

# Diurnal and Seasonal Surface Temperature Variations: A Case Study in Baghdad

Mustafa Naem, Robert Corner, and Ashraf Dewan

Department of Spatial Sciences, Curtin University, WA, Australia;

Emails: m.hamoodi@postgrad.curtin.edu.au (M.N.); r.corner@curtin.edu.au (R.C.);

a.dewan@curtin.edu.au (A.D.)

## SUMMARY

Urban land use and land cover (LULC) classification is an important technique to study a variety of applications in remote sensing, especially in urban climate and environment. In this study, a new approach was applied to classify urban LULC area into four main categories using Landsat TM. This approach used the impervious surface area (ISA) technique by fusing the night thermal band with day multispectral bands of Landsat data. In addition, masks of water and vegetation cover were applied to extract their categories. In the second part, diurnal and seasonal variations in surface temperature were analysed using LST maps. Landsat TM images during daytime and night time for Summer and Winter in 1990 have been utilised to estimate surface temperature and spectral indices (MNDWI and NDVI).

Keywords: Impervious surface area, Classification, Land surface temperature, Urban Heat Island, Baghdad

## INTRODUCTION

The earth's climate has been significantly affected through long-term land use and land cover (LULC) changes, as a result of the interrelationship between land surface and the atmosphere at local and regional scales [1]. LULC changes are associated with human use of land resources [2]. Some of the most important issues that have affected the ecosystem are urbanisation and other practices of land use attributable to human activities [3, 4]. According to previous studies, the main effect of urbanisation is to cause variation in urban surface temperature [5]. Many studies have examined urban heat islands, and have documented increases in temperature for many cities around the world in recent decades. However diurnal and seasonal variability in temperature are associated with environmental effects such as water vapour, cloudiness and precipitation [6], as well as geographical location. In addition, population changes and urban growth have led to significant changes in LULC. As a result, the phenomenon of urban heat islands over cities occurs [7]. The urban thermal environment is locally affected by the diurnal and seasonal variability in surface temperature for LULC types, especially in soil moisture and tree canopy through evaporative cooling [8].

Thermal remote sensing is a useful tool for examining diurnal and seasonal variations in land surface temperature (LST) in a variety of environmental domains. It has been widely used in studies of climate change and urban heat islands [1, 9]. The study carried out by [8], examined the relationship between landscape pattern and land surface temperature over four seasons in Indianapolis in the United States. Work by [10] investigated the response of urban heat islands to seasonal variation of LULC in Piracicaba, Brazil. The surface temperature in the city of Delhi across four seasons was studied by [11] using Landsat 5 Thematic Mapper. In the studies above, different approaches were used in analysing diurnal and seasonal variations of temperature with LULC patterns. However, the use of day and night Landsat images to investigate diurnal and seasonal surface temperature is rarely found. Numerous LULC classification methods have been using a range of satellite data, but there are still some challenges. In urban areas these relate to mixed pixels among LULC patterns, especially between built-up and bare land.

It is therefore difficult to obtain an optimal result using standard classification methods in an urban area. In this study a new method was applied to Landsat TM images by fusing a night thermal band

with day multispectral bands in order to improve ISA mapping performance. This study is divided into two parts. First, this method was applied to classify the Landsat TM image of the study area into four main categories (built-up areas, green areas, bare land and water bodies). Secondly, the spatial distribution of temperature was visualised to locate warmer and cooler densities of LULC patterns.

The main objective of this research is to investigate trends of diurnal and seasonal surface temperature variability across different types of LULC over the central Baghdad area using Landsat TM images.

## STUDY AREA

The study area of central Baghdad province is located in central Iraq on of the Tigris River with geographic coordinates latitudes 33° 10.77' N to 33° 29.26' N, longitudes 44° 11.55' E to 44° 34.23' E as shown in Figure 1. The total area of the administrative boundary of Baghdad mayoralty is 870 km<sup>2</sup>. The climate of Baghdad is described as a hot arid and subtropical desert climate type (BWh) according to Köppen's climate classification system, dry and extremely hot in summer with short, cool winters [12].

## MATERIALS AND METHODOLOGY

### **Datasets:**

Landsat TM images were downloaded from the U.S. Geological Survey. The images were acquired for two seasons during daytime and night-time in 1990 (Table 1). Those images were chosen based on availability, especially during the night. Images within a window of five days between day and night for each season were chosen. This early date was used as they will form a baseline for further work.

**Table 1.** Landsat TM Images of Baghdad central area

	Season	D/N	Acquisition date	Local time	Path	Row
Landsat 5_TM	Summer	Day	12-08-1990	09:53:36 am	168	037
Landsat 4_TM		Night	09-08-1990	09:22:06 pm	034	207
Landsat 4_TM	Winter	Day	08-01-1990	10:06:14 am	168	037
Landsat 4_TM		Night	13-01-1990	09:25:53 pm	034	207

### **Data pre-processing:**

The dark object subtraction method (DOS) [13] was applied to remove atmospheric effects. It was conducted in a two-step process using ENVI 5.1 Software. Firstly, digital numbers (DN) were converted to top of atmosphere (TOA) reflectance. Then, the values of the darkest pixels were subtracted from the entire image. The images were co-registered in order to enable direct comparison of values between images.

### **Image classification:**

A proposed new method requiring fusion of the Landsat night thermal band with daytime multispectral bands was used in order to increase delimitation of LULC patterns, especially for built-up areas.

This method extracts the LULC categories sequentially using different techniques. The water category is extracted using MNDWI, the ISA method was used to extract built-up areas and next, vegetation cover was estimated using NDVI.

### **Water masking:**

Water has similar spectral characteristics with some LULC surfaces such as asphalt, shadows and green area. Thus, it is necessary to mask out water from the images before further processing. Water masking was carried out using the modified normalised difference water index (MNDWI), as developed by [14]. The MNDWI was calculated for Landsat TM images using equation (1). The water features were determined by threshold values, then, converted to polygons.

$$MNDWI = \frac{(\rho(\text{band}2) - \rho(\text{band}5))}{(\rho(\text{band}2) + \rho(\text{band}5))} \quad (1)$$

Where:

$\rho(\text{band}2)$  is the spectral reflectance of green band  
 $\rho(\text{band}5)$  is the spectral reflectance of short wave-infrared band

**ISA:**

Impervious surfaces prevent water infiltrating into the soil, such as building rooftops, streets, parking lots and sidewalks [15]. ISA techniques have been used to extract urban areas from remotely sensed data. Principle component analysis (PCA) was used to convert the fused images, with a water mask applied, to a new dataset. Endmembers for high albedo surfaces, low albedo surfaces, green areas and bare land were chosen from the scatterplots of the PCA bands. Then, linear spectral unmixing was used to convert the image into four fractional images. The high and low albedo fraction images were combined to one image showing ISA as described by [16]. The ISA image was converted to polygons to facilitated post classification editing.

**NDVI:**

Normalised difference vegetation index (NDVI) is a vegetation index which is widely used to describe vegetation characteristics such as green biomass and chlorophyll content. It is calculated from the red band and near infrared band for Landsat TM image using the equation (2) and its values range from (-1 to 1) [17].

$$NDVI = \frac{\rho(\text{band4}) - \rho(\text{band3})}{\rho(\text{band4}) + \rho(\text{band3})} \quad (2)$$

Where:

$\rho(\text{band3})$  is the spectral reflectance of red band  
 $\rho(\text{band4})$  is the spectral reflectance of near infrared band

The NDVI values were calculated with threshold values for determining vegetation cover being manually selected. The resulting image was reclassified and converted to polygons and masked from the image as a separate category.

**Bare land:**

Based on the study area dataset (polygon file) the three categories, water, ISA and vegetation cover were clipped out from this file and the remaining areas represent the fourth category that is bare land.

**LST mapping:**

LST maps were prepared by using Arc GIS 10.2. Firstly, surface temperatures were retrieved using the equation (3) from the spectral radiance values of the Landsat 4 and 5 TM thermal band [18].

$$T = \frac{K2}{\ln(K1 / L\lambda + 1)} \quad (3)$$

Where: T is the effective at-satellite temperature in Kelvin, K1 and K2 are specific thermal band calibration constants 1 and 2 respectively for the TM 4 and 5,  $L\lambda$  is spectral radiance  $W/(m^2 \cdot sr \cdot \mu m)$ .

**RESULTS AND DISCUSSION**

Statistical details for the LULC classes, including the minimum, maximum and average surface temperature of diurnal and seasonal maps in summer and winter were calculated. Comparisons of thermal behaviour of LULC categories between day and night, and between summer and winter were conducted using land surface temperatures. The spatial distribution of land surface temperatures was analysed using the LST maps.

**Urban LULC classification**

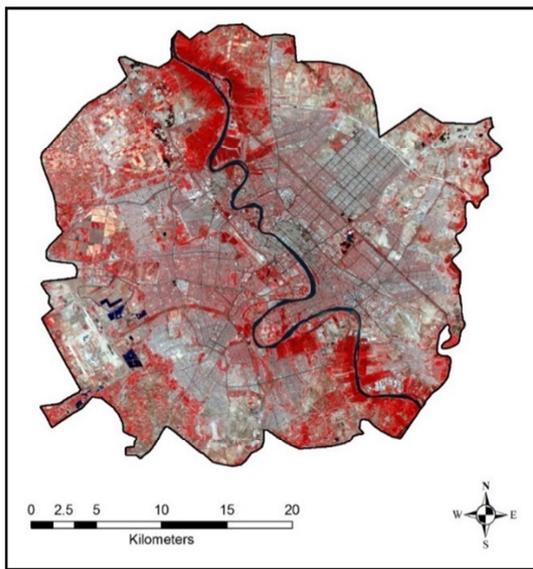
The urban LULC classification is shown in Figure 2 and shows a reasonable representation of the main LULC categories, including ISA (built-up and man-made area), water (river and artificial lakes), green area (orchard, agricultural fields and vegetation) and bare land (open space without artificial and vegetative cover, and cultivated land).

The classified map was checked for accuracy using a historical high resolution aerial photograph using the error matrix method. 125 random points were generated on the reference image and attributed to the four categories, then converted to a raster layer with 30 m resolution and combined with the classified map. The overall accuracy and Kappa coefficient of classified map were 86.6% and 0.81, respectively.

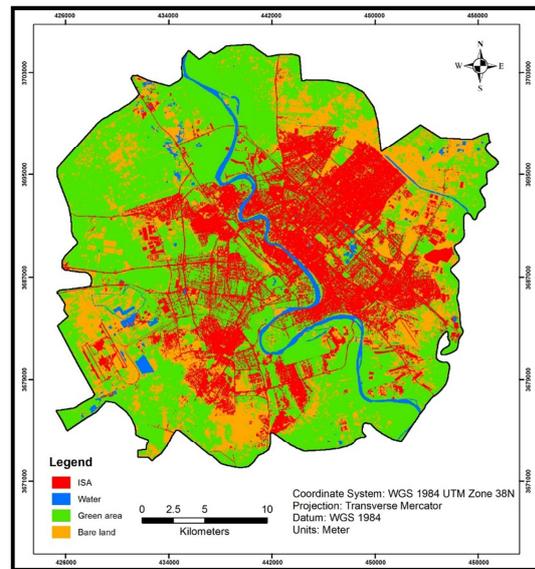
## Diurnal and Seasonal variations

### Diurnal variations:

Diurnal variation is defined as the change in temperature from day to night, as a result of the daily rotation of the Earth and is essentially the difference between maximum and minimum temperatures [19]. Here the twice-daily surface temperatures estimated from Landsat TM images at around 10:00 AM and 9:24 PM, the local time of the satellite overpasses, were used to compare between LULC categories. The diurnal variations in surface temperature for LULC categories are shown graphically in Figure 3 and 4 for summer and winter. Analysis of the summer LST maps, graph and table in Figure 3 shows that the LST parameters (min, max and mean) for all LULC categories decreased gradually from day to night. The LST of bare land was highest during the day, followed by built-up area, green cover and water, while at night built-up areas had the highest LST, followed by bare land, water and green cover. Bare land and green cover categories showed the highest diurnal range in LST, whereas the range for built-up areas and water categories was lower.

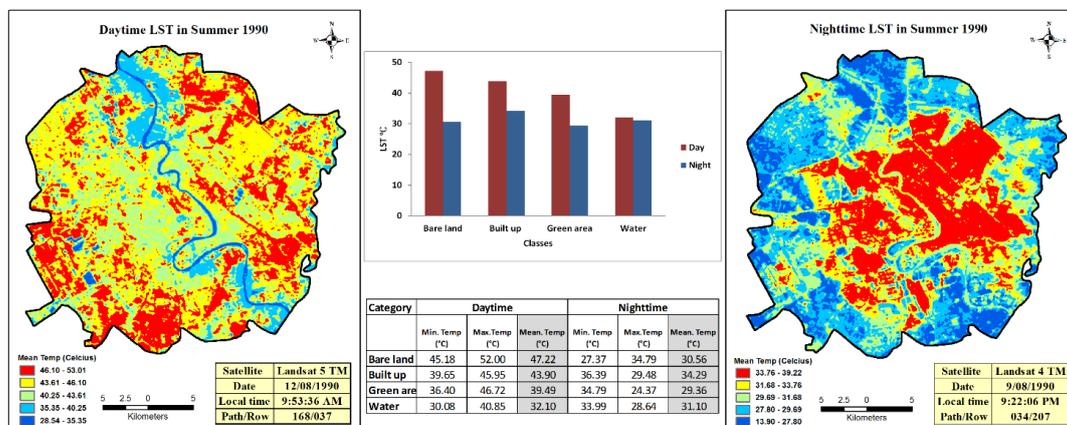


**Figure 1.** The study area of Baghdad city (TM image, bands 4, 3, 2)



**Figure 2.** Classified map of major LULC categories for Baghdad city in 1990

Figure 4 shows that in winter, the LST values for all LULC categories fell sharply at night. Bare land had the highest LST and water the lowest LST during the day. But at night water had the highest LST and green area the lowest. The nightly decrease in the LST values for green areas and bare land is more severe than for built-up areas and water which release heat more due to their higher heat capacity. This situation occurs in both summer and winter, but the difference of the diurnal LST values is more noticeable in winter than summer.



**Figure 3.** LST maps in summer during daytime and nighttime

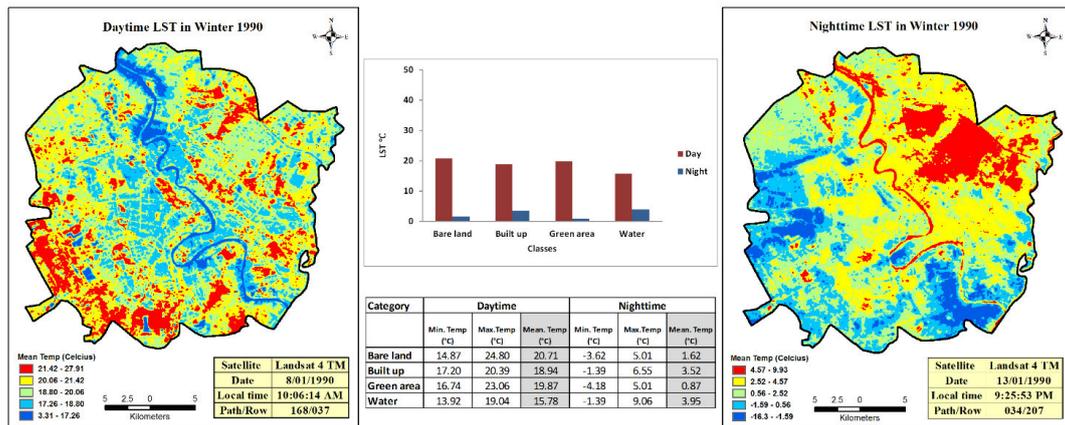


Figure 4. LST maps in winter during daytime and nighttime

### Seasonal variation:

The seasonal surface temperature variations of LULC categories during day and night are shown in Figure 5. The summer values of LST were higher than those in winter, for both day and nighttime. This is as expected given the seasonal differences cloud cover and insolation. It can be seen that the contrast between summer and winter, based on of the spatial distribution of mean LST is around 20 °C during daytime but at nighttime increases to almost 30 °C.

The highest summer daytime LST was found on bare land (47.2 °C), followed by built-up area (43.9 °C), green area (39.4), and water (32.1). During the summer nighttime, there is a little difference in temperature between all categories. The highest summer nighttime value of LST was found on built-up area (34.2 °C), followed by water (31.1 °C), bare land (30.5 °C), and green area (29.3 °C).

Winter daytime, LST values were highest on bare land and green area (20.7 °C) and (19.8 °C) and, lower for built-up area and water (18.9 °C) and (15.7 °C), respectively. On winter nights there is a change in the order of these categories during winter nighttime. Higher values were observed in water and built-up area (3.95 °C) and (3.52 °C), respectively, and lower for green area and bare land (0.87 °C) and (1.62 °C), respectively.

In general high temperatures occur in the summer season for all LULC categories of the study area compared with the winter season, for both times day and night.

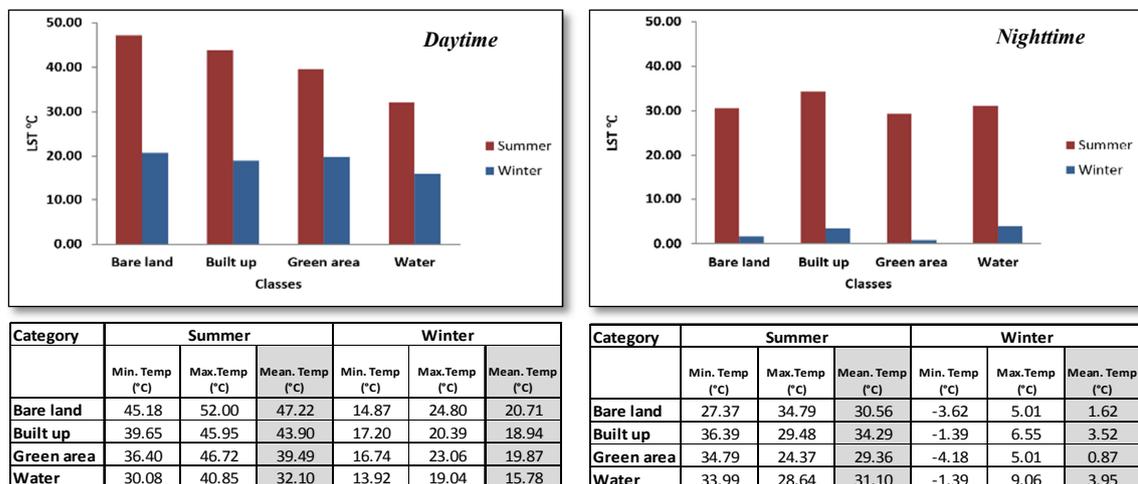


Figure 5. LST in summer and winter during daytime and nighttime

## CONCLUSION

This study has assessed an urban LULC classification method that has been developed using historical daytime and nighttime Landsat TM images for Baghdad city in 1990. The study shows that extraction of ISA by fusing the night thermal band with multispectral Landsat image has improved classification

in term of built-up area. This method solves the problem of mixing between built-up and bare land. However, its use is limited because night thermal images from Landsat satellite are rare. The study, furthermore, has examined diurnal and seasonal variations in surface temperature using LST maps which were produced from Landsat images.

## REFERENCES

- [1] Voogt, J. A. and Oke, T. R. Thermal remote sensing of urban climates. *Remote sensing of environment* 86(3) (2003), 370-384.
- [2] Bounoua, L., DeFries, R., Collatz, G. J., Sellers, P. and Khan, H. Effects of land cover conversion on surface climate. *Climatic Change* 52 (1-2) (2002), 29-64.
- [3] Jones, P.D., Groisman, P.Y., Coughlan, M., Plummer, N., Wang, W.C. and Karl, T.R. Assessment of urbanization effects in time series of surface air temperature over land. *Nature* 347 (1990), 169-172.
- [4] Amiri, R., Weng, Q., Alimohammadi, A. and Alavipanah, S. K. Spatial-temporal dynamics of land surface temperature in relation to fractional vegetation cover and land use/cover in the Tabriz urban area, Iran. *Remote sensing of environment* 113(12) (2009), 2606-2617.
- [5] Oke, T. R. *Boundary layer climates. Second edition.* Routledge: New York. (1987).
- [6] Dai, A., Trenberth, K. E. and Karl, T. R. Effects of clouds, soil moisture, precipitation, and water vapor on diurnal temperature range. *Journal of Climate* 12(8) (1999), 2451-2473.
- [7] Karl, T. R., Knight, R. W., Gallo, K. P., Peterson, T. C., Jones, P. D., Kukla, G., ... and Charlson, R. J. A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature. *Bulletin of the American Meteorological Society* 74(6) (1993), 1007-1023.
- [8] Liu, H. and Weng, Q. Seasonal variations in the relationship between landscape pattern and land surface temperature in Indianapolis, USA. *Environmental Monitoring and Assessment* 144(1-3) (2008), 199-219.
- [9] Voogt, J. A. and Oke, T. R. Complete urban surface temperatures. *Journal of Applied Meteorology* 36(9) (1997), 1117-1132.
- [10] Coltri, P. P., Ferreira, N. J., Freitas, S. and Demetrio, V. A. Changes in land cover and use affect the local and regional climate in Piracicaba, Brazil. *Journal of Urban and Environmental Engineering* 2(2) (2009).
- [11] Singh, R. B., Grover, A. and Zhan, J. Inter-seasonal variations of surface temperature in the urbanized environment of Delhi using Landsat thermal data. *Energies* 7(3) (2014), 1811-1828.
- [12] Climate. 2007. Köppen Classification. <http://www.meteorologyclimate.com/koppenclassification.html>. Accessed: 2 November 2015.
- [13] Chavez Jr, P.S. An improved dark-object subtraction technique for atmospheric scattering correction for multispectral data. *Remote Sensing of Environment* 24 (1988), 459-479.
- [14] Xu H. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing* 27 (2006), 3025-3033.
- [15] Arnold, C.L. and C.J. Gibbons Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American Planning Association* 62(2) (1996), 243-258.
- [16] Wu, C., and A. T. Murray. Estimating impervious surface distribution by spectral mixture analysis. *Remote Sensing of Environment* 84 (2003), 493-505.
- [17] Rouse Jr, J., Haas, R. H., Schell, J. A. and Deering, D. W. Monitoring vegetation systems in the Great Plains with ERTS. *NASA special publication 351, U.S. Gov. Washington* Vol. I (1974), 309-317.
- [18] NASA. 2002. Landsat 7 Science Data Users Handbook. National Aeronautics and Space Administration. Available online at: [http://landsathandbook.gsfc.nasa.gov/pdfs/Landsat7\\_Handbook.pdf](http://landsathandbook.gsfc.nasa.gov/pdfs/Landsat7_Handbook.pdf)
- [19] Folland, C. K. and T. R. Karl. 2001. *Observed Climate Variability and Change, in Climate Change 2001: The Scientific Basis*, edited by J. T. Houghton et al., Cambridge Univ. Press, New York, pp. 99- 181.