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Application of Thermal Infrared Remote Sensing to Explore the Relationship between Land Use-Land Cover Changes and Urban Heat Island Effect: A Case Study of Khulna City

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Abstract

Urban climate has gained a significant focus due to global mean surface temperature increase since the late 19th century. The climate in and around urban areas are changed due to Land Use/Land Cover (LULC)[*]and its relative anthropogenic activities which create a lot of problems. Among these, the most imperative problem is increase of land surface temperature. The aim of this study was to identify the effect on originating micro Urban Heat Islands (UHIs) due to land use/land cover changes of Khulna city. Landsat 5 TM[*] (Thematic Mapper) images for 1989, 1999, and 2011 were used to estimate land surface temperature (LST)[*] from thermal band and to prepare the LULC map with the help of visible and near infra-red band. The spatial variability of surface radiant temperatures caused by the thermal behavior of different land cover (emissivity) was retrieved from satellite data by using Normalized Difference Vegetation Index (NDVI) and used to estimate LST. Finally, the land surface temperature and the classified land cover theme were then exported to GIS environment for urban heat mapping analysis. Thus the effects of urban development on the geographical distribution of surface radiant temperatures are calculated and the UHI was investigated.

Introduction

The environment in and around urban areas are changed due to changes in LULC and its relative anthropogenic activities. Rapid urbanization causes LULC changes and various subsequent impacts which create a lot of problems. Among these, the most imperative problem is the increase of LST and is related with LULC of urban areas and surrounding. Increase in LST due to LULC change affect the environment by drastically degrading the living conditions within the urban areas. It continues a snail process of environmental degradation over urban areas and surrounding which creates the temperature difference between urban and rural settings causing the UHI effect. As increasing LST has relation to LULC (Dontree, 2010), it is interesting to investigate how it varies among different LULC types.

Many researchers have estimated the relative warmth of urban areas by measuring the air temperature, using land based observation stations and related weather data. Some researchers used measurements of temperature using sensors and equipments which are both expensive and time consuming. It also leads to problems in spatial interpolation to identify relation between land surface temperature and land use/land cover. But, remote sensing is the best alternative to the field based methods. In remote sensing, Thermal infrared (TIR) sensors can obtain detailed quantitative

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[*]LULC (**Land-use and land-cover change**) is a general term for the human modification of Earth's terrestrial surface.

[*]TM (**Thematic Mapper)** is one of the Earth observing sensors introduced in the Landsat program.

[*]LST (Land Surface Temperature) is the radiative skin temperature of land surface. LST is determined by the land surface energy balance and varies rapidly because of the low thermal inertia of the land surface

information of LST across the LULC categories. In this regard to obtain the relation between LST and LULC in order to indicate environmental quality, remote sensing data is the best option now. In this study relation between LST and LULC has been delineated using various spatial and statistical analyses. Spatial analysis shows the distribution and variation of land surface temperature across the LULC and statistical analysis shows how strong and convenient the relationship is which helps to validate and project data. Indices like NDVI and NDBI also helps to define the consistency and strength of relation over LULC.

Research Question

How to establish Relationship between Land use/Land Cover changes and Urban Heat Island effect

Study Area

Khulna is the headquarter of Khulna District and the principal city of Khulna Division. It is the 3rd largest city in Bangladesh and one of the important industrial and commercial areas of the country. The population of the city (under the jurisdiction of the city corporation) is 1,400,689 (BBS, 2011). Khulna is located in south-western Bangladesh at 2°49′0″N 89°33′0″E, on the banks of the Rupsha and Bhairab River. It covers a total area of 2 45.65 km² while the district itself is about 4394.46 km². In the southern part of the delta lies the Sundarban, the world's largest mangrove forest. Urban Heat Island is one of the upcoming urban climatological problems developing within the city. Built up of such excess heat in the urban area due to reduced vegetated cover and increased built-up surfaces with concrete, asphalt, etc. The present study attempts to find the spatial variability of LST over different LULC classes of Khulna city. The geographical location study area of Khulna is shown in Fig. 1.

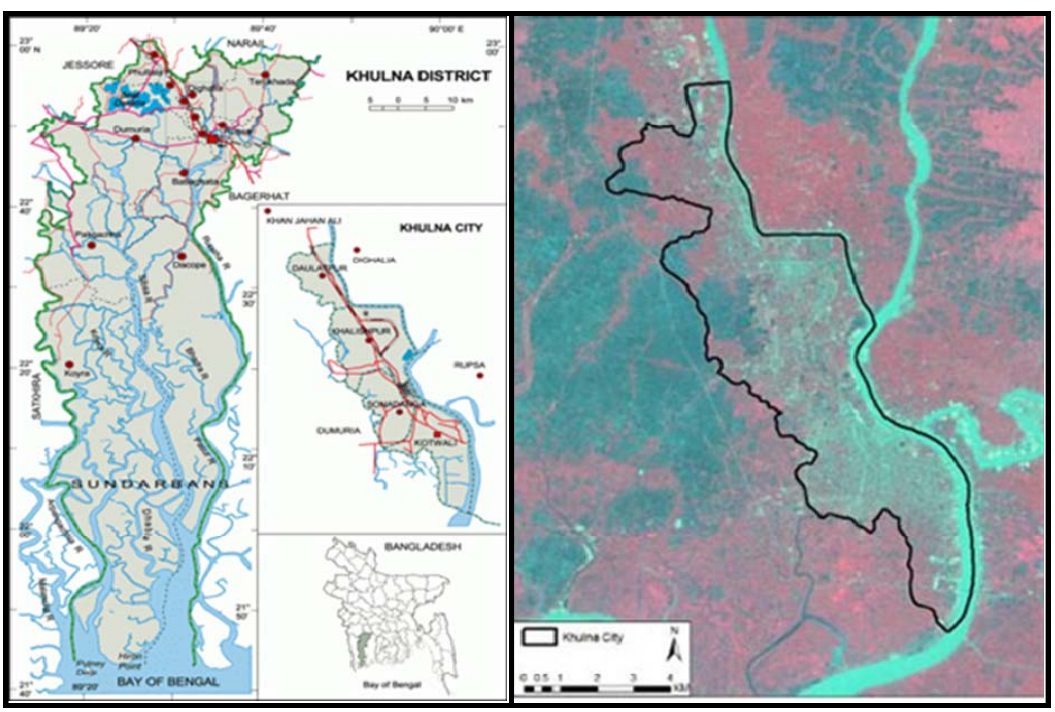

Figure 1: Map of Khulna City; Source: Author

Methodology

The following sections are the methodological steps considered in this study. And the following has been followed throughout the study.

Satellite data collection

Landsat 5 TM data are used in this study to estimate LST, prepare LULC classes, extract the emissivity and considered indices values. Landsat 5 TM data is free to download. Data used in this study was downloaded from the relevant website of United State geological Survey (USGS) (http://glovis.usgs.gov/). Details of the used data are given below in Table 1.

Table 1: Details of Landsat data collected

Date of Image	Satellite/ Sensor	Reference system/Path/ Row
11-11-1989	Landsat 5 TM	WRS-2, Path 138, Row 044
15-11-1999	Landsat 5 TM	WRS-2, Path 138, Row 044
08-11-2011	Landsat 5 TM	WRS-2, Path 138, Row 044

Satellite data processing

Downloaded satellite data quality was acceptable. So, it didn't need much more processing. In processing, at first study area was extracted with the help of Area of Interest (AOI). The data acquisition date has a highly clear atmospheric condition. All images bands 1-5 and 7 have a spatial resolution of 30m, and the thermal infrared band (band6) has a spatial resolution of 120m for Landsat 5 TM images.

Land use/land Cover map preparation

Using bands 1-5 and 7 of the pre-processed images the LULC pattern was mapped by Hybrid classification method which is the combination of unsupervised and supervised classification with the maximum likelihood classification algorithm. Classes considered from land use/land cover are-

(1) Built-up area (2) Barren / Vacant Land (3) Vegetation (4) Agriculture (5) Water bodies.

Classification Accuracy assessments were done with field knowledge, visual interpretation and also referring the Google Earth. The classification accuracy was also calculated for the LULC map.

Retrieving data for LST

To estimate LST, it is required to extract the information like NDVI, NDBI and emissivity. All these information were retrieved through using appropriate relative methods.

Retrieving NDVI and NDBI

This study retrieved NDVI through the conventional approach with the built-in tool in ERDAS IMAGINE. But there is no built-in tool to retrieve NDBI value. So, Model Maker was used to make a model which followed the method of Zhou and Wang (2010).

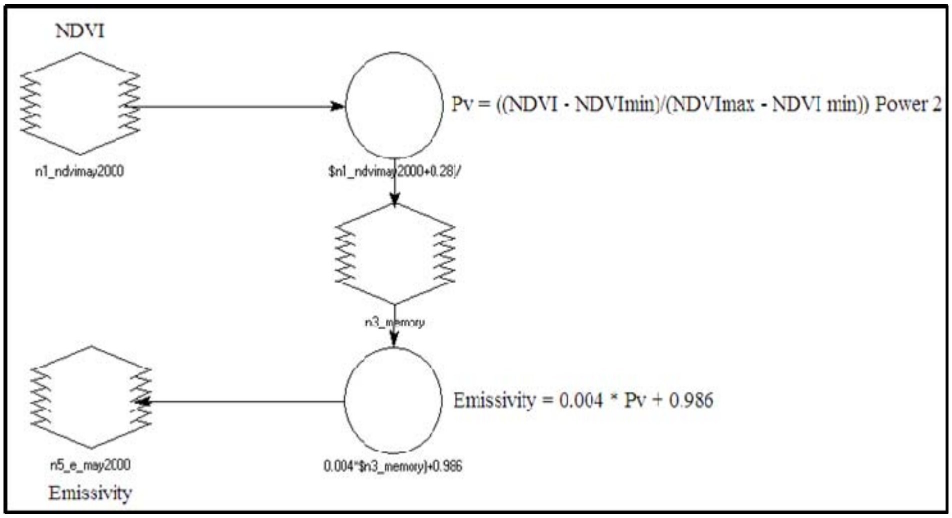

Figure 2: Model to retrieve NDBI; Source: Author.

Mathematical approach of this method is illustrated by equation 1 where NDBI values were retrieved through Mid Infra-Red (MIR) and Near Infra-Red (NIR). NDVI was used as a parameter to retrieve emissivity and both NDVI and NDBI were use as indices.

$$NDBI = \frac{R_{MIR} - R_{NIR}}{R_{MIR} + R_{NIR}} \ldots\ldots\ldots\ldots 1$$

Retrieving Emissivity

There is no doubt that to ensure least error in estimation of LST that's why emissivity correction is the best option. But emissivity should be retrieved from the remote sensing data also. Emissivity was used in this study to estimate LST with least error and the method is used followed by Abdi (2011).

Abdi (2011) used two equations to retrieve emissivity from NDVI. This study mentioned emissivity as land surface emissivity and use the below equation 2.

$$\varepsilon TM6 = 0.004 P_v + 0.986 \ldots\ldots\ldots 2$$

Where Pv is the proportion of vegetation obtained and is calculated through

$$P_v = [(NDVI - NDVImin)/(NDVImax - NDVImin)]^2 \ldots\ldots\ldots 3$$

Based on the mathematical approaches of the method, a model was made in ERDAS Model Maker to retrieve this.

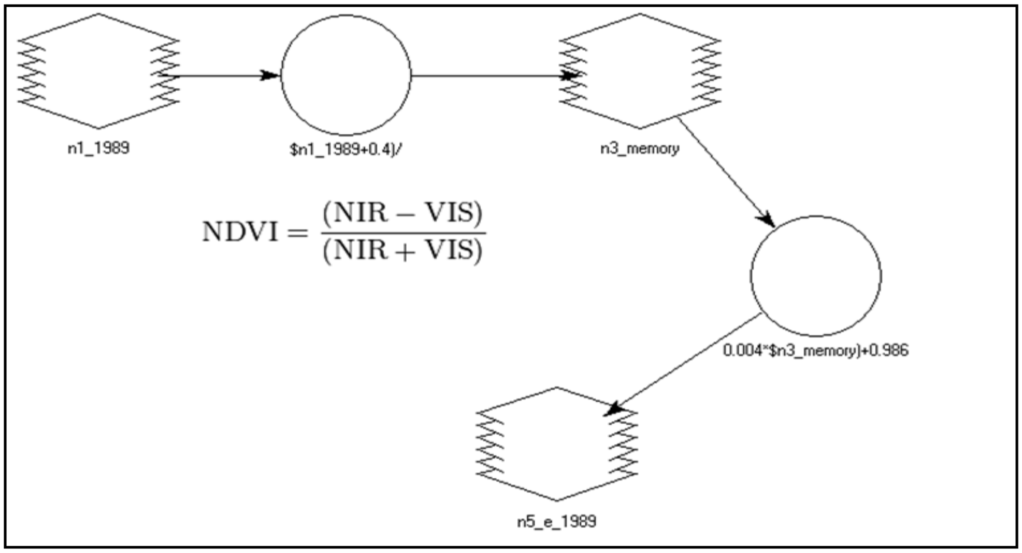

Figure 3: Model to retrieve Emissivity; Source: Author.

Estimation of Land Surface Temperature

Estimation of land surface temperature is the prime focus of methodology in this study. It has two phases.

Phase 1: First phase consists of conversion of DN values into radiance. This phase used conventional method followed by Dontree (2010) illustrated in equation 4

$$L_{\lambda} = \frac{LMAX_{\lambda} - LMIN_{\lambda}}{QCALMAX - QCALMIN} \times (QCAL - QCALMIN) + LMIN_{\lambda} \ldots\ldots\ldots\ldots 4$$

Where,

QCAL = the quantized calibrated pixel value in DN

$LMIN_{\lambda}$ = the spectral radiance scaled to QCALMIN in watt / (meter squared × ster ×µm)

$LMAX_{\lambda}$ = the spectral radiance scaled to QCALMAX in watt / (meter squared × ster × µm)

QCALMIN = the minimum quantized calibrated pixel value in DN = 1

QCALMAX= the maximum quantized calibrated pixel value in DN = 255

Phase 2: Second phase converted the radiance into land surface temperature through the method used by Mallick et al (2008) illustrated in equation 5

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_{\lambda}} + 1\right)} \ldots\ldots\ldots\ldots\ldots 2$$

Where,

T = Effective at-satellite temperature in Kelvin

K2 = Calibration constant (607.76 for Landsat 5 TM and 666.09 for Landsat 7 ETM+)

K1 = Calibration constant (1260.56 for Landsat 5 TM and 1282.71 for Landsat 7 ETM+)

$L\lambda$ = Spectral radiance in watt / (meter squared x ster x µm)

These two phases were combined in Model Maker to estimate the land surface temperature easily. Thermal band of satellite image and extracted emissivity values were used an input in the model which gave the land surface temperature as output.

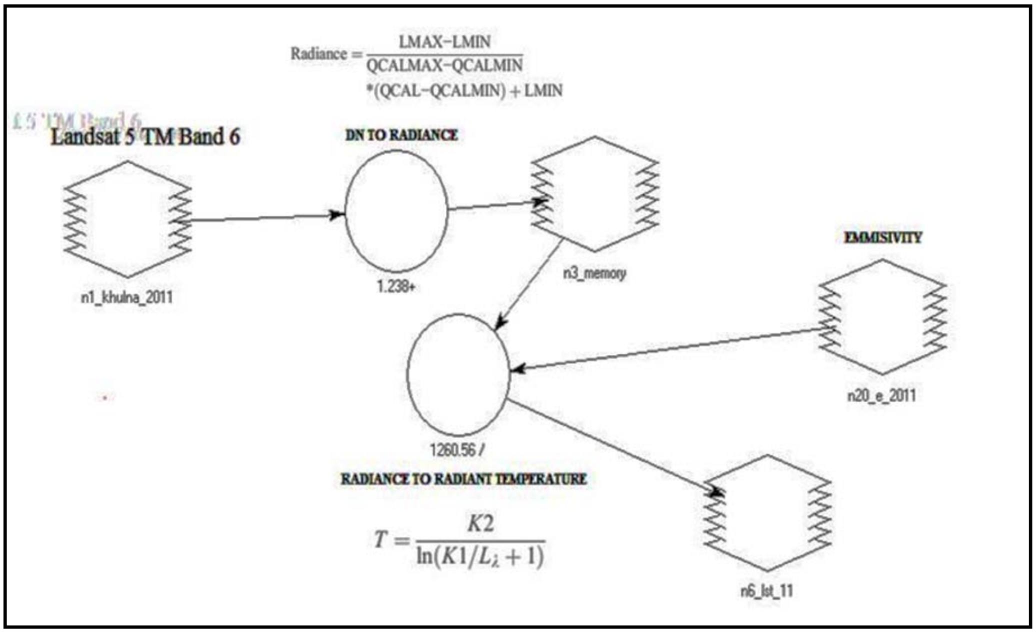

Figure 4: Model to retrieve LST; Source: Author.

Values of all the necessary constants like $LMIN_{\lambda}$, $LMAX_{\lambda}$, QCALMIN, QCALMAX for were taken from MTL file of downloaded image and used in the mentioned model.

Analysis

This section is describing the nature of land surface temperature in context of various land use/land cover. It so describes the significance of relation in context of the indices.

Spatial Variation of Land Surface Temperature in 1989

Land surface temperature of the study area in November 1989 varied significantly over various land use/land cover classes.

Table 2: Land Surface Temperature over Land Use/Land Cover, 1989

Land Use/Land Cover Class	Land Use Amount (In Hectare)	Land Surface Temperature (in ^{0}C)		
		Maximum	Minimum	Average
Agriculture	951	28.72	22.65	25.69
Barren / Vacant Land	1104	30.14	24.81	27.48
Built-up area	945	31.74	27.28	29.51
Vegetation	1408	26.32	20.04	23.18
Water body	708	24.70	20.56	22.63

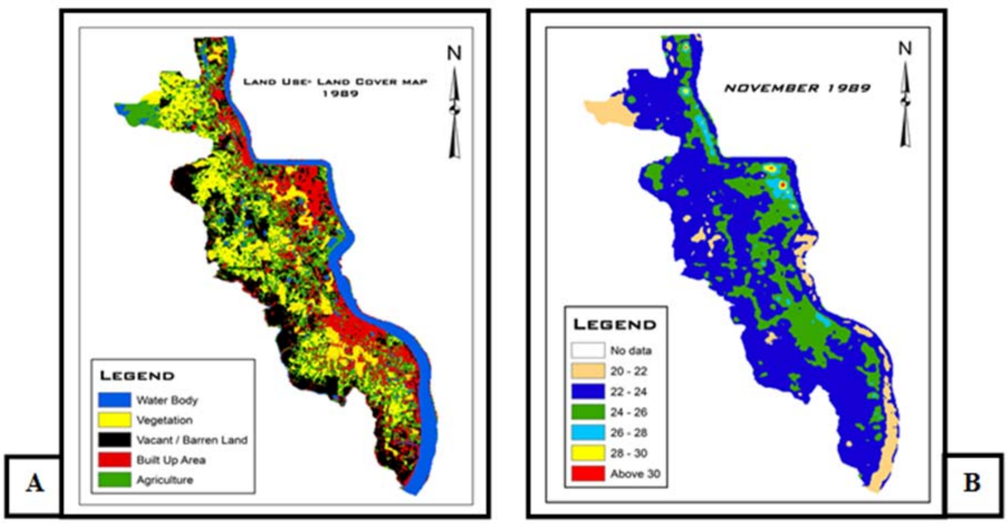

Figure 5: Land Use/Land Cover (A) and Land Surface Temperature (B) in 1989; Source: Author.

In 1989, most of the study area consists of 22 to 24 ºC LST where the LULC classes are dominated by vegetation and vacant land. Built up area consisted of the highest average land surface temperature of 29.51 ºC followed by vacant land 27.480C. In 1989, agriculture had slightly higher temperature of 25.69 ºC. Waterbody consisted of lowest average land surface temperature of 22.63 ºC. It also showed lowest minimum temperature of 20.04 ºC.

Spatial Variation of Land Surface Temperature in 1999

Land surface temperature of the study area in 1999 also varied significantly over various land use/land cover classes.

Table 3: Land Surface Temperature over Land Use/Land Cover, 1999

Land Use/Land Cover Class	Land Use Amount (In Hectare)	Land Surface Temperature (in ^{0}C)		
		Maximum	Minimum	Average
Agriculture	1127	29.65	23.46	26.56
Barren / Vacant Land	734	31.41	25.18	28.30
Built-up area	1318	32.47	28.82	30.65
Vegetation	1297	26.23	21.04	23.64
Water body	640	24.07	20.65	22.36

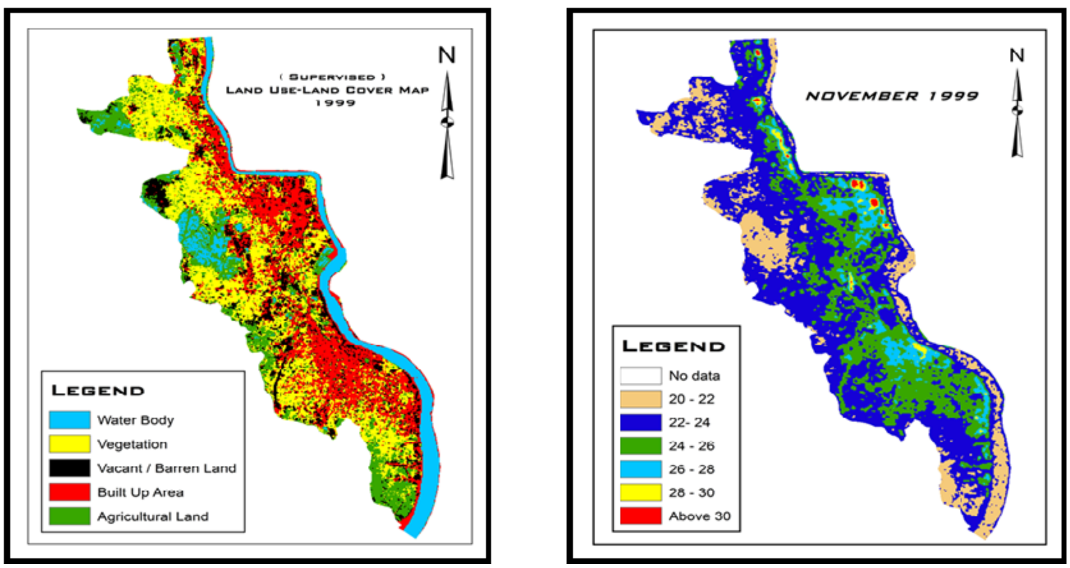

Figure 6: Land Use/Land Cover (A) and Land Surface Temperature (B) in 1999; Source: Author

In 1999, most of the study area consists of 22 to 26 ºC. Again built up area consisted of the highest average land surface temperature of 30.65 ºC followed by vacant land 28.30 ºC and the peak temperate zones are also located in built up areas too. Agriculture had slightly higher temperature of 26.56 ºC. Water body consisted of lowest average LST of 22.36 ºC. It also showed lowest minimum temperature of 20.65 ºC. In 1999, it showed the changing trend of temperate zone from 1989 as the land use dynamics is changing accordingly. The vegetation fraction is decreasing and as a replacement the space is occupying the built up area and agricultural land.

Spatial Variation of Land Surface Temperature in 2011

Land surface temperature in 2011 also shows the most significant variation rather than 1989 and 1999 over various land use/land cover classes.

Table 4: Land Surface Temperature over Land Use/Land Cover in November, 2011

Land Use/Land Cover Class	Land Use Amount (In Hectare)	Land Surface Temperature (in ^{0}C)		
		Maximum	Minimum	Average
Agriculture	1366	29.46	24.74	27.10
Barren / Vacant Land	231	31.85	26.18	29.02
Built-up area	2059	33.47	28.95	31.21
Vegetation	903	26.78	23.63	25.21
Water body	557	24.70	21.65	23.18

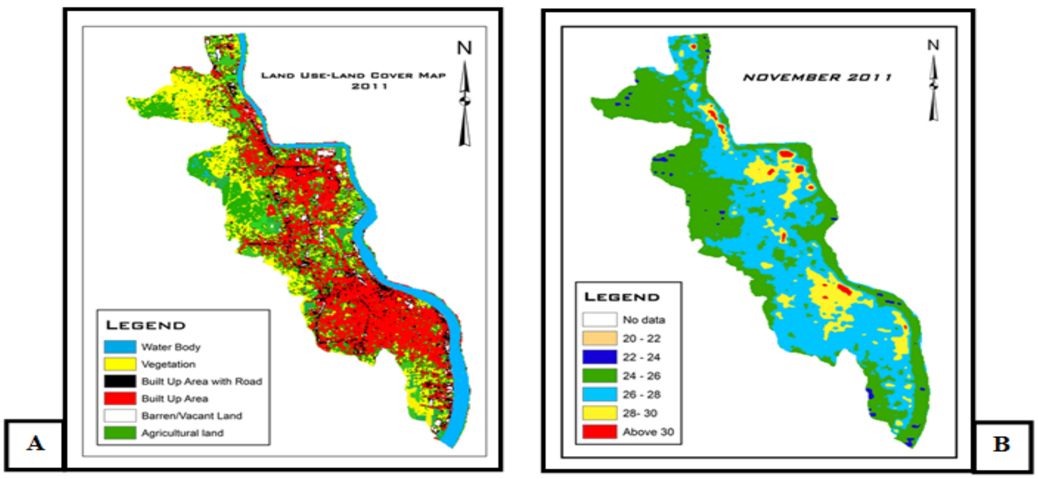

Figure 7: Land Use/Land Cover (A) and Land Surface Temperature (B) in 2011; Source: Author

In 2011, built up area consisted of the highest average land surface temperature 31.21 ºC followed by vacant land 29.02 ºC. In 1999, agriculture had slightly higher temperature of 27.10 ºC than vegetation. Water body consisted of lowest average land surface temperature 23.18 ºC. It also showed lowest minimum temperature 21.65 ºC. The LST has drastically changes in 2011 due to the abundance of vegetated area that replaced with built up area radically. The peak temperate zone has spread out throughout the whole city. Not only the sphere of the past years' peak temperate zones has increased but also the newly peaked temperate zone has emerged too in the south-western part of the city.

Results

Land Use change comparison

In the study area LULC has changed drastically form 1989 to 2011 especially from 1999 to 2011. Figure 8 shows the changes in land use/land cover from 1989 to 2011 in a comparative perspective

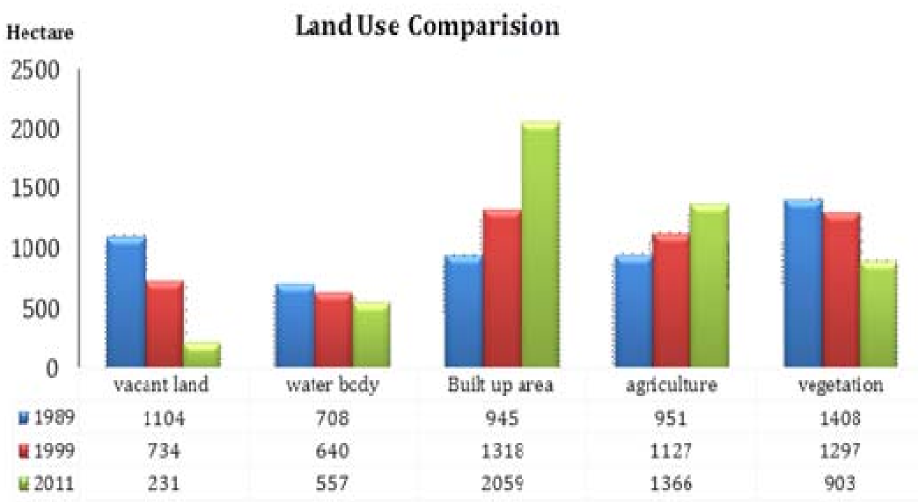

Figure 8: Land use/Land Cover comparison; Source: Author

In the last 20 years the radical expansion has occurred in the category of built up area (18% to 40%). Accordingly the vacant land has reduced considerably (22% to 4%) and also the vegetated area (27% to 18%) and has replaced with agricultural land (19% to 27%) and built up area.

Land Surface Temperature Comparison

In the study area land surface temperature has increased in gradual basis from 1989 to 2011 especially from 1999 to 2011. Figure 8 shows the changes in LST those happened from 1989 to 2011 in a comparative perspective.

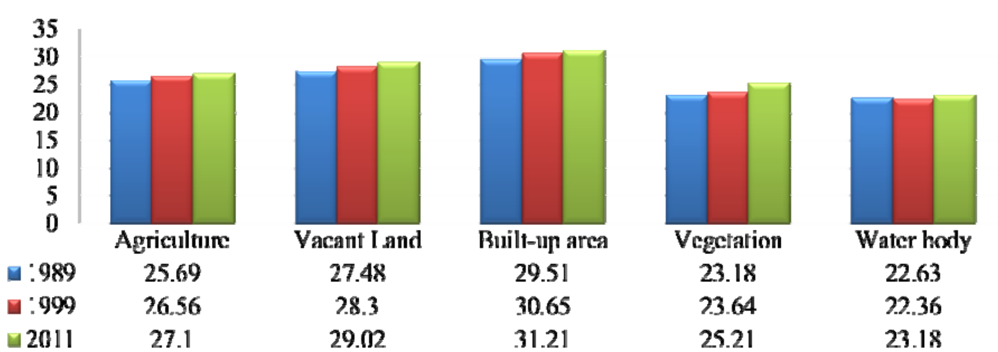

Figure 9: Land surface temperature comparison; Source: Author.

The significant difference in mean LST values between different land covers mentioned above (Figure 8) indicated that an obvious UHI effect existed in the study area. It is evident from the maps that some hot spots, warm corridors and heat islands can be easily identified for the three observed years. The heat islands of 1989 and 1999 were mainly distributed some of the industrial center of the north-western part of the city. But, the heat islands in 2009 spread from industrial center to the south-western corner of the city which is the main urban core of the city with a relatively stronger UHI intensity.

Nature of Changes of Temperatures with Land Use from 1989 to 2011

It is obvious that LULC change is producing a dynamic impact on the increase of LST. Table 5 shows the extent and nature of LST change with the change in LULC.

Table 5: Change in land Surface Temperature over Land use/land Cover Changes

Change in Land use/Land Cover	Average Change in Land Surface Temperature (in ºC)	
	1989-1999	1999-2011
Agriculture to Others	0.75	0.92
Agriculture to Built-up Area	1.12	1.59
Built-up To Built-up Area	0.95	1.21
Vacant Land to Agriculture	0.46	0.62
Vacant Land to Built-up Area	0.61	0.97
Vacant Land to Vegetation	0.06	0.11
Vacant Land to Others	1.01	1.33
Vegetation to Others	0.71	0.95
Vegetation to Built-up Area	1.56	1.94
Water body to Others	1.14	1.38
Water body to Built-up Area	2.88	3.02

Change of average land surface temperature in 1989-1999 was obvious from1999-2011. It brings a significant increase in LST with the conversion of LULC. In both intervals, the highest change of LST occurs to the change of water body to built-up area (2.88 ºC in 1989-1999 and 3.02 ºC in 1999-2011). Another significant change occurs at changes of vegetation to built-up area (1.56 ºC in 1989-1999 and 1.94 ºC in 1999-2011) followed by the change of water body to built-up area.

Conclusion

In this study, three multi-temporal TM images of 1989, 1999 and 2011 were used to detect the LULC changes and associated LST and UHI effect variations in Khulna, Bangladesh. The Landsat remote sensing method provides a useful measure in exploring the relation of LULC change and LST from 1989 to 2011 at a city scale. Result showed that Economic development in the study area accelerated the urbanization process, leading to a growth rate of built-up area of 22% during 1989 to 2011. Vegetated area decreased by nearly 9% with the area increase of 8% in agriculture and built up area.

The average LST of different LULC derived from the images helps to better understand the thermal response of surface materials. Results showed that the water bodies and vegetation had relatively lower surface temperatures and were efficient in decreasing urban LST and mitigating the UHI effect. This encourages urban planners and to devote more efforts in protecting urban lakes and vegetation. In contrary built-up area were detected as the main heat in observed area, as expected.

All these results prove that LST is certainly a function of LULC and has an impact on its surrounding environment. This study is showing the drastic change of LST over various LULC. With the change in global climate, temperature is increasing and it is difficult to decrease it. so the best way to control it is to utilize the land use/land cover. Anyhow, land surface temperature should be controlled to ensure a good living urban environment. Otherwise, urban areas smell like a desert.

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