC [4].

The aim of this study is to investigate the thermal condition and temperature changes in Ulaanbaatar city, Mongolia using multitemporal thermal infrared images taken from space platforms. For this purpose, Landsat TM band 6 of 09 October 1990, ASTER bands 13 and 14 of 31 May 2001 and Landsat ETM+ bands 61 and 62 of 31 August 2001 have been used. The original Landsat data sets were represented in digital numbers (DNs), while the ASTER bands were represented in temperatures expressed in degrees of Celsius. Therefore, to conduct further analysis the Landsat data values had to be converted to temperature values. For this purpose, initially, the thermal infrared band values expressed in digital numbers have been converted to the radiance values. Then, the temperature values were derived using the inverse of the Planck function.

2. Test area

As a test site Ulaanbaatar area, Mongolia has been selected. Ulaanbaatar is situated in the central part of Mongolia, on the Tuul River, at an average height of 1350m above sea level and currently has nearly 900,000 inhabitants [5]. The city is surrounded by the mountains which are spurs of the Khentii Mountain Ranges. The selected part of the capital city is about 43kmx33km and is characterized by such land cover classes as urban area, forest, grassland, soil and water. The average daily temperature of Ulaanbaatar is about 25°C above zero in July and in January it is about -21°C below zero. One remarkable feature of Ulaanbaatar and most of Mongolia is that it has more than 270 sunny days throughout the year and it makes the country very suitable for using the optical RS images [2].

3. Conversion of Landsat TM and ETM+ thermal bands to temperature data

As known the Landsat TM and ETM+ sensors acquire the surface temperature data and store them as 8 bit DNs. In order to convert these DNs to temperature data expressed in degrees of Celsius, firstly they should be converted to radiance values using the gain and offset values specific to the individual scenes and then, the radiance data should be converted to the degrees of Celsius.

3.1. Conversion of DNs to radiance values

The Landsat TM and ETM+ thermal bands have different gain and offset values. Therefore, for the calculation of their radiance values different formulas are used. In the present study, for the calculation of the radiance values of the TM data the following formula has been used:

Radiance = DN*Gain + Offset

Where

Gain=0.0551582
Offset=1.2377996.

whereas for the calculation of the radiance of the ETM+ data the following formula was used:

$$Radiance = ((L_{MAX}-L_{MIN}) / (DN_{MAX}-DN_{MIN})) * (DN- DN_{MIN})+ L_{MIN}$$

Where for band 6L and for band 6H

L_{MAX} = 17.04	L_{MAX} = 12.65
L_{MIN} = 0.0	L_{MIN} = 3.2
DN_{MAX}=255	DN_{MAX}=255
DN_{MIN} =1	DN_{MIN} =1.

The values for all these parameters have been obtained from the data header files.

3.2. Conversion of radiance values to degrees of Celsius

After calculation of the radiance values, the temperature values are derived using the inverse of the Planck function which is expressed as follows:

$$T(^{o}C) = \frac{K_2}{Ln\left(\frac{K_1}{CV_R}+1\right)} - 273$$

Where:

$T(^{o}C)$ is degrees of Celsius
CV_R is the cell (pixel) value as radiance
K1 is 607.76 (for TM) or 666.09 (for ETM+)
K2 is 1260.56 (for TM) or 1282.71 (for ETM+).

4. Investigation of urban temperature changes

As it is known, the ASTER has 5 TIR bands ((band10: 8.125µm-8.457µm), (band11: 8.457µm -8.825µm), (band12: 8.925µm -9.275µm), (band13: 10.25µm -10.95µm), (band14: 10.95µm -11.65µm)) [3]. In order to compare with the Landsat thermal images (band6: 10.4µm -12.5µm), we have taken the average of the bands 13 and 14 of the ASTER.

Initially, the temperature values have been calculated for the Landsat images and the related temperature images have been obtained. Then, all the images have been resampled to the coordinates of the ETM (+) images and then from each image a subset covering the same area was subtracted. The statistical comparison of the calculated and directly derived temperatures of the Landsat and ASTER are shown in table 1 and the related gray scale as well as density sliced temperature images are shown in figure 1 (I,II).

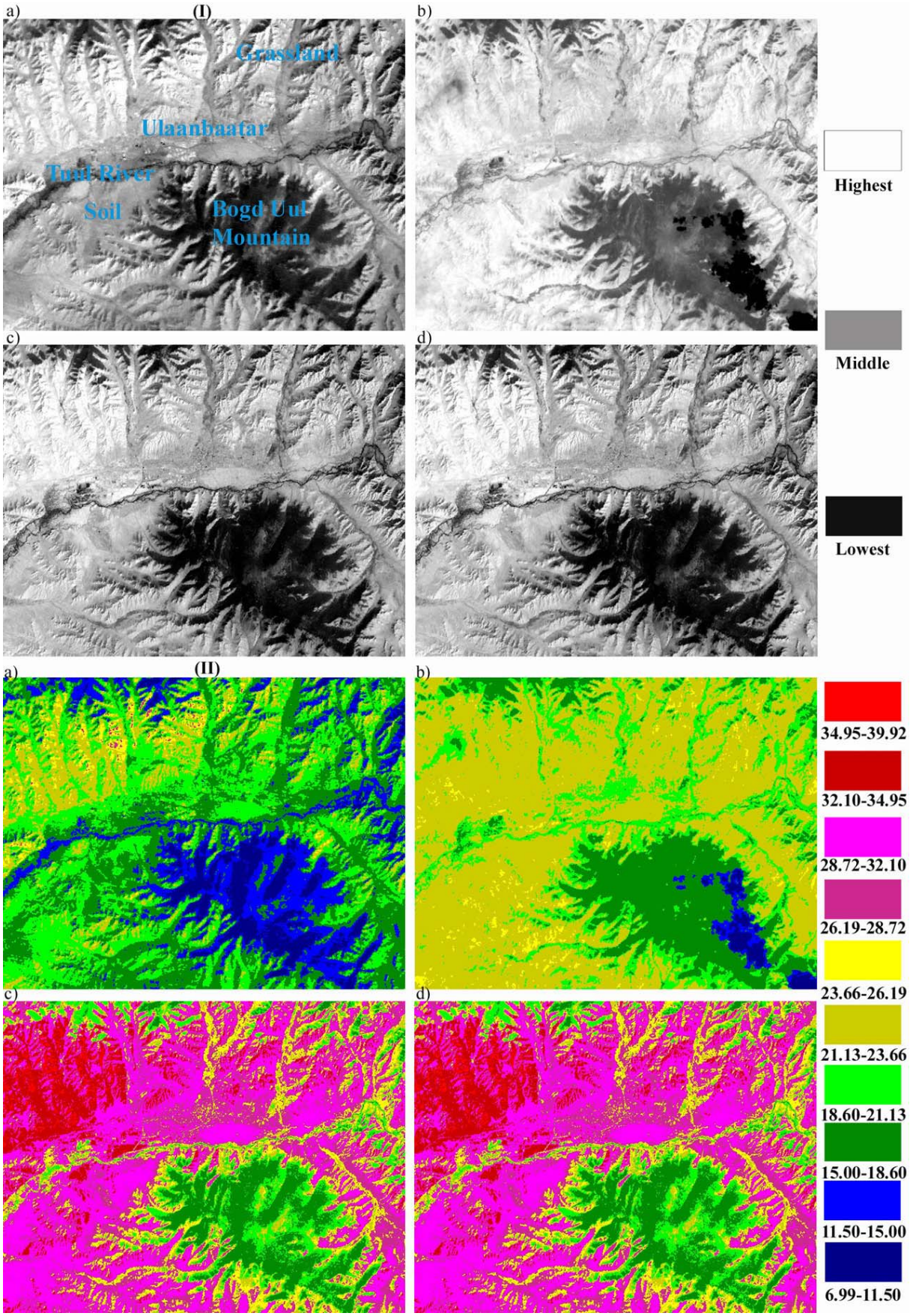

Fig. 1. Temperature images indicating temperature changes in Ulaanbaatar area.
I) Gray scale temperature images, II) Density sliced temperature images.

Table 1. The statistical comparison of the temperature changes in Ulaanbaatar area estimated from multitemporal RS images

	TM 09 October 1990	ASTER 31 May 2001	ETM+ 61 31 August 2001	ETM+ 62 31 August 2001
Min (ºC)	**6.99**	**9.59**	**8.23**	**8.20**
Max (ºC)	**28.72**	**25.06**	**39.61**	**39.92**
Mean (ºC)	**17.65**	**20.74**	**26.70**	**26.80**
SD (ºC)	**3.50**	**2.57**	**4.90**	**4.90**

As seen from table 1, at the beginning of October 1990 the temperatures ranged from 6.99ºC to 28.72ºC with the average of 17.65ºC, while at the end of May 2001 the temperatures changed in between 9.59ºC and 25.06ºC with the average of 20.74ºC. From figure 1, it is seen that on both TM and ASTER images the forest areas represent the lowest temperatures and the sun facing fore slopes of the mountains represent the highest temperatures and the city areas represent the moderate temperatures, meanwhile indicating that in May in most areas of Ulaanbaatar city the temperatures were higher than in October. Moreover, as seen from table 1, the temperatures significantly increased at the end of August 2001 with the average temperatures of 26.70ºC and 26.80ºC estimated from the low and high gain states. From figure 1, it is seen that in August the city temperatures are higher than in other seasons ranging from 23.66ºC to 28.72ºC.

5. Conclusions

The overall idea of the study was to investigate the temperature changes in Ulaanbaatar city, Mongolia using multitemporal thermal infrared images taken from space platforms. For this purpose, Landsat TM thermal data of 09 October 1990, ASTER bands 13 and 14 of 31 May 2001 and Landsat ETM+ bands 61 and 62 of 31 August 2001 were used. As seen from the research, the result of this study is just a preliminary evaluation of temperature changes conducted within a resolution cell of the used data sets and in order to be accepted in a decision making level it should be validated by the ground truth data. Furthermore, it is seen that both low and high gain images produce very similar images and either can be used for the investigation of the surface thermal conditions.

References

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