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REMOTE SENSING OF URBAN MICROCLIMATE WITH SPECIAL REFERENCE TO URBAN HEAT ISLAND USING LANDSAT THERMAL DATA

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Abstract

Remote sensing studies have shown that urban areas have unique environmental, climatic, land use/cover characteristics as a result of intense anthropogenic activities. Consequently, urban areas have developed distinct microclimate and elevated temperatures. Thermal remote sensing data has been widely used to study these characteristics. In this study, an attempt has been made to review the studies involving Landsat remote sensing dataset for investigating land surface temperature. Landsat is oldest finer resolution thermal dataset, which has been effectively used in mapping and analysis of land surface temperature, urban heat island and urban microclimate. Since 1978, it has been providing thermal data through Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Thermal Infrared Sensor (TIRS) sensors.

Keywords

land surface temperature • urbanisation • Landsat thermal data • surface urban heat island

Introduction

The process of urban heat island (UHI) has aggravated and has become more widespread with increasing population in urban areas. Urbanisation has changed the land use/cover of urban areas, thereby altering its physical environment and heat balance (Oke 1982; Lo & Quattrochi 2003). The permeable surfaces are replaced by impermeable ones like roads, buildings, parking areas and others. The urban infrastructure material like steel has higher heat storing capacities and lower albedo (Owen et al. 1998) which are responsible for creation of micro climate around urban centers. Various other factors like building geometry, vegetation cover, water bodies, anthropogenic emissions, local weather and geographic location are also contributing in development of UHI.

The concept of UHI focuses on the imbalance caused in the urban surface energy budget between incoming and outgoing solar radiations. The energy budget of urban areas differs from that of countryside. The surface temperature of urban areas at all point of time, in all seasons is observed to be higher than that of hinterland and this phenomenon of elevated temperature in cities and towns is called the UHI (Voogt & Oke 2003). The UHI is broadly of two types – Surface Urban Heat Island (SUHI) and Atmospheric Urban Heat Island (AUHI) (Voogt & Oke 2003; Valsson & Bharat 2009). The Surface UHIs are more prominent during daytime in summer season. It is possible to calculate SUHI using thermal band of remote sensing images.

On the other hand, Atmospheric UHIs are more intense at night and in winters (Chen et al. 2006). There is lesser spatial and temporal variation in AUHI due to mixing of air. The ideal method of AUHI analysis is through static or moving weather recording systems. AUHI can be further of two types – canopy layer urban heat islands that exist in the layer of air where people live, from the ground to below the tops of trees and roofs; boundary layer urban heat islands that start from the rooftop and treetop level and extend up to the point where urban landscapes no longer influence the atmosphere. This region typically extends no more than one mile (1.5 km) from the surface.

Most UHI studies concentrate on SUHI rather than AUHI (Pandey et al. 2009; Pichierri et al. 2012). This is due to a number of factors and the foremost being availability of recent reliable good quality satellite images of all parts of the world. The data is available for over two decades and is dependable. With the possibility of pixel based analysis, the methodologies have also improved and become more intense. AUHI, though seems to be more relevant, but paucity of reliable continuous long term data makes it less useful for UHI understanding. There exists intricate but direct relationship between surface and atmospheric temperatures, especially the canopy layer and it has been observed that the forest areas, vegetated areas and water bodies have cooler surface temperatures contributing to lower atmospheric temperatures and vice versa is applicable to dense built up zones and concrete areas. Therefore, SUHI in all parameters is a better indicator for understanding the existence and dynamics of UHI.

Principal satellite data used for UHI analysis

There are six major sensors systems that provide thermal data and are mostly used by scientists (Tab. 1) for estimation of Urban Micro Climate (UMC) and UHI. Landsat 4 and 5 (TM), 7 (ETM+), 8 (TIRS 1 and 2), Advanced Spaceborne Thermal Emission and Reflection (ASTER) and Moderate Resolution Imaging Spectroradiometer (MODIS) are sun-synchronous satellite systems, while Advanced Very High Resolution Radiometer (AVHRR) is polar orbiting sensor. The Landsat and AVHRR are the oldest and largest thermal data sensors that have been providing the data since early 1980s. ASTER and MODIS on the other hand have been recently launched (1999) but have been proved to be very effective for land surface temperature (LST) studies.

The Landsat has been providing thermal data since March 5, 1978, with the launch of Landsat 3. Since then, it has had a series of satellite missions (Landsat 5, 6 and 7) and recently the Landsat 8 was launched. The 6th band of Landsat 4 (TM), 5 (TM) and 7 (ETM+) has been providing the thermal data in the wavelength of 10.40-12.50 μm. The Landsat 7 ETM+ acquires thermal data at two levels, which are often referred as band 6L and band 6H. The band 6L is acquired using low gain setting and is useful for temperature ranging between 130-350

Table 1. Details of major satellite data used for UMC and UHI analysis

Satellite and Sensors	Launch and decommission date	Wavelength (μm)	Band	Spatial Resolution (m)	Temporal Resolution (days)	Equatorial crossing time
Landsat 4TM	July 16, 1982 - June 30, 2001	10.40-12.50	6	1 20	16	9:45
Landsat 5TM	March 1, 1984 - June 5, 2013	10.40-12.50	6	120	16	9:45
Landsat 7 ETM+	April 15, 1999 - till date	10.40-12.50	6	60	16	10:00
Landsat 8 TIRS1	February 11, 2013	10.60-11.19	10	100	16	10:00
Landsat 8 TIRS2	February 11, 2013	11.50-12.51	11	100	16	10:00
Terra ASTER* Aqua ASTER	December 18, 1999 May 2002	8.12-8.46	10	90	16	10:30 -12:00 1:00 -15:00*
		8.46-8.82	11	90	16	
		8.92–9.28	12	90	16	
		10.25-10.95	13	90	16	
		10.95-11.65	14	90	16	
Terra MODIS* Aqua MODIS	December 18, 1999	10.78-11.28	31	1000	2/day	10:30/22:00
		11.77-12.27	32	1000	2/day	10:30/22:00
NOAA/ AVHRR	August 24, 81	10.3-11.3	4	1100	--	07:30
		11.3-12.5	5	1100	--	07:30

TM – Thematic Mapper, ETM+ – Enhanced Thematic Mapper Plus, TIRS – Thermal Infrared Sensor, ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer, MODIS – MODerate-resolution Imaging Spectroradiometer, NOAA/AVHRR – National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer
* Benali et al. (2012) (Local time)

Kelvin. The band 6H is acquired using high gain setting and is useful for temperature range of 240-320 Kelvin (Chander et al. 2009). In the low gain and high gain setting, the minimum saturation level are 17.21 and 12.78 W/(m^2srμm) (NASA 2003). The Landsat 8 (TIRS) acquire thermal data in two spectral bands, i.e. 10.6-11.19 μm and 11.5-12.51 μm, which are not identical to its predecessor sensors. The ASTER provides thermal data in five spectral bands ranging from 8.125-11.65 μm, while, the MODIS and AVHRR provide thermal data in two spectral bandseach. For all the sensors, the broad wavelength for thermal data ranges between 8.125-12.5 μm.

The spatial resolution of Landsat 4 and 5 (TM) is 120 m, while Landsat 7 (ETM+) provides the finer resolution thermal data (60 m). The recent Landsat 8 (TIRS) provide thermal data at 100 m spatial resolution. Similarly, ASTER is also a fine resolution thermal data (90 m). Thus, their data are best suited for large scales areas such as city level and results can be compared. The MODIS and AVHRR are coarse resolution images (1000 and 1100 m); therefore they are best suited for small scale areas such as continents or countries.

The researchers have attempted to compare day and night time LST, UMC and UHI. The Landsat images are captured during the day time (Hung et al. 2006; Sharma & Joshi 2012; Ding & Shi 2013), therefore they are mostly used to compare the daytime temperatures. The ASTER and MODIS images are acquired both during day and night, so they are in addition used to compare day and night time LST and UHI. The AVHRR gives the aggregate surface conditions.

Most of the thermal data are now provided free of cost via USGS through many websites (NASA 2003). Most important and frequently used websites are http://glovis.usgs.gov, http://earthexplorer.usgs.gov, http://glcf.umd.edu/ http://www.landcover.org/ https://lpdaac.usgs.gov/.

Methodologies used for UHI studies using Landsat thermal data

There are many methodologies used for estimating LST and further the UHI phenomena in different parts and cities of the world using Landsat thermal data (6th band in TM and ETM+) (10th and 11th band in TIRS). The availability of free access to Landsat data has promoted increased use of thermal data for UHI analysis. The understanding of UHI phenomenon is not recent but use of Landsat data is used to understanding various facets of surface temperature. It has felicitated in establishing relationship of land surface data with land use / cover, UHI, Urban Micro Climate (UMC), Normalised Difference Vegetation Index (NDVI), Normalised Difference Build-up Index (NDBI), health and others. The horizon of UHI studies has expanded in all parts of the world since the launch of Landsat 3 and particularly after the data were freely distributed.

Majority of the studies have used following three steps for estimating the surface temperature as also suggested by Markham and Barker (1986) for Landsat 4 TM, Chander and Markham (2003) for Landsat 5 TM and Chander et al. (2009) for entire series of Landsat thermal data including, Landsat 4 TM, Landsat 5 TM, Landsat 7 ETM+. Landsat 7 Science Data Users Handbook of NASA (2003) has particularly explained the following steps for Landsat 7 ETM+ thermal data.

1) Conversion of the Digital Number (DN) to at-sensor Spectral Radiance (L).

2) Conversion of Spectral Radiance to Temperature in Kelvin.

3) Conversion of Kelvin to Celsius.

The 6th band of the Landsat TM and ETM+ data have been used for mapping and estimating LST and further the UHI phenomena in urban areas. The 6th band is also known as thermal band or thermal channel. Of the above stated steps to convert the raw thermal band to temperature, first and second steps are essential and the third is optional. Many studies have restricted to second step, i.e. Kelvin scale of temperature and many have used third step, i.e. further converting the Kelvin to degree Celsius scale. While the satellite images are obtained, they are in raw form and many atmospheric corrections and further pre-processing are needed to be applied on them. Initially, the raw satellite images (6th band in the case of thermal remote sensing) are converted to at-sensor spectral radiance values using equation 1. Further, the spectral radiance values (image) are atmospherically corrected and essentially converted to top-of-atmosphere brightness temperatures using equation 2. The resulted temperature values are in Kelvin scale and in some cases the temperature values are further converted from Kelvin to degree Celsius scale using equation 3.

Markham and Barker (1986), Chander and Markham (2003), Chander et al. (2009) and Xiong et al. (2012) have suggested three standard algorithms for above stated following three standard steps to estimate the LST from Landsat thermal data.

1) Conversion to at-sensor spectral radiance

$$L_\lambda = G_{rescale} \times Q_{cal} + B_{rescale} \tag{1}$$

Or

$$L_\lambda = Gain \times DN + Bias$$

Where

L_λ – Spectral radiance at the sensor's aperture $[W/(m^2 sr \mu m)]$

Q_{cal} – Quantized calibrated pixel value [DN]

$G_{rescale}$ – Band-specific rescaling gain factor $[(W/(m^2 sr \mu m))/DN]$

$B_{rescale}$ – Band-specific rescaling bias factor [W/(m²srμm)]

Gain – It is also known as $G_{rescale}$, which is calculated using the equation $(L_{max} - L_{min})/255$

Bias – It is also known as $B_{rescale}$ and L_{min}

$L_{MIN\lambda}$ – It is lowest radiance measured by detector in $mWcm^{-2}sr^{-1}$

$L_{MAX\lambda}$ – It is maximum radiance measured at detector in $mWcm^{-2}sr^{-1}$)

2) Conversion to at-sensor brightness temperature

$$T_B = K_2/\ln((K_1/L_\lambda)+1 \qquad (2)$$

Where

T_B – Effective at-sensor brightness temperature [K]

K_2 – Calibration constant 2 [K]

K_1 – Calibration constant 1 [W/(m²srμm)]

L_λ – Spectral radiance at the sensor's aperture [W/(m²srμm)]

ln – Natural logarithm

3) Conversion of Kelvin to degree Celsius

$$T_B = T_B - 273 \qquad (3)$$

Xiong et al. (2012) and Liu and Zhang (2011) suggest that temperature obtained through the above stated procedures is the black body temperature. The atmospheric and spectral emissivity corrections based on the nature of land surface are thus essentially needed to be applied on images of black body temperature in order to estimate LST. Methods of estimating emissivity-corrected LST have been very well explained by Xiong et al. (2012), Liu and Zhang (2011), Zhang and Wang (2008), Li et al. (2012). Each land cover type is assigned particular emissivity values and thus emissivity-corrected LST are obtained. However, Lo and Quattrochi (2003) suggest that there is not much difference in the black body temperature image and emissivity-corrected LST. Thus, the black body temperature are adequate for using in surface temperature mapping from thermal infrared images, which also saves an extra computation step (Lo & Quattrochi 2003). Singh et al. (2014) have computed LST for Delhi, India using same steps (Fig. 1). Among the other important methods of estimating LST from Landsat single band is radiative transfer equation as explained in detail by Jimenéz-Muñoz et. al. (2009), Sobrino et. al. (2004).

Global distribution of major UHI studies and various facets using Landsat

Urbanisation as a phenomenon is apparent in both developed and developing countries of the world. As per United Nations Report on Cities and Climate Change: Global report on human settlements (UN-HABITAT 2011), the number of cities in the world with populations greater than one million increased from 75 in 1950 to 447 in 2011 and it is projected that by 2020 there will be 527 cities with population over one million. The creation and spread of urban areas is responsible for transforming the porous and green surfaces to concrete, land use/cover changes, modifications in heat budget and addition of pollutants in the atmosphere. The reduction in forest cover, increased building height, concretization and green house gases emissions from traffic and industries is mainly responsible for the UHI effect.

Worldwide, generous amount of research is carried out with regard to UMC and UHI. Landsat thermal data has been extensively utilized for understanding the impact and extent of UHI for various cities in the world. Most researched country is China, wherein the fast growing cities of Shanghai and Beijing have been extensively studied (Tab. 2). Apart from these, Guangzhou, Boluo, Dongguan, Panyu, Foshan, Gaoming, Huadu, Huizhou, Nanhai and Sanshui in Guangdong Province, Guizhou Province, Zhujiang Delta, Pearl River Delta and Wuhan city are other areas where similar research has been carried out. Asian cities of Hong Kong, Singapore, Tokyo, Seoul, Pyongyang, Bangkok, Manila, Ho Chi Minh City, Ahmedabad and Delhi have also been explored. Twin Cities Metropolitan Area (TCMA) of Minnesota, Atlanta and Indianapolis in United States of America were examined with UHI intensity. Few researches can be seen in Mexico, Tabriz urban area, Iran and Israel–Egypt border. In Europe, Łódź and

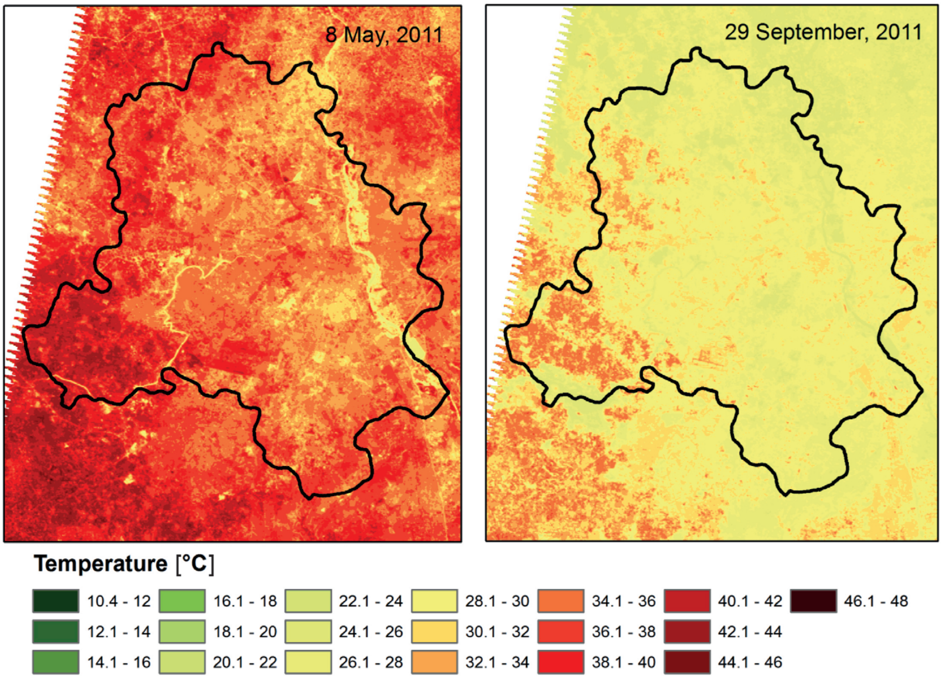

Figure 1. Inter-seasonal variations of spatial patterns of surface temperature in Delhi – summer (May) and autumn (September)

Source: Singh et al. (2014).

Wrocław cities of Poland, Bucharest urban area in Romania have been studied recently using Landsat TM and ETM + data. The high levels of urbanisation and industrialisation in Poland led to UMC formation and this has been extensively researched using array of methodologies. Most studied cities are Łódź, Krakow and Warsaw. Kłysik and Fortuniak (1999) utilised weather research station data for Łódź, Pongrácz et al. (2010) applied MODIS data for Belgrade, Bucharest, Budapest, Milan, Munich, Sofia, Vienna, Warsaw and Zagreb in Central Europe. The rapid urbanisation growth in past two decades accompanied with high population in Asian cities have impelled and promoted vast UHI research in Asian cities (Tab. 2).

The understanding of urban micro climate (UMC) and UHIs that air temperatures of a city are often higher than its countryside was first proved by Howard (1833). Since then, this fact has been tested for a range of cities in the world. Different components and aspects of UHI have been studied including its characteristics, causes and impacts (Tab. 3). The basic characteristic features of UHI using Landsat thermal data have been researched by Li et al. (2012), Hung et al. (2006), Singh et al. (2014) and Nichol (2005). LST is the most basic and fundamental criterion for establishing linkage between surface changes and temperature changes. Using Landsat data, the process of land use/cover changes and associated thermal properties have been extensively examined for world leading cities. Jiang and Tian (2010), Ding and Shi (2013) presented their results for Beijing, China; Li et al. (2011) for Shanghai, whereas, Zhang and Wang (2008), Chen et al. (2006), Xiao and Weng (2007), Weng and Yang (2004) on different provinces and cities of China. Other prominent researches are by Southworth (2004) on forest area of Yucatan, Mexico, and on Delhi by Mallick et al. (2008, 2012).

Table 2. UHI studies conducted in major cities of the world using Landsat thermal data

City/Region	Satellite/Sensors	Reference
Shanghai, China	Landsat TM and ETM+	Li et al. 2012
Shanghai, China	Landsat ETM+	Yue et al. 2007
Shanghai, China	Landsat ETM+	Li et al. 2011
Beijing, China	Landsat TM	Zhang et al. 2010
Beijing, China	Landsat TM and ETM+	Ding & Shi 2013
Beijing, China	Landsat TM and ETM+	Jiang & Tian 2010
Guangzhou, Boluo, Dongguan, Panyu, Foshan, Gaoming, Huadu, Huizhou, Nanhai and Sanshui, China	Landsat ETM+	Zhang & Wang 2008
Pearl River Delta, China	Landsat TM and ETM+	Chen et al. 2006
Guizhou Province, China	Landsat TM	Xiao & Weng 2007
Guangzhou, China	Landsat TM	Weng & Yang 2004
Wuhan, China	Landsat TM	Zhang et al. 2012
TuenMun, Hong Kong	Landsat ETM +	Nichol 2005
Hong Kong	Landsat TM	Liu & Zhang 2011
Hong Kong	Landsat ETM +	Xipo et al. 2007
Tokyo, Japan	Landsat TM	Kawashima 1994
Tokyo, Japan	Landsat TM and ETM+	Bagan & Yamagata 2012
Atlanta, Georgia	Landsat TM	Lo & Quattrochi 2003
Twin Cities Metropolitan Area of Minnesota, USA	Landsat TM and ETM+	Yuan & Bauer 2007
Indianapolis, USA	Landsat ETM+	Weng et al. 2004
Tabriz urban area, Iran	Landsat TM and ETM+	Amiri et al. 2009
Ticul, Mexico	Landsat TM	Southworth 2004
Singapore	Landsat ETM+	Jusuf et al. 2007
Israel-Egypt border	Landsat TM	Qin et al. 2001
Tokyo, Beijing, Shanghai, Seoul, Pyongyang, Bangkok, Manila and Ho Chi Minh City	Landsat ETM +	Hung et al. 2006
Krakow, Poland	Landsat TM and ETM+	Walawender et al. 2014
Wrocław, Poland	Landsat ETM +	Szymanowski & Kryza 2011
Bucharest, Romania	Landsat TM and ETM+	Zoran 2011
Ahmedabad, India	Landsat TM and ETM+	Raykar 2005
Delhi, India	Landsat TM	Rahman et al. 2009
Delhi, India	Landsat TM	Mallick et al. 2012
Delhi, India	Landsat ETM +	Mallick et al. 2008
Delhi, India	Landsat TM and ETM+	Sharma & Joshi 2012
Delhi, India	Landsat TM	Singh et al. 2014

Table 3. UHI studies conducted in relation to its driving forces and impacts

Title	Reference	City/Region	Time period
Urban heat island studies			
Monitoring patterns of urban heat islands of the fast-growing Shanghai metropolis, China: Using time-series of Landsat TM/ETM+ data	Li et al. 2012	Shanghai, China	1997 and 2008
Land surface temperature patterns in the urban agglomeration of Krakow (Poland) derived from Landsat-7/ETM+ data	Walawender et al. 2014	Krakow, Poland	Mar 2001 April 2000 May 2000 May 2001 July 2000 August 2002
Application of remotely sensed data for spatial approximation of urban heat island in the city of Wrocław, Poland	Szymanowski & Kryza 2011	Wrocław, Poland	4 May 2001 15 October 2001 and 3 January 2002
Satellite observations of Urban heat island effect	Zoran 2011	Bucharest, Romania	August 1989 August 1990 July 2002 September 2004 August 2007 July 2010
Defining relationship between urban heat islands and urban morphology	Raykar 2005	Ahamdabad, Gujarat, India	19 October 1991 and 22 October 2000
Assessment with satellite data of the urban heat island effects in Asian mega cities	Hung et al. 2006	Tokyo, Beijing, Shanghai, Seoul and Pyongyang, Bangkok, Manila and Ho Chi Minh City	8 January 2002 and 13 February 2002
Remote sensing of urban heat islands by day and night	Nichol 2005	TuenMun, Hong Kong	17 September 2001
Inter-seasonal variations of surface temperature in the urbanized environment of Delhi using Landsat thermal data	Singh et al. 2014	Delhi, India	January 2011 March 2011 May 2011 September 2011
Urban Heat Island, Land Surface Temperature and Land Use/Cover Change studies			
Analysis of the impact of land use/land cover change on land surface temperature with remote sensing	Jiang & Tian 2010	Beijing, China	9 April 1995 and 30 April 2000
Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China	Li et al. 2011	Shanghai, China	13 March and 2 July 2001
Study of the relationships between the spatial extent of surface urban heat islands and urban characteristic factors based on Landsat ETM+ data	Zhang & Wang 2008	Guangzhou, Boluo, Dongguan, Panyu, Foshan, Gaoming, Huadu, Huizhou, Nanhai and Sanshui in Guangdong Province, China	17 January 2003
Land-use/land-cover change and its influence on surface temperature: A case study in Beijing	Ding & Shi 2013	Beijing	2 August 1999 and 8 August 2010

Title	Reference	City/Region	Time period
Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes	Chen et al. 2006	Pearl River Delta, China	13 October 1990 29 October 1994 3 March 1996 22 December 1998 14 September 2000 and 1 November 2000
The impact of land use and land cover changes on land surface temperature in a karst area of China	Xiao & Weng 2007	Guizhou Province, China	7 November 1991 5 December 1994 19 December 2001
Managing the adverse thermal effects of urban development in a densely populated Chinese city	Weng & Yang 2004	Guangzhou, China	13 December 1989 and 29 August 1997
An assessment of Landsat TM band 6 thermal data for analyzing land cover in tropical dry forest regions	Southworth 2004	Ticul, Yucatan, Mexico (forest area)	27 March 1995
Land surface emissivity retrieval based on moisture index from Landsat TM satellite data over heterogeneous surfaces of Delhi	Mallick et al. 2012	Delhi, India	25 October 2009
Landsat analysis of urban growth: How Tokyo became the world's largest mega-city during the last 40 years	Bagan & Yamagata 2012	Tokyo, Japan	1972; 1987; 2001 and 2011
The influence of land use on the urban heat island in Singapore	Jusuf et al. 2007	Singapore	11 October 2002
Estimation of land surface temperature over Delhi using Landsat7 ETM+	Mallick et al. 2008	Delhi, India	22 October 1999
A mono-window algorithm for retrieving land surface temperature from Landsat TM data and its application to the Israel-Egypt border region	Qin et al. 2001	Israel-Egypt border region	29 March 1995
Urban Heat Island, Land Surface Temperature and NDVI			
Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery	Yuan & Bauer 2007	Twin Cities Metropolitan Area (TCMA) of Minnesota	16 July 2002 12 September 2000 27 February 2001 and 21 May 2002
Spatial–temporal dynamics of land surface temperature in relation to fractional vegetation cover and land use/cover in the Tabriz urban area, Iran	Amiri et al. 2009	Tabriz urban area, Iran	30 June 1989 18 August 1998 and 2 August 2001
Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies	Weng et al. 2004	Indianapolis, USA	22 June 2002
Relation between vegetation, surface temperature, and surface composition Tokyo region during winter	Kawashima 1994	Tokyo, Japan	23 January 1985
The relationship between land surface temperature and NDVI with remote sensing: application to Shanghai Landsat 7 ETM+ data	Yue et al. 2007	Shanghai, China	14 June 2000

Title	Reference	City/Region	Time period
Relationship between vegetation greenness and urban heat island effect in Beijing of China	Zhang et al. 2010	Beijing, China	8 September 2004
Study on urban heat island effect based on Normalized Difference Vegetated Index: A case study of Wuhan	Zhang et al. 2012	Wuhan, China	16 October 2006
Urban heat island analysis using the Landsat TM data and ASTER data: A case study in Hong Kong	Liu & Zhang 2011	Hong Kong	23 November 2005
Urban heat island and health			
Land-use and land-cover change, urban heat island phenomenon, and health implications: A remote sensing approach	Lo & Quattrochi 2003	Atlanta, Georgia	1983; 1987; 1988; 1992; 1997 and 1998
Urban Heat Island and Air Pollution			
An assessment of urban environmental issues using remote sensing and GIS techniques: an integrated approach. A case study: Delhi, India	Rahman et al. 2009	Delhi, India	1992

NDVI change is regarded as a reliable indicator of UHI as the forest and tree cover in a densely populated city act as cooling agents. The forested areas and vegetation cover have low surface temperatures. On the other hand, concrete zones have higher temperature. With respect to this understanding, abundant literature is available on validation of this fact. Some prominent ones that have used the Landsat thermal data are on Twin Cities Metropolitan Area (TCMA) of Minnesota by Yuan and Bauer (2007), Amiri et al. (2009) on Tabriz urban area, Iran, Weng et al. (2004) on Indianapolis, USA, Kawashima (1994) on Tokyo, Japan, Liu and Zhang (2011) on Hong Kong, Yue et al. (2007), Zhang et al. (2010, 2012) on fast growing cities of China. Rahman et al. (2009) tried to assess the various environmental issues related to UHI for the city of Delhi using Landsat data.

Unlike the vast literature available on characteristics, intensity and causes of UHI, the works on its impact are scarce. UHI phenomenon not only indicates the changes in heat budget of an urban area but also is useful in understanding the spatial pattern of spread of urban diseases caused by increase in temperature and air pollution. The most prominent study in this regard is by Lo and Quattrochi (2003) on Atlanta metropolitan area, Georgia.

There exists prolific research work on investigation, testing and analysis on UHI and UMC using diverse sources of remote sensing platforms. However, examination with the help of Landsat thermal data is recent in usage. A varied range of journals have published UHI research. Remote Sensing of Environment, International Journal of Remote Sensing, International Journal of Applied Earth Observation and Geoinformation and Procedia Environmental Sciences have published maximum number of articles. The importance and significance of UHI in view of rapid unplanned urbanisation in developing countries has fostered proliferation of research in varied journals like Journal of Environmental Management, Photogrammetric Engineering & Remote Sensing, Journal of Indian Geophysical Union, Journal of Indian Society of Remote Sensing, Pedosphere, Habitat International, Sensors, Pure and applied Geophysics, Proceedings of the Global Conference on Global Warming, Joint Urban Remote Sensing Event and Remote Sensing.

Conclusion

The urban environment has been widely and effectively studied by Landsat thermal data. It is the single largest and fine scale thermal data set as compared to other sources and is provided by USGS. The study reveals that analysis of urban environment, microclimate and UHI is vitally essential in view of its distinct characteristics and significant implications on health conditions and ecosystems services. The temperature of urban built-up area is elevated as compared to other land use/cover types. The building material, their geometry (height and width ratio), absence of green spaces, traffic congestion and different land use practices with in urban built-up land lead to UHI phenomena in cities. Consequently the human population is exposed to different types of diseases including heat stroke, respiratory problems, heart problem and skin infections etc. The UHI studies were first initiated in USA. However, majority of the UHI study involving Landsat thermal data have been done in Asia and especially in China. The cities of USA have also been substantially studied. The heat island studies in India are particularly at infant stages. Only the city of Delhi has been well studied for its UHI and microclimate, while the other cities have not adequately been studied.

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Unless otherwise stated, the sources of tables and figures are the author(s), on the basis of their own research.

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