GIS-BASED SPATIAL SIMULATION OF IMPACTS OF URBAN DEVELOPMENT ON CHANGING BOTH LAND COVER AREA AND LAND SURFACE TEMPERATURE IN DHAKA CITY

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Debasish Roy Raja

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ABSTRACT

Dhaka city is confronted with a big challenge due to significantly high rate of physical and population growth since 1981, which has created tremendous pressure on urban land, utility services, and other amenities of urban life. A substantial growth of built-up areas i.e. *urban development* is transforming increasingly the landscape from natural cover types to Impervious Surface (IS). It is building up Urban Heat Island (UHT), which has adverse effect on the *urban climate change* such as abrupt temperature rise, erratic rainfall, degrading air quality. Therefore, Dhaka city is adversely affected by erratic rainfall and heat stress, resulting calamities like flood, water logging, health outbreak, and water scarcity including greenhouse climate changes. A goal of this study is thus set to find out the impacts of urban development on land cover areas (LCA) and land surface temperature (LST) in Dhaka city over the period of 1989 to 2010. To achieve this goal, the study is carried out to assess the relationship between the land surface temperatures (LST) and land cover (LC) area from both quantitative and qualitative perspectives. In this study, the proposed study area is confined to Dhaka Metropolitan Area (DMA). Satellite images of DMA area over the period of 1989 to 2010 is compiled from USGS website as zip format. To conduct this research, two well-known softwares namely ArcGIS 9.2 and Erdas Imagine 9.1 are utilized. Spatial simulation and analysis are carried out using advanced geographic information systems (GIS).

Supervised classification methods have been taken to prepare the LC map and LST is derived from the thermal band of Landsat TM/ETM+ using the calibration of spectral radiance and emissivity correction of remote sensing. GIS based spatial simulation has been conducted to establish the relationship of LC and LST. The result shows that category of built-up is grown up to 23.18% in constant growth rate and it was changed from the categories of water bodies and vegetation Land Cover during the period of 1989 to 2010. The changing of LST is directly correlated with LC transition and LST is increasing in those areas where LC of built-up and earth fill or sand categories (urban development) are grown up. In addition, it is also proved from the result that the amount of vegetation (NDVI) is negatively correlated with LST. For that reason, the built-up areas for which NDVI value is greater have been found to have low LST value. Again, the NDBI value is positively correlated with the LST. The trend of LST and LC transition indicates that LST of the Dhaka city will be abruptly increased in near future. The

outcome thus obtained from this study would address the future consequences of changing both LCA and LST in Dhaka and would propose a strategic roadmap to reduce LST and UHI as a unique contribution to knowledge-base of scientific community. Moreover, this significantly important research for urban planning would provide supports to decision makers to prepare the planning strategies for the reduction of heat island effect and the quality improvement of urban environment. The urban temperature distribution maps, the analyses of thermal-land cover relationships and the spatial simulated maps of impacts of LST changes can be used as a guideline for urban planning and a smart solution to the reduction of UHI effect. Finally, some strategies are proposed to reduce urban heat islands build-up. On the basis of these research findings, intelligent land use planning for controlling undesirable development, cool roof or green roof for improving the solar reflectance of roofs, conservation of vegetation area and water bodies, guideline for urban geometry are considered as the solution to reduce the LST.

ABBREVIATION & ACRONYMS

BBS	Bangladesh Bureau Statistics
DCC	Dhaka City Corporation
DN	Digital Number
DMA	Dhaka Metropolitan Area
DMDP	Dhaka Metropolitan Development Plan
GIS	Geography Information System
ETM+	Enhanced Thematic Mappper Plus
IS	Impervious Surface
LST	Land Surface Temperature
LC	Land Cover
LCA	Land Cover Area
LCC	Land Cover Change
LPGS	Level 1 Product Generation System
LSTC	Land Surface Temperature Change
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built-Up Index
NIR	Near Infrared
NLAPS	Landsat Archive Production System
RS	Remote Sensing
ST	At-Satellite Temperature
TM	Thematic Mapper
USGS	United State of Geological Survey
UD	Urban Development
UHI	Urban Heat Island
UHIE	Urban Heat Island Effect
UTM	Universal Transverse Mercator
WGS	World Geodetic System

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CHAPTER 01
INTRODUCTION

1.1 Background of the study:

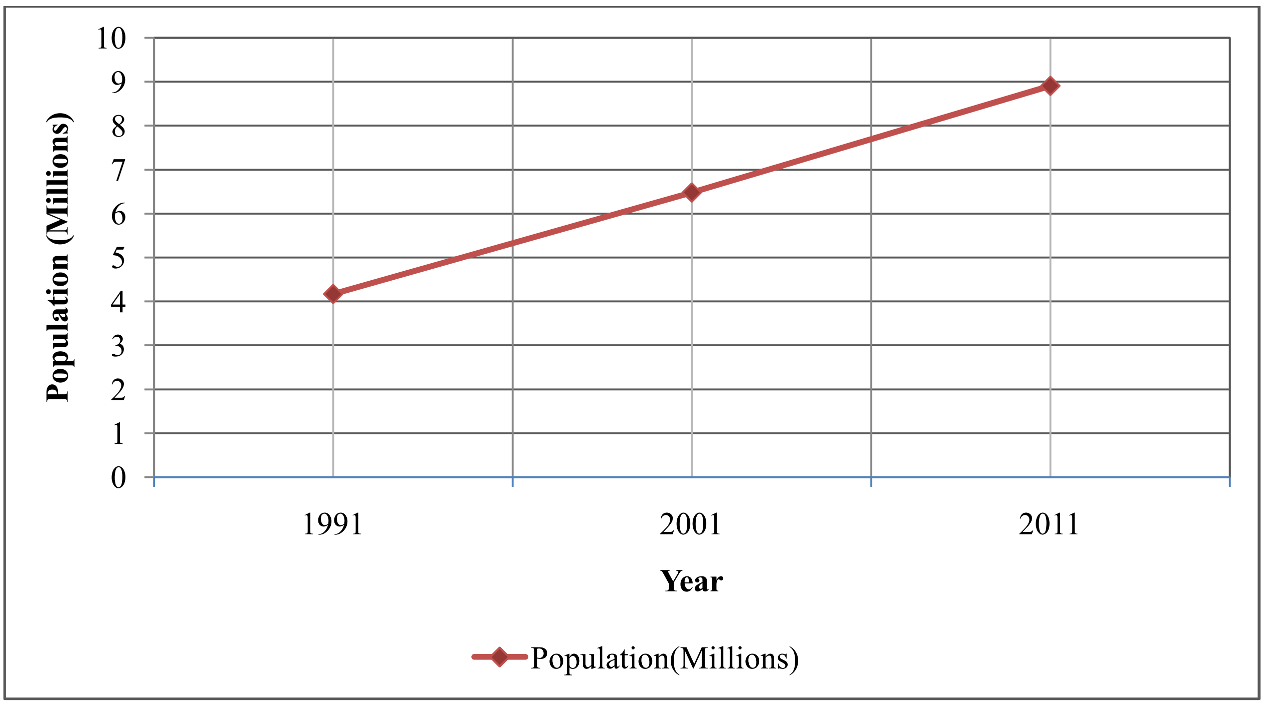
Dhaka City has developed over a long span of time. It has confronted its highest rate of physical and population growth during 1981-1991, with the population doubling during that decade and the city expanding from 510 sq. km to 1353 sq. km. (BBS, 1997) shown in Table A2(Appendix A). The population of the city is increasing very rapidly due mainly to rural-urban migration and has reached to 14.54 million in 2011 and the population growth has been 35.88% in the last decade (BBS, 2012). The area of Dhaka metropolitan area (DMA) is about 306 sq. km. which population has reached to 8.91 million in 2011(BBS, 2012). The density of DMA is about 29,104 person per sq.km. It indicates that it is very densely populated area. The demographic features of DMA have been shown in Table 1.1 and Figure 1.1. These additional people have created tremendous pressure on urban land, utility services and other amenities of urban life. As a result bad development and improper management of natural resource have been happened and it degrades the quality of environment of the city.

Substantial growth of built-up areas resulted significant decrease in the area of vegetation, cultivated lands, forested lands and water bodies. Therefore, such an urban growth and development transforms the landscape from natural cover types to increasingly impervious urban land in different shape and orientation. This change can have significant impacts on local weather and climate (Mayer, *et al.*, 2003; Ifatimehin, *et al.*, 2010). Besides it is building up urban heat island (UHT) which has resulted in an adverse impact on the urban environment (Hossain, 2008; Atkinson, 2002; Dewan, *et al.,* 2009). Dhaka city is mainly affected in two ways such as erratic rainfall through heat stress. As a result flood, water logging, health outbreak, water scarcity are frequently occurred in the last several years (Alam, *et al.*, 2007). Assessing the climate of a Dhaka city requires consideration of the complex variable such as urban development, urban growth or urbanization that interacts between economic, environmental, and social factors.

Table 1.1: Demographic feature of Dhaka metropolitan area (DMA), 1991 to 2011

Year	Area (Sq. Km)	Population (Million)	% increase of population over preceding year	Density (Per Sq. Km.)
1991	306	4.17	--	13,639
2001	306	6.48	55.32	21,185
2011	306	8.91	37.37	29,104

Source: BBS, 1997, BBS 2003 and BBS, 2012



Source: BBS 1997, BBS 2003 and BBS, 2012

Graph 1.1: Population trend of DMA, 1991 to 2011

In several studies, remote sensing data were utilized to assess urban land cover area and it's thermal characteristics through mapping sub-pixel impervious surfaces and assessing thermal infrared images. Most of those studies have been analyzed the relationship between the land surface temperature (LST) and land cover area (LCA). The results of those studies show same result although methodologies and the study areas are different. Vegetation type land cover areas have the least temperature where as urban area has always higher temperature (voogt & Oke, 2003; Ifatimehin *et al.*, 2010; Cao, *et al.*, 2008, and Weng, 2001). In the study of Twin Cities Metropolitan Area Minnesota (USA) and Shanghai (China), the result indicates the strong linear relationship between LST and impervious surface for all seasons (Yuan*,* *et al.*, 2007; Zhang, *et al.*, 2008 and Xian, *et al.*, 2005). But some studies have different results. As for the study of Guangzhou city (Guang Dong Province, China), white soil is about 3 degrees higher than urban area (Zhang, *et al*., 2007). So result can be varied with geographical location. Remote sensing data were also used to analyze urban environmental quality (UEQ) of Hong Kong. In the study, UEQ has assessed by examining the relationship between temperature and biomass (Nichol, *et al*., 2006).

Recently, it has also been emphasized that climate changes are due to the different scenarios of increased level of CO_2 concentration. Enhanced greenhouse climatic changes have been reported studying compilations of climatic datasets, but now-a-days urban factor has been given due consideration. It has just been *qualitatively* realized that detected warming is not only due to the increase of greenhouse gases but also to urbanization and other plausible climatic factors such as desertification (Nasrallah and Balling, 1993). There have been suggestions that a significant proportion of the 0.5^0 C warming seen over the last century may be related to urbanization influences (Kukla *et al*., 1986; Wood, 1988).

From literature survey, it is clear that only few studies have been conducted for assessing the climate change in Dhaka city but evidently *no study* has been performed yet to correlate climate change with urban development. Therefore, it is important to examine *both qualitatively and quantitatively* the impacts of urban development on climate change in Dhaka city and to find out its consequences for the foreseeable future. This study will explore the land surface temperature (LST) differences over different land cover areas (LCA) in Dhaka city over different time-periods.

1.2 Objectives of the study

The main goal of the study is to study the impacts of urban development on land cover areas (LCA) and land surface temperature (LST) in Dhaka city. To achieve the goal, following objectives are adopted:

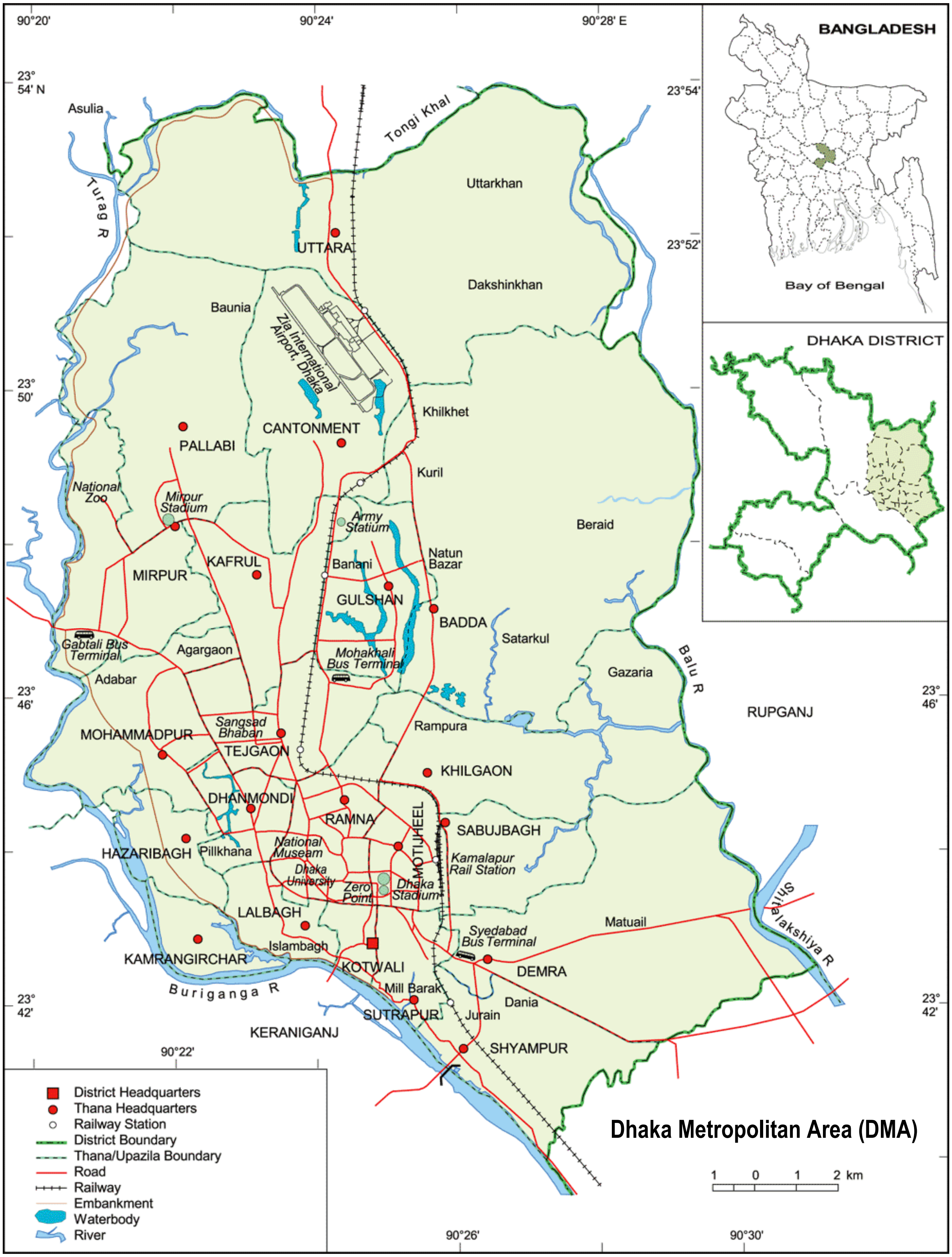
1. To study the association among urban development, changing of LCA and LST
2. To determine LST changes over different LCA in Dhaka city over different time-periods using remote sensing and spatial techniques of GIS
3. To examine the impacts of the LST changes on climate of Dhaka using GIS-based spatial simulation

1.3 Study area profile

Dhaka is the capital city of Bangladesh and it is located at Latitude 23°43'0"N, Longitude 90°24'0"E. The whole city is surrounded by river named Buriganga, Shitalakshiya, Balu and Turag. The proposed study area of this research is Dhaka Metropolitan Area (DMA) shown in Figure 1.2. The area of DMA is about 306 sq. km which consists of 41 *Thana* (Police station) boundaries (BBS, 2012) shown in Table A1 (see Appendix A).The population of the DMA is 8.91 million in 2011 (BBS, 2012). The major topographic features of the city are high land and low land. The centre of the city where the physical development has been built is high land. Low land means floodplains, depressions and abandoned channels which is located in and around the city. The low lying swamps and marshes also are located in and around in the city (Tawhid, 2004).

Dhaka city has three distinct seasons. They are winter (November- February), pre-monsoon (March- May) and monsoon (June - October). In winter season, the weather is very dry with temperature 10°C to 20°C. In Pre-monsoon season, some rain has been observed and the weather is very hot with temperature reaching up to 40°C. The weather is found very wet with temperature 30°C in monsoon season. The annual rain fall of the Dhaka city is about 2000 mm, of which 80% falls during this monsoon season (Banglapedia, 2012).

Dhaka city is the oldest city and capital in Bangladesh. It's economic and urban agglomeration is high (Basak, 2006). It has been grown very rapidly (Rabbani, 2010) in last few years. Besides Dhaka city has huge potentiality to face massive urban growth in near future based on the current trend of the rapid growth of urbanization (WUP, 2012). Modern Dhaka is the centre of political, cultural and economic life in Bangladesh. Although its urban infrastructure is the most developed in the country, Dhaka suffers from urban problems such as pollution and overpopulation (Dewan



Source: Bangla Pedia, 2012

Figure 1.1: Location map of the study area

et al., 2009). Moreover the microclimate has been changed day by day due to unplanned growth of the city (Rahman, n.d.).

1.4 Scope of the study:

During the last 25 years, rapid urbanization has taken place in Dhaka City. Substantial increase in built-up areas has taken place due to development of residential and commercial areas mostly through private land developers and real estate business. These activities resulted in substantial increase in impervious area in different shape and orientation which affect local climate (Mayer, *et al.*, 2003). It is important to realize how this substantial development affects the climate such as temperature of the Dhaka city. This research focused to find out thermal-land cover relationships and the spatial simulated maps of impacts of LST changes, which will be helpful for a guideline to reduce of Urban Heat Island Effect (UHIE).

The findings of this study will be able to address the future consequences of urban climate changes in Dhaka. In addition, this kind of research is undoubtedly important for urban environment planning that will help decision makers to prepare the planning strategies for quality improvement of urban environment.

1.5 Limitation:

It is important to select the appropriate satellite image to study LST change due to urban development over different period. For this research, Landsat satellite images have been selected because LST can be determined from its thermal band. Besides, different period of images are available in free public-domain. The main limitation of this kind of image is low spatial resolution which is 30m. There is other better option of high resolution images for this research such as IKONOS, Quick Bird etc. but these kinds of satellite images are only available for commercial. So due to limitation of resource, only free public-domain data have been used for this research.

Though Landsat image of same interval period are found in free public-domin but same season image are not available. For better result of this research, year of 1989, 2000 and 2010 images are chosen which have low seasonal variation.

Another limitation of the study is collection of reference data which are necessary for the preparation of different land cover area classification map. Year 1989, 2000 and 2010 Landsat TM/ETM+ images have been used to prepare the LCA classified map. To perform this research, Google earth image and different band composite images of the same year have been used for preparing LCA map.

1.6 Organization of the thesis

This thesis work has been presented in eight (8) chapters. In chapter 01 background, objectives, study area profile, scope and limitation has been described. In Chapter 02, the theoretical concepts such as land cover area, land surface temperature, climate change and its cause and affects etc. has been explained. In chapter 03, the detail methodological steps have been illustrated. In chapter 04, how the data are processed for analysis is described. Chapter 05 explains the relationship between the LST and LCA of DMA and how LST affects the LCA. Chapter 06 describes the relationship between the LST, LC, NDVI and NDBI with simulated curve and map. Major findings and results have been discussed in this chapter 07.some recommendation and conclusion has been drawn on the basis of the major findings in chapter 08.

CHAPTER 02
THEORETICAL FRAMEWORK

2.1 Concept of urban development

Urban development means a whole combination of processes that have always been at work in towns and cities and result in a regeneration and revitalization of the existing fabrics, both old and recent which involves urban renewal or redevelopment measures. (Allain and Baudelle, 2006) Urban development can also be explained that it is a type of community zoning classification that is planned and developed within a city, municipality or state that contains both residential and non-residential buildings. Open land, such as for parks, is also often included in the zones. Developing countries like Bangladesh, cities have been grownup without proper planning and recreational area such as parks or opens apace such as vegetation has been provided insufficient. As a result impervious land of this area is increasing day by day. Impervious land contains more heat than open space or park because of vegetation. So surface temperature of these areas is increased compare to suburban area where more open space is available. In this way, urban development affects in micro climate.

2.2 Concept of urban heat island (UHI)

Urban heat island (UHI) can be defined as:

"An area of higher temperatures in an urban setting compared to the temperatures of the suburban and rural surroundings. It appears as an 'island' in the pattern of isotherms on a surface map." (Sailor, 2002)

The principal reason of UHI is that heat of buildings block surface are radiating into the relatively cold night sky. There are other two reasons which can affect the UHI. They are thermal properties of surface materials and lack of evapotranspiration. Evapotranspiration means vegetation absorbs heat for evaporation. Concrete and asphalt kind of materials are commonly used in urban areas for pavement and roofs which has significantly different thermal heat capacity and conductivity than the surrounding rural and suburban areas. Again it has also different surface radiative properties such as albedo and emissivity than rural areas. This causes a change in the energy balance of the urban area, often leading to higher temperatures than surrounding rural areas (Wikipedia, 2012).

2.3 Climate change

Climate change can be defined as follows:

"Changes in the earth's weather, including changes in temperature, wind patterns and rainfall, especially the increase in the temperature of the earth's atmosphere that is caused by the increase of particular gases, especially carbon dioxide." (Oxford dictionary, 2010).

Climate change is a long-term change in the statistical distribution of weather patterns over periods of time that range from decades to millions of years. It may be a change in the average weather conditions or a change in the distribution of weather events with respect to an average, for example, greater or fewer extreme weather events. Climate change may be limited to a specific region, or may occur across the whole Earth.

Human activities are affecting the heat/energy-exchange balance between Earth, the atmosphere, space, and inducing global climate change, often termed "Global Warming.". Human activities such as burning of fossil fuels, industrial production, deforestation, and certain land-use practices have increased atmospheric concentrations of carbon dioxide (CO_2) by 35% over the past 150 years. It affects the global average temperatures and it has risen 0.6 °C in the last 100 years (Justus & Fletcher, 2006).

High rate of growing population creates the demand of extra energy and land. To meet this extra demand agricultural land and water bodies are converted into urban areas which reduce the surface evaporation capacity and increase heat storage of construction materials such as concrete and asphalt. Again the geometric features of the settlement such as densely packed building or orientation of the building creates heat stagnation. Besides the energy consumption increased the anthropogenic heat. As a result the temperature is gradually increased in the urban area. This climate change creates impact on territorial ecosystem (low productivity of agricultural sector, desertification, scarcity of waters in the summer season, fall the biodiversity of the water bodies), human system (human health, economic, insurance and other financial services) and atmospheric system (Weather, Storms, Floods and Droughts) (Houghton, 2007).

2.3.1 Climate change in Dhaka city

Megacity, Dhaka is regularly threatened by natural hazards. Risks associates with floods, temperature rise and heat stress in mainly are expected to increase in the years to come because of global climate change and rapid urbanization (Rahman and Mallick, n.d.). Greater Dhaka is expected to grow from 13.5 million inhabitants in 2007 to 22 million inhabitants by 2025(WUP, 2012). The vast majority of this growth will take place in informal settlements. This large population activity causes the microclimate change in the Dhaka city. Recently Heat Stress is one of the newly natural hazards (Afrin, 2012 and Monsur, 2011).

2.4 Geographic information system (GIS) and remote sensing (RS)

2.4.1 Concept of geographic information system (GIS)

Geographic Information System (GIS) refers to any scientific effort integrate data to help researchers visualize, analyze, and explore geographically referenced information. According to Carter, 1989 “An institutional entity, reflection and organizational structure that integrates technology with a database, expertise and continuing functional support over time.”(Majuire, n.d.) According to Chang, 2008 “Geographic Information System (GIS) is a computer system for capturing, storing, querying, analyzing and displaying geospatial data. Also called geographically referenced data”. GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of geo-referenced data to solve complex problems regarding planning and management of resources. Functions of GIS include data entry, data display, data management, information retrieval and analysis. The applications of GIS include mapping locations, quantities and densities, finding distances and mapping and monitoring change. GIS can be applied in the field of hydrology, crime, history, urban planning & engineering, environmental and natural resources management, data acquisition and prepossessing, networking, facility managements.

2.4.2 Concept of remote sensing (RS)

According to John, Wiley and Sons, Inc, 1979 the definition of remote sensing is " The science and art of obtaining useful information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation." (Lillesand & Kiefer, 1994). Traditionally, the energy collected and measured in remote sensing has been electromagnetic radiation, including visible light and invisible thermal infrared (heat) energy, which is reflected or emitted in varying degrees by all natural and synthetic objects. The scope of remote sensing has been recently broadened to include acoustical or sound energy, which is propagated under water. The instruments used for this special technology are known as remote sensors and include photographic cameras, mechanical scanners, and imaging radar systems. Regardless of type, they are designed to both collect and record specific types of energy that impinges upon them. Remote sensing devices can be differentiated in terms of whether they are *active* or *passive.* Active systems, such as radar and sonar, beam artificially produced energy to a target and record the reflected component. Passive systems, including the photographic camera, detect only energy emanating naturally from an object, such as reflected sunlight or thermal infrared emissions. Today, remote sensors, excluding sonar devices, are typically carried on aircraft and earth-orbiting spacecraft.

2.4.3 Landsat satellite images

Landsat image provide calibrated high spatial resolution data of the Earth's surface. It is uesd for a broad and varied user community, including agribusiness, global change researchers, academia, state and local governments, commercial users, military, and the international community (NASA, 2010). Landsat TM and Landsat ETM have 6 and 7 bands of data respectively. Each band of data provides a record of the amount of energy reflected in a specific portion of the electromagnetic spectrum. For example band 4 measures the intensity of Near Infrared energy reflected, and Band 3 measures the intensity of green light reflected. For each pixel in each band of data, there is a numerical value called image digital number (DN value) given to the amount of energy reflected from the Earth's surface. The characteristics of Landsat TM/ETM band is shown in the Table2.1.

Table 2.1: Landsat TM / ETM+ Band character

Band	**Color**	**Wavelength (µm)**	**Spatial Resolution (meter)**	**Generalized Applications**
band 1	Blue	0.45-0.52	30	Separation of soil and vegetation
band 2	Green	0.52-0.60	30	Reflection of vegetation
band 3	Red	0.63-0.69	30	Chlorophyll absorption
band 4	Near Infrared	0.76-0.90	30	Delineation of water boundaries
band 5	Mid Infrared	1.55-1.75	30	Vegetative moisture
band 6	Thermal	10.4-12.5	60	Hydrothermal mapping
band 7	Far Infrared	2.08-2.35	30	Plant heat stress

Source: US Geological Survey, 2012

2.5 Land covers area (LCA) classification

In general crust of the earth is naturally made of soil or rock. But it is covered with different element such as vegetations, concrete, paved area, water bodies etc. which is defined as land cover area (LCA) in this research. This LCA has been changed over different periods of time. The LC of the urban area is complex. It contains different LC type such as concrete, paved, asphalt, vegetations, water bodies, bare soil, sand fill area etc. So Satellite images can be used to classify the urban LCA into different categories using classification methods such as supervised and unsupervised classification of remote sensing. Besides special type of land can be extracted or defined by different types of methods such as Normalized Difference Vegetation Index (NDVI) for identifying vegetations and Normalized Difference Built-up Index (NDBI) for identifying built-up areas. The types of classification techniques are briefly described in the following.

2.5.1 Unsupervised classification technique

Unsupervised Classification is the identification of natural groups, or structures, within multi-spectral data by the algorithms programmed into the software. The following characteristics apply to an unsupervised classification (Dougherty, et *al*, 1995):

- There is no extensive prior knowledge of the region that is required for unsupervised classification unlike supervised classification that requires detailed knowledge of the area.

- The opportunity for human error is minimized with unsupervised classification because the operator may specify only the number of categories desired and sometimes constraints governing the distinctness and uniformity of groups. Many of the detailed decisions required for supervised classification are not required for unsupervised classification creating less opportunity for the operator to make errors.
- Unsupervised classification allows unique classes to be recognized as distinct -units. Supervised classification may allow these unique classes to go unrecognized and could inadvertently be incorporated into other classes creating error throughout the entire classification.

2.5.2 Supervised classification techniques

Supervised classification is the process of using samples of known identity to classify pixels of unknown identity. The following characteristics apply to a supervised classification ((Dougherty, et *al*, 1995)):

- The analyst has control of a set, selected menu of informational categories tailored to a specific purpose and geographic region.
- Supervised classification is tied to specific areas of known identity, provided by selecting training areas.
- Supervised classification is not faced with the problem of matching spectral categories on the final map with the informational categories of interest.
- The operator may be able to detect serious errors by examining training data to determine whether they have been correctly classified.
- In supervised training, it is important to have a set of desired classes in mind, and then create the appropriate signatures from the data. You must also have some way of recognizing pixels that represent the classes that you want to extract.

2.6 Concept of normalized difference vegetation index (NDVI)

The Normalized difference vegetation index (NDVI) is a measure of the amount and vigor of vegetation on the land surface and NDVI spatial composite images are developed to more easily distinguish green vegetation from bare soils. NDVI is calculated from satellite imagery whereby the satellite's spectrometer or radiometric sensor measures and stores reflectance values for both red and near-infrared (NIR) bands on two separate channels or images (Kriegler, et *al*. 1969) and it is calculated by subtracting the red channel from the NIR channel and dividing their difference by the sum of the two channels. The formula are given in the below.

NDVI= (NIR - RED) / (NIR + RED)……………………………………….. (1)

Where,

NIR= Near infrared band of the image

RED= Red band of the image

For Lansat satellite image the calculation formula of NDVI is given below.

NDVI = (band 4 - band 3) / (band 4 + band 3)…………………………….. (2)

Where,

Band 4= 4 no. band of the Landsat image

Band 3= 3 no. band of the landsat image

2.7 Concept of normalized difference built-up index (NDBI)

Normalized difference built-up index (NDBI) value is sensitive for the built-up area. The index value is also represented as the imperviousness of land. The variable range of positive value generally indicates the built-up area. This range of index value can be selected on the basis the ground truth data for more accurate identified built-up area (Chen *et al*., 2006). Generally the range of 0.15 to 0.3 is sensitive for built-up area. The NDBI can be derived from the Landsat image using the following formula (Zha *et al*., 2003).

NDBI= (band 5 - band 4) / (band 5 + band 4)……………………………… (3)

Where,

Band 4= 4 no. band of the Landsat image

Band 5= 5 no. band of the landsat image

2.8 Land surface temperature (LST)

At first Land Surface Temperature (LST) was referred to standard surface-air temperature measured by a sheltered thermometer 1.5–3.5 m above a flat grassy, well-ventilated surface.

With satellite technology, another type of LST, satellite-based surface temperature called skin temperature, is becoming available globally. Satellite LST products provide an estimate of the kinetic temperature of the earth's surface skin Difference from air temperature (Dickinson, 1994; Becker and Li, 1995). To correct the emissivity of the surface LST can be derived from the satellite images.

2.8.1 Methods of computing LST

The surface brightness temperature is directly calculated by means of the plank's law form the surface radiance. Emissivity is a key factor on LST measurement. The following method can be used for measuring at- satellite Brightness temperature form the Landsat data. At first image digital number need to convert to radiance. During 1G product rendering image pixels are converted to units of absolute radiance using 32 bit floating point calculations. Pixel values are then scaled to byte values prior to media output. The following equation is used to convert DN's in a 1G product back to radiance units (NASA, 2010):

Radiance, L_λ = gain * DN + offset …………………………………………………….. (4)

Where,

gain = slope of the response

DN= Digital Number

offset = Intercept of response

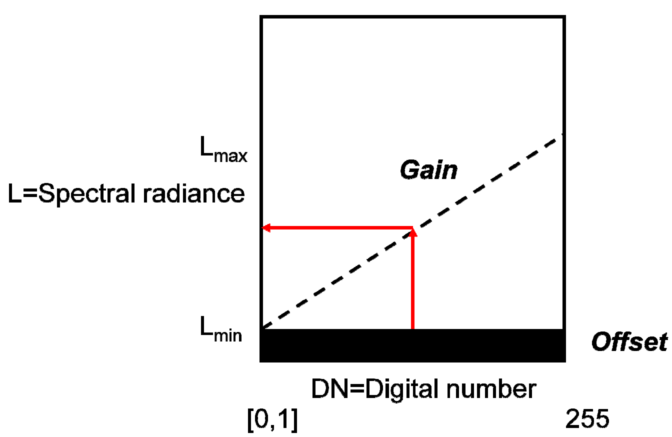


Figure 2.1: Radiometric response function for an individual TM channel

The above equation which is also expressed as:

For Landsat TM,

Radiance, $\mathbf{L\lambda}$ = (**QCAL**/255) *(($\mathbf{L_{MAX}}$-$\mathbf{L_{MIN}}$) + $\mathbf{L_{MIN}}$ **……………………………………..** **(5)**

For Landsat ETM+,

Radiance, $\mathbf{L_{\lambda}}$ = (($\mathbf{L_{MAX}}$-$\mathbf{L_{MIN}}$)/($\mathbf{QCAL_{MAX}}$-$\mathbf{QCAL_{MIN}}$)) * (**QCAL**-$\mathbf{QCAL_{MIN}}$) + $\mathbf{L_{MIN}}$ **……** **(6)**

Where:	$\mathbf{QCAL_{MIN}}$	= Minimum Digital Number(DN) Value
	$\mathbf{QCAL_{MAX}}$	= Maximum Image Digital Number(DN) value
	QCAL	= Digital Number(DN) of the Band 6
	$\mathbf{L_{MAX}}$	= Maximum spectral radiances
	$\mathbf{L_{MIN}}$	= Minimum spectral radiances

The L_{MIN} and L_{MAX} are the spectral radiances for each band at digital numbers 0 or 1 and 255 (i.e $QCAL_{MIN}$, $QCAL_{MAX}$), respectively. There are two process systems which generate the USGS Landsat standard data products. They are: Level 1 Product Generation System (LPGS) & National Land Archive Production System (NLAPS). LPGS uses 1 for $QCAL_{MIN}$ while NLAPS uses 0 for $QCAL_{MIN}$. Other product differences exist as well. One L_{MIN}/L_{MAX} set exists for each gain state (USGS, 2010). At first LST at- satellite Brightness temperature can be derived from spectral radiance by the following formulas (NASA, 2010; Zhang *et al*, 2008).

$$\boldsymbol{T_B = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda}+1\right)}} \quad \text{……………………………………………………} \quad \textbf{(7)}$$

Where

T_B = At- satellite Brightness temperature

L_λ = Spectral Radiance

K_1 and K_2 are calibrated constant depending on the sensor of TM and ETM

Table 2.2: ETM+ and TM Thermal Band Calibration Constants

	K_1 ($Wm^{-2}\ sr^{-1}\mu m^{-1}$)	K_2 (K)
TM	607.76	1260.56
ETM+	666.09	1282.71

Source : NASA, 2008

LST can be derived using several emissivity correction formulas. The following formula can be used to emissivity correction (Weng, 2001). As to emissivity, Weng, 2001 draw attention to the research by Nichol, 1994 and proposed a simple grouping for emissivity (ε), that is, 0.95 for vegetative areas and 0.92 for non-vegetative areas.

$$S_t = \frac{T_B}{1+(\lambda.T_B/\rho).ln\ \varepsilon} \quad \text{.......} \quad (8)$$

Where

S_t = Land Surface Temperature

λ = 11.457μm

ρ= 1.438× 10^{-2} mK

ε= Emissivity

2.9 Kernel density estimation method

Kernel density estimation usually produces a smoother output than the simple estimation method. It associates each known points with a kernel function for the purpose of estimation. Expressed as a bivariate probability density function, a kernel function looks like a "bump" centering at a known point and tapering off to 0 over defined bandwidth determines the amount of smoothing in estimation shown in Figure 2.2 (Chang, 2008). The kernel density estimator at point x is then the sum of the bumps placed at known point's x_i within the band width:

$$f(x) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{h_i}K(\frac{x - x_i}{h_i}) \quad \text{...} \quad \textbf{(9)}$$

Where,

f(*x*) = Kernel density estimation

K() = Kernel function

h = Bandwidth

n = Number of known points within the bandwidth

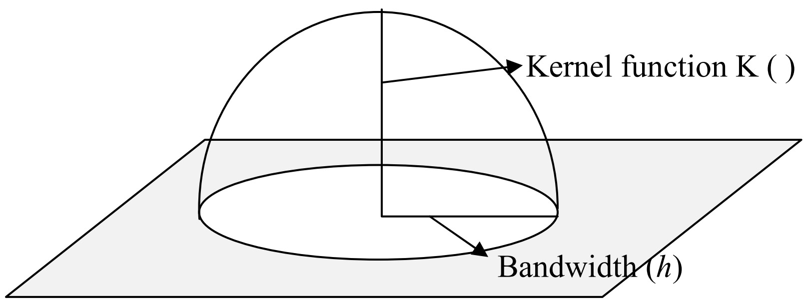


Figure 2.2: A kernel function, which represents a probability density function, looks like a "bump" above the surface

As surface interpolation method, kernel density estimation has been applied to a wide variety of field such as forest resource, crime and natural hazards.

CHAPTER 03
METHODOLOGY OF THE STUDY

3.1 Methodological flow chart and steps

This chapter discusses methodological steps of the entire research. A flow chart is given to show the steps of the study shown in Figure 3.1.

3.1.1 Literature review

An extensive literature review has been done to have a clear understanding on the effects of urban development on Land surface temperature (LST) changes. How GIS and Remote sensing data can be used to measure theses parameters, is also studied in this review. Various journal papers, books, reports, conference papers and dissertation have been overviewed to understand the methods of measuring LST and Land cover areas (LCA).

3.1.2 Problem Identification & Research objectives

Because of high rate of physical and population growth, the demand of urban land, utility services and other amenities of urban life have been increased which is found from the literature review. As a result, a substantial growth of built-up areas (*urban development)* is transforming increasingly the landscape from natural cover types to Impervious Surface (IS). It is building up Urban Heat Island (UHT), which has adverse effect on the *urban climate change*. On the basis of this problem, the research objectives are to find out the association among urban development, changing LCA and LST, to find out the changing LST with LCA and to examine the impact of the LST change on climate of the study area using spatial simulation.

3.1.3 Selection of the study area

In this study, the proposed study area is confined to Dhaka Metropolitan Area (DMA) because of its high level growth development in the last two decades (Rabbani, 2010). Their surrounding impact areas also have been considered for the analysis.

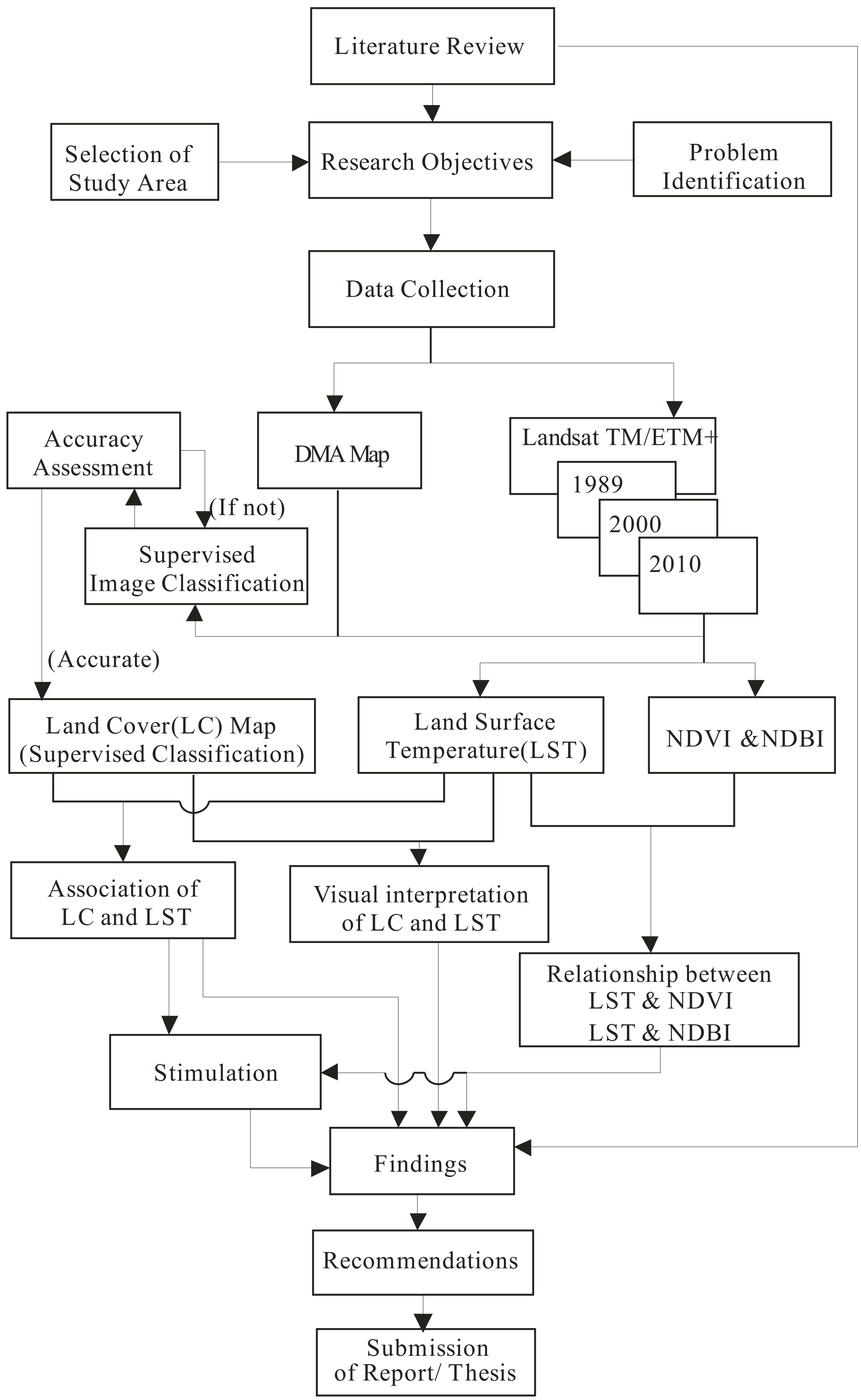


Figure 3.1: Flow chart of the methodology

3.1.4 Data collection

This study is depended on secondary data. To achieve the research objective, Landsat Satellite images of DMA area over different time period (1989, 2000 & 2010) is compiled from USGS website as zip format. The detail of the Landsat data for analysis is shown in Table 3.1. The Landsat TM/ETM+ image is collected as Universal Transverse Mercator (UTM) within 46N-Datum World Geodetic System (WGS) 1984. The pixel size of all bands Landsat images is 30 meters.

Table 3.1: Landsat TM/ETM+ images used in the study

Representative year	Path and Row	Date & Scan time	sensor	Weather	Resolution	Cloud %	Remarks
1989	137 & 44	Jan 12, 1989 09:57:14	Landsat 4 TM	Normal	30m	0	**Low seasonal variation**
2000	137 & 44	Feb 28, 2000 10:17:27	Landsat 7 ETM+	Normal	30m	0	
2010	137 & 44	Jan 30, 2010 10:15:40	Landsat 5 TM	Normal	30m	0	

Source: US Geological Survey, 2010

3.1.5 Data Processing

3.1.5.1 Land Cover map preparation

Image classification process of remote sensing is used to prepare land cover area (LCA) maps from the Landsat satellite image of DMA. To prepare a LCA map, Landsat images have been classified with different land cover types using supervised classification of maximum likelihood of parametric rule. Accuracy of the map has also been assessed in this classification method. The detail method has been described in the chapter 04.

3.1.5.2 Land surface temperature map preparation

Thermal band of Landsat TM/ETM+ is used to convert into land surface temperature (LST) using the calibration of spectral radiance of remote sensing. In this method, several formulas have been used to convert the image digital number (DN) to LST. At first the value of image digital number (DN) is converted to spectral radiance. This spectral radiance is the absorption value of reflecting thermal ray from different types of LCA. Then Spectral radiance has been converted to black body temperature or at-satellite brightness temperature. Finally this temperature has been converted to Land surface temperature (LST) using emissivity correction. The detail method has been discussed in chapter 4.

3.1.5.3 Preparation of NDVI and NDBI map

In remote sensing Normalized Difference of Vegetation Index (NDVI) has been used to measure the vegetation density. On the other hand, Normalized Differences of Built-up Index (NDBI) is for measuring built-up areas. NDVI and NDBI have been calculated using the equation no 2 and 3, respectively. Details discussions have been illustrated in chapter 04.

3.1.6 Spatial data analysis

To establish the relationship of LST and LC, both qualitative and quantitative analyses have been conducted. Visual interpretation has been done compare with the same year LST and LC images. The land surface temperature (LST) and the land cover (LC) map are integrated with the help of the different spatial analysis functions of GIS. As a result, the relationships of LST and LC have been depicted as graphically. In the same way, how NDVI affect the LST is illustrated in the simulated curve. It is also illustrated that increasing LST with changing LCA types over different periods is the result of urban heat Island Effect (UHIE). Spatial simulation based on GIS is performed to assess the impacts of urban development on changing both LCA and LST of DMA. The detail analysis has been described in chapter 05 and 06.

3.1.6 Findings of the research

After spatial data analysis, results and Major findings have been sorted out on the basis of the research objectives. Details discussions have been illustrated in chapter 07

3.1.8 Recommendations and conclusions

After obtaining research findings and results, some recommendations have been given for reducing the LST of the DMA area. It has been illustrated in chapter 08.

3.2 Toots used for this study

To perform this research, two well-known software's namely ArcGIS 9.2 and Erdas Imagine 9.1 are used. Remote sensing data and images are processed using advanced image classification techniques of Erdas Imagine 9.1. Besides, CorelDRAW Graphics suite X4, Micrisoft word and excel 2007 has been used for calculating data and other purpose.

CHAPTER 04

DATA PROCESSING

The procedure of preparing land cover area (LCA) and land surface temperature (LST) map for analyzing temperature change due to urban development are described in this chapter.

Land sat Image of year 1989, 2000 and 2010 have been used to prepare the LC and LST map. The steps are given below.

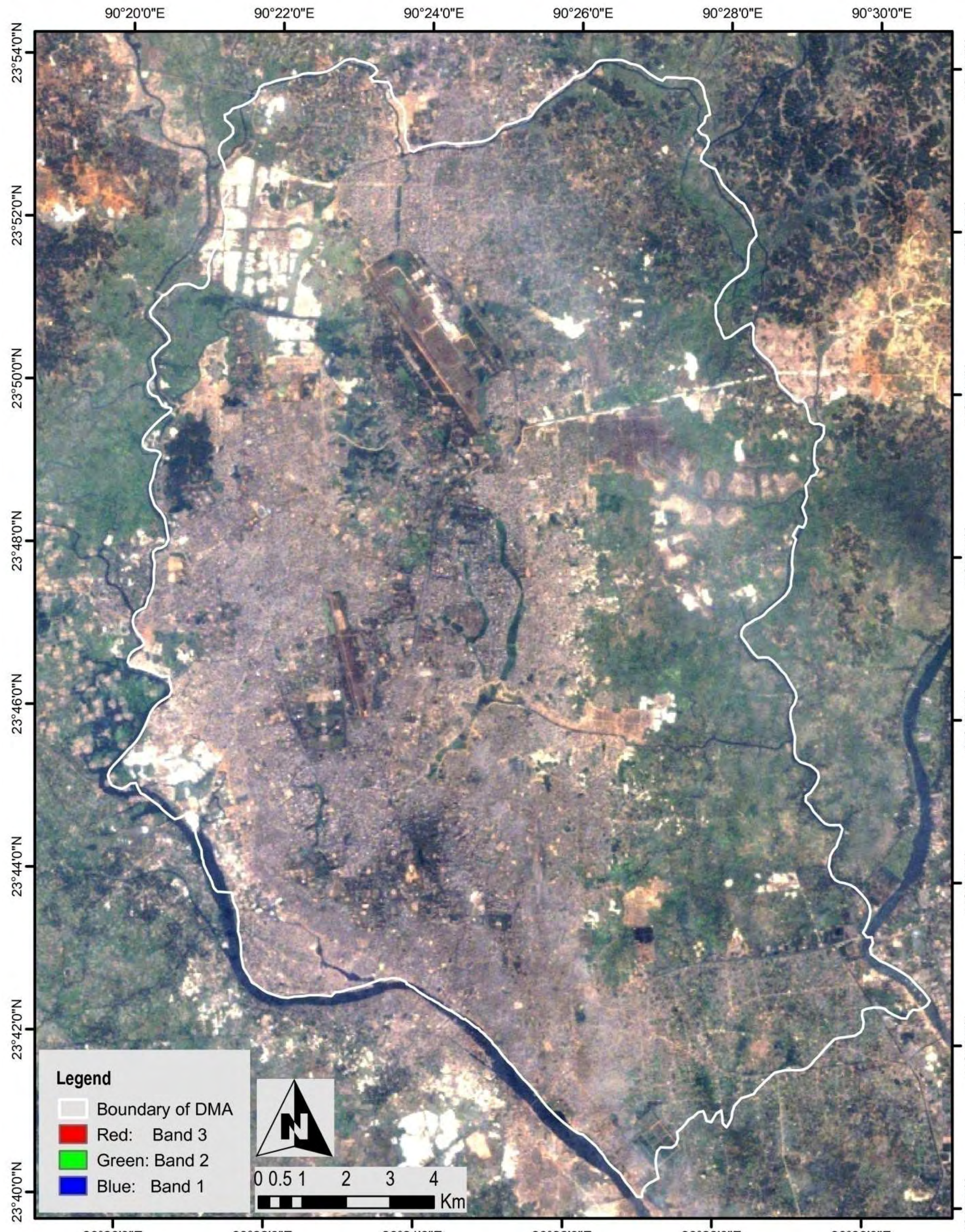
4.1 Land cover map preparation

To prepare LC map image enhancement is necessary tool to identify and select the interest area. Image can be enhanced in several ways such as Contrast Enhancement, Intensity/ hue/ saturation transformations,   Density slicing etc.

Landsat image also can be enhanced by generating composite band combination. Generation of composite band combination such as false color composite (FCC), true color composite, false natural color composite etc. are used for this research.

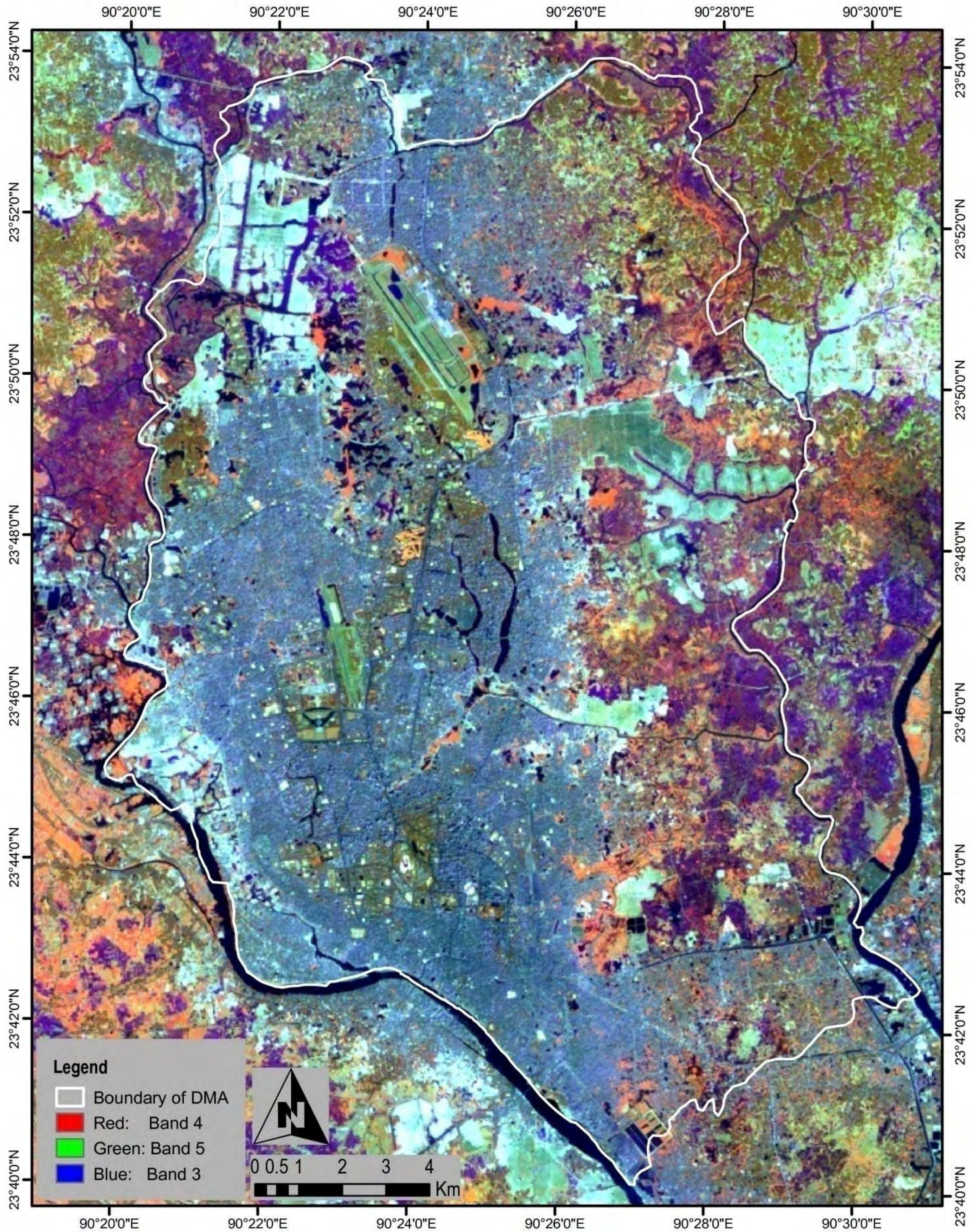
4.1.1 Composite band combination

Landsat TM/ETM+ image has several bands. Any of three (3) bands of the same sensor are formed an image that is called as false color composite (FCC) (NASA, 2008). Several composites of Landsat 5 TM images (Dhaka city, 2010) have been shown in the Figure 4.1 to Figure 4.5 using different band combination. RGB means basic three color read, green and blue and it has been used for band 4, 3 and 2 to make false color composite(FCC) which is shown in Figure 4.4. This FCC usually shows the urban area as blue, vegetation as read, water bodies as dark blue to red, soil without vegetation as white to brown. In the same way, true color composite shows the different land cover as its real color of the LCA. Trafficability composite (RGB= Band 6, 4 & 3) emphasis the traffic lane and built-up area as dark purple color shown in Figure 4.5. These band composite images are used to identify and select the interest area for building the signature of image classification. The FCC (RGB=B 4, 3 & 2) map of Dhaka city over different time period are shown in Figure 4.6. Figure draw the attention that red color cells represent the vegetation, dark



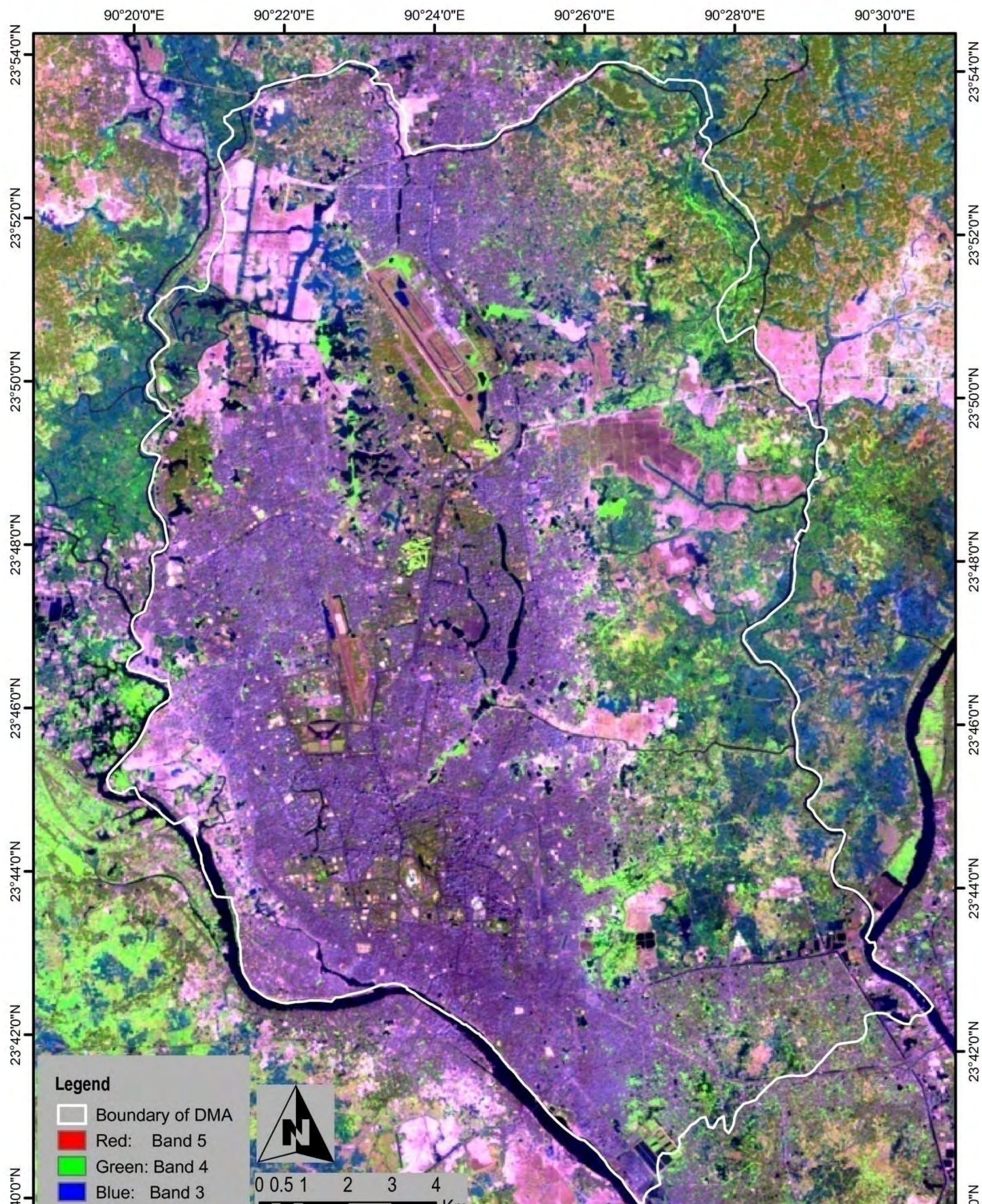
Source: Produced by Author

Figure 4.1: Composite Band Combination(False color composite, RGB= Band 321) of the Dhaka city, January 2010



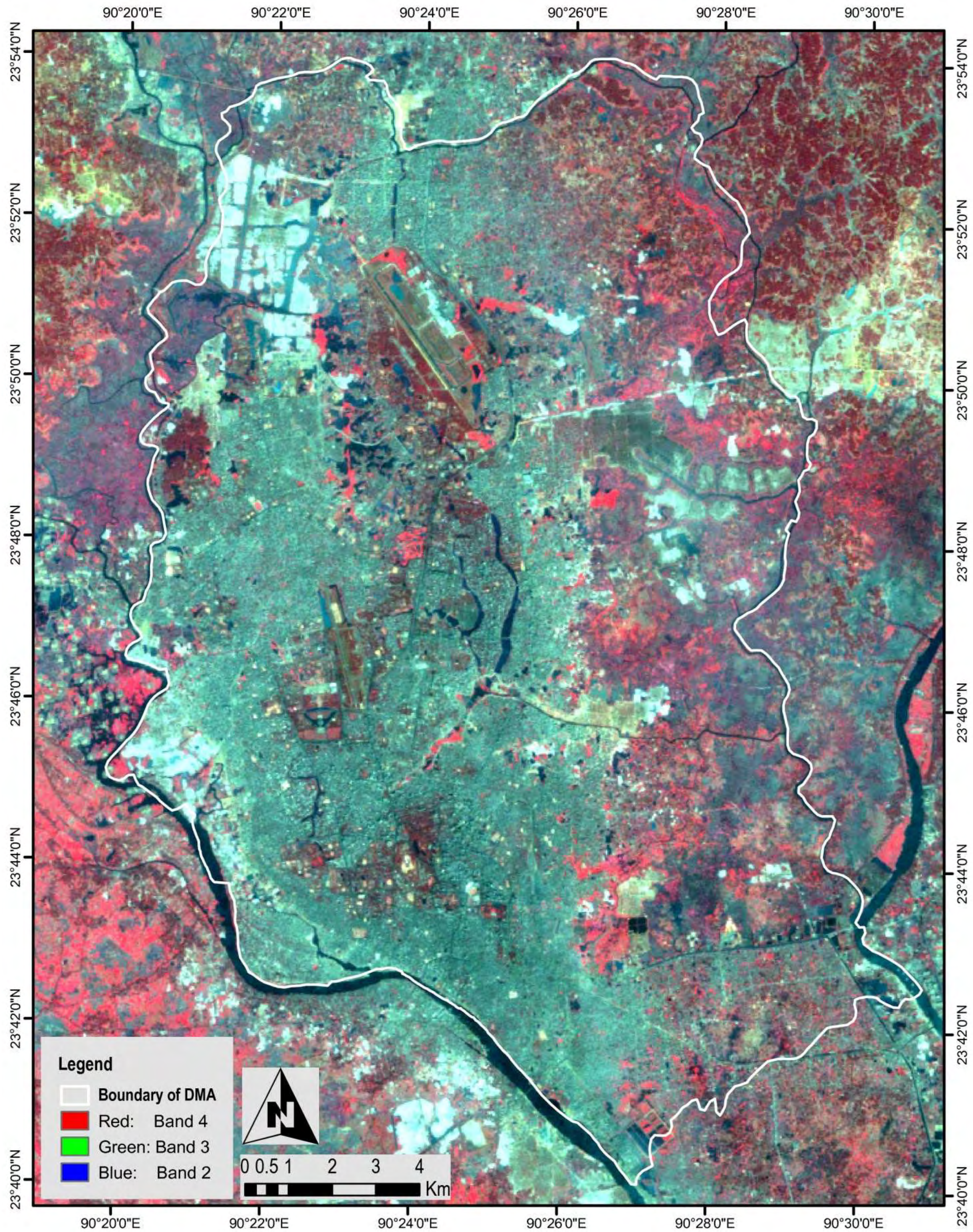
Source: Produced by Author

Figure 4.2: Composite Band Combination(False color composite, RGB= Band 453) of the Dhaka city, January 2010



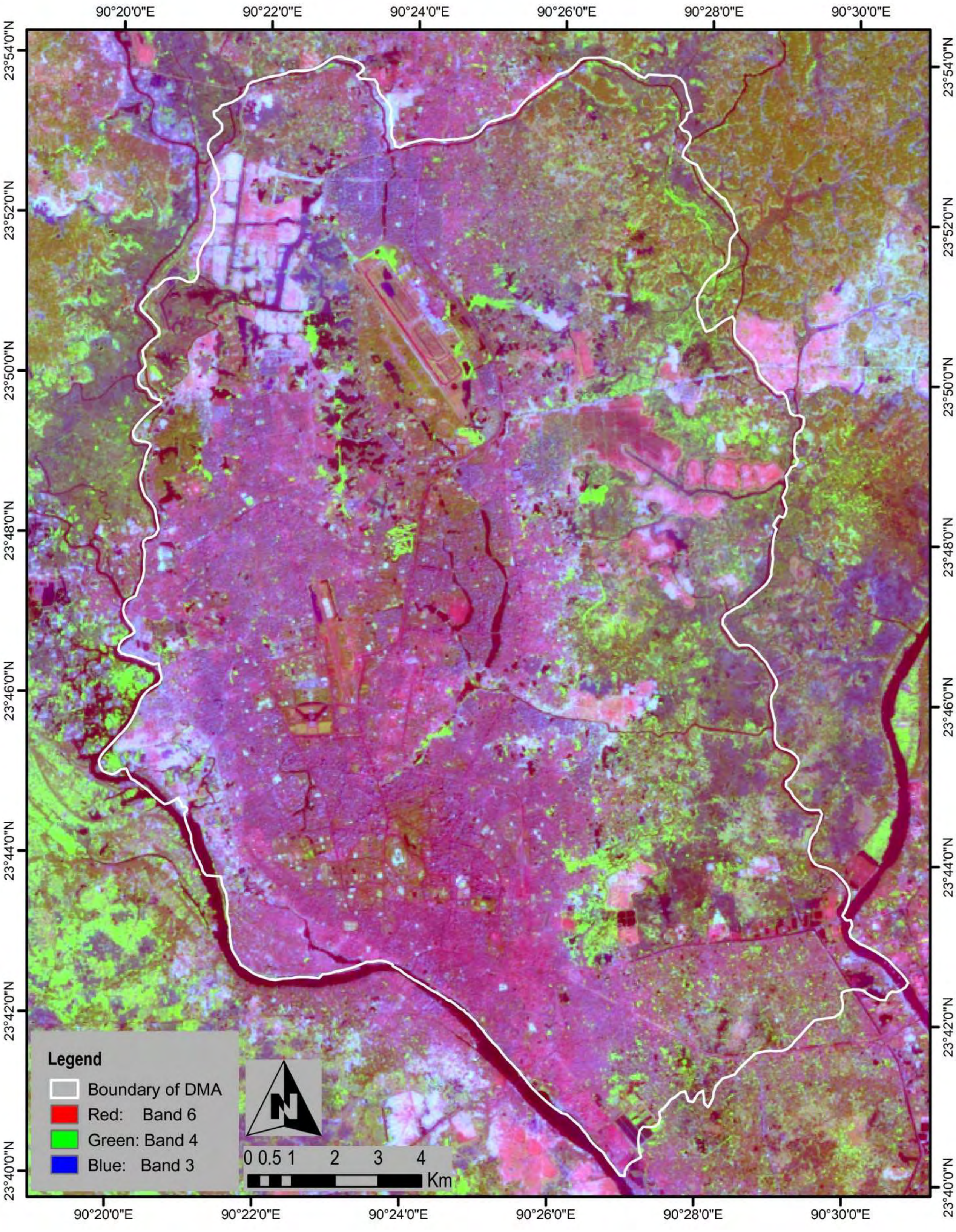
Source: Produced by Author

Figure 4.3: Composite Band Combination(False natural color composite, RGB= Band 543) of the Dhaka city, January 2010



Source: Produced by Author

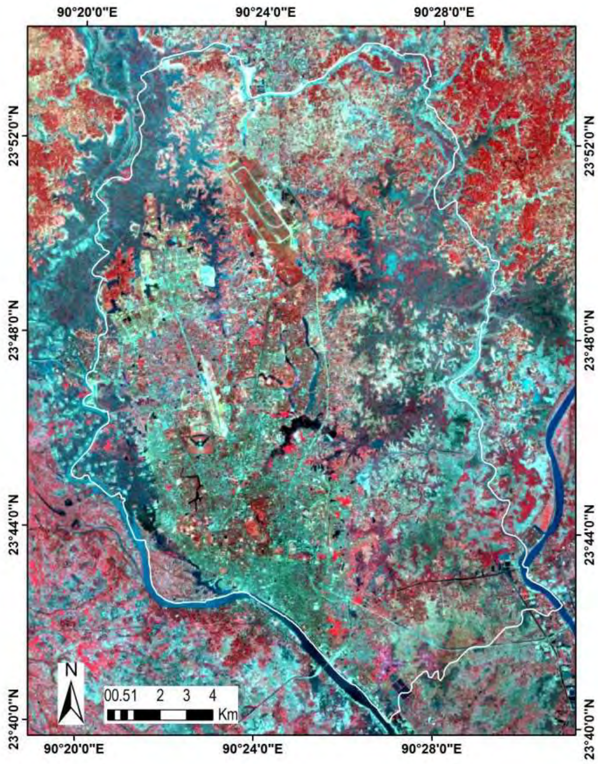
Figure 4.4: Composite Band Combination(False natural color composite, RGB= Band 432)of the Dhaka city, January 2010



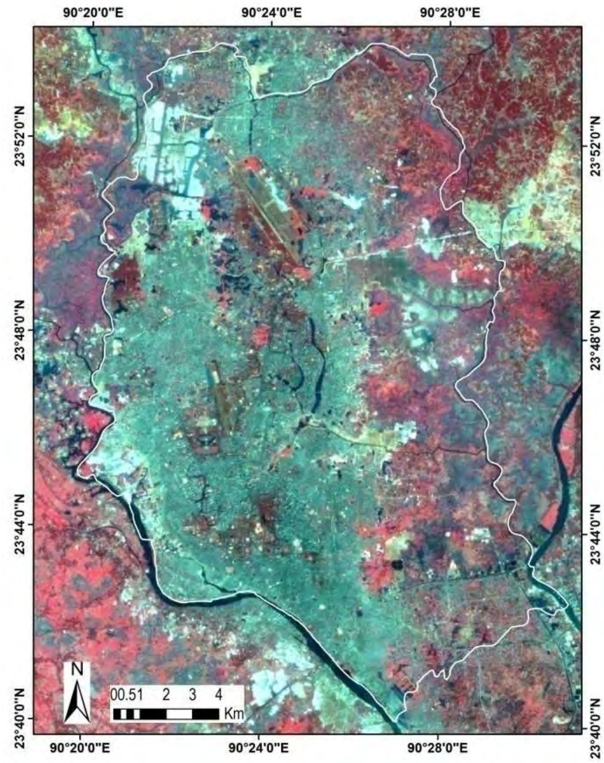
Source: Produced by Author

Figure 4.5: Composite Band Combination(Traficability composite, RGB= Band 643) of the Dhaka city, January 2010

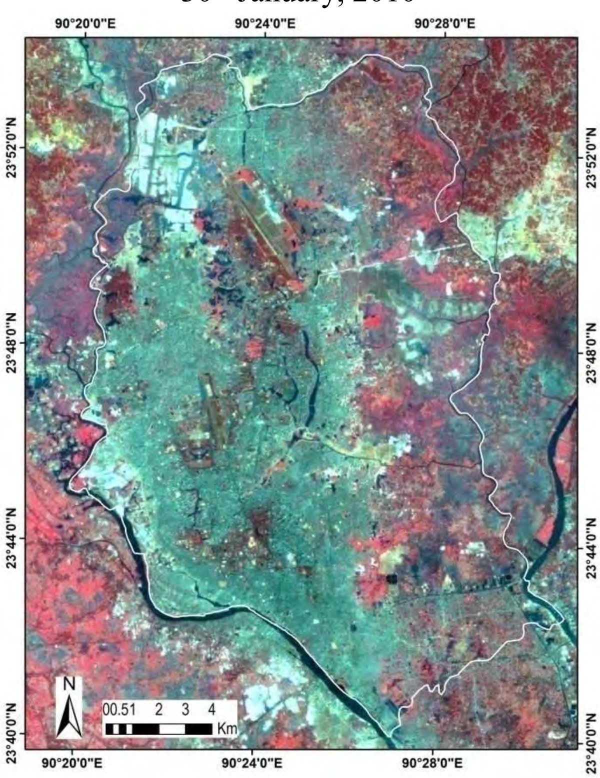
12th January, 1989



28th February, 2000



30th January, 2010



False Color Composite (RGB= Band 4, 3 & 2) image of Dhaka Metropolitan area(DMA) over different time period

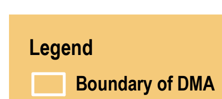
Different colors represent different Land cover types

Blue = urban area

Red = vegitation

White to Brown = soil without vegitation

Dark blue to Black = water



Source: Produced by Author

Fiqure 4.6: Landsat satellite images of Dhaka city, 1989 to 2010 blue to black represent water, brown to white represent Bare soil without vegetation. So, different LCA types can be separated by choosing color composite image. Color intensity of the composite image represents how much the probability of any LCA types.

4.1.2 Image classification

Image classification is a process of sorting pixels into a finite number of individual classes, or categories, of data based on their values. Image classification can be done by various operations such as image restoration, enhancement, image pre-processing, spatial filtration, pattern recognition etc. There are two basic techniques used in image classification: supervised and unsupervised classification. In this study, supervised classification technique has been used. Supervised classification is usually appropriate when user have selected training sites that can be verified with ground truth data, or when it can be identified distinct, homogeneous regions that represent each class. In supervised classification method user defines the known land cover and develop the cell/ spatial signature value (Signature values contain the DN value of each band of this image such as the reflectance value of the cell) for each LCA type for the whole image. The steps of this method are described in the following categories.

4.1.2.1 Building Signature

In this step the composite band images are used to digitize the known land covers so that the signature value can be collected. In this way, as more as possible known signature values have been collected for each land cover types based on reference data mentioned earlier. It is called signature development. For this research, 5 (five) types of land cover have been selected on the basis of their similar character shown in Table 4.1. For this 5(five) land cover type, A signature table is developed. From the signature table, lots of signature values are determined for each land cover types and a statistical mean value can also be derived for each land cover from this value. This is called combine signature or merge signature.

4.1.2.2 Evaluation of signature

While signature values are collected from the composite band image, there may be deviation or error. It can be evaluated from the signature mean graph or separability cell array shown in Figure 4.3 & Table 4.2. It is found from the figure that the signature value range of each land cover types

Table 4.1 Selected criteria for land cover area classification

Land cover area type	Criteria
Water	River, Permanent open water, pond, canal, lake, reservoir, permanent and seasonal wetland
Vegetation Type	Trees , agricultural land, grassy land, park and playfield etc.
Built-up Area	All type of infrastructure such as residential, commercial , industrial, road, village settlement etc.
Earth Fill or Sand	Constructions site , development land, earth filling or sand
Bare soil	low land, , marshy land, vacant land

is separated from others. From the combine signature mean graph it is found that each land cover type mean signature value is different from others. Though the difference of Land cover type signature mean value is closely for one band but in other band the difference is found high. For the image of 1989, built-up and vegetation mean signature difference value is low for band 5 but it is highly difference in band 4. So the signature of each land cover is collected correctly. From the signature separator table it is found that the average signature separability are 52.9, 59.3 and 51.7 for respetively year 1989, 2000 and 2010. It is acceptable for signature evaluation(Erdas, 2006).

4.1.2.3 Classify with Maximum likelihood of parametric rule

In this step the image is classified using developed signature. The supervised classification techniques are divided into two groups: non-parametric and parametric rules. These two groups can be divided into several sub groups. For this research, maximum likelihood of parametric rule is used for classification as it provides an estimated of overlap areas based on statistics. A parametric method of supervised classification is based on statistical parameters (e.g., mean and covariance matrix) of the pixels. Maximum likelihood classification considers not only the mean or average values in assigning classification, but also the variability of brightness values in each class. The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class.

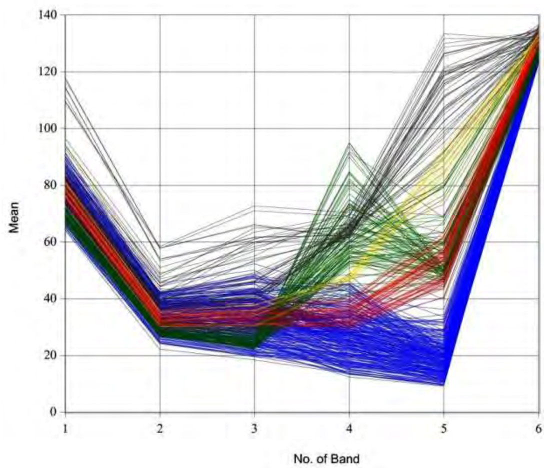
The classified images of different years are shown in the Figure 4.4, 4.5 and 4.6.

Table 4.2: Signature separability

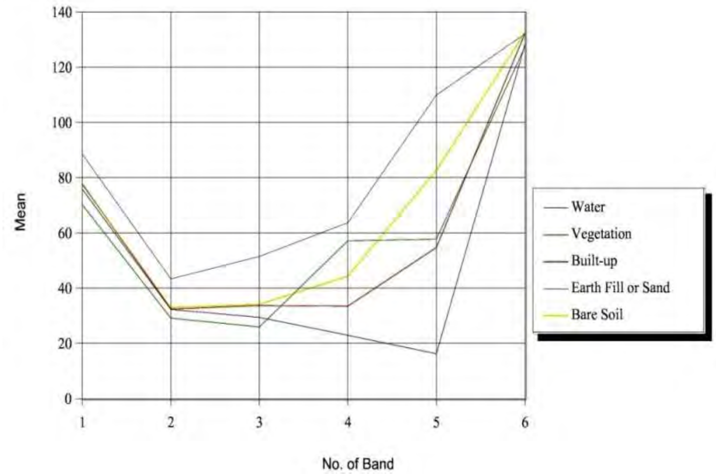
Signature separability, 1989					
Distance measure: Euclidean Distance Using layer: 123456 Taken 6 at a time Best Average separability : 50.9099 Combination: 123456					
Signature name	**1**	**2**	**3**	**4**	**5**
Water **1**	0	54.2325	40.375	105.934	70.0947
Vegetation **2**	54.2325	0	26.8029	63.1005	30.8057
Built-up **3**	40.375	26.8029	0	67.1667	29.9777
Earth Fill or Sand **4**	105.934	63.1005	67.1661	0	40.6097
Bare Soil **5**	70.0947	30.8057	29.9777	40.6097	0

Signature separability, 2000					
Distance measure: Euclidean Distance Using layer: 123456 Taken 6 at a time Best Average separability : 59.3428 Combination: 123456					
Signature name	**1**	**2**	**3**	**4**	**5**
Water **1**	0	66.7079	116.9330	51.5792	53.8909
Vegetation **2**	66.7079	0	79.1016	42.7939	25.6888
Built-up **3**	116.9330	73.1016	0	65.7506	70.9993
Earth Fill or Sand **4**	51.5792	42.7939	65.7503	0	19.9831
Bare Soil **5**	53.8909	25.688	70.9993	19.9831	0

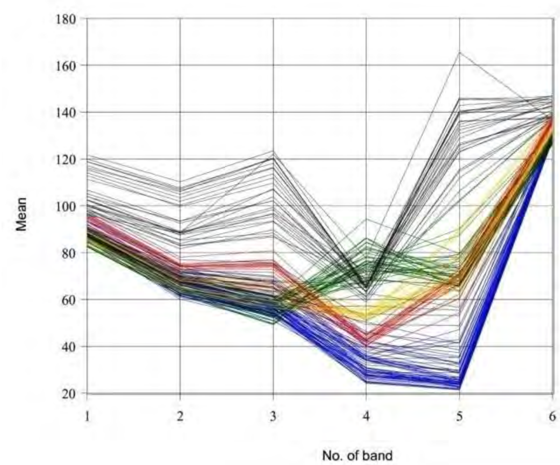
Signature separability, 2010					
Distance measure: Euclidean Distance Using layer: 123456 Taken 6 at a time Best Average separability : 51.7383 Combination: 123456					
Signature name	**1**	**2**	**3**	**4**	**5**
Water **1**	0	50.1513	101.8040	64.8479	32.0401
Vegetation **2**	50.1513	0	64.8412	29.2218	27.7009
Built-up **3**	101.8040	64.8412	0	42.9638	70.3109
Earth Fill or Sand **4**	64.8479	29.2218	42.9638	0	33.5002
Bare Soil **5**	32.0401	27.7009	70.3109	33.5002	0



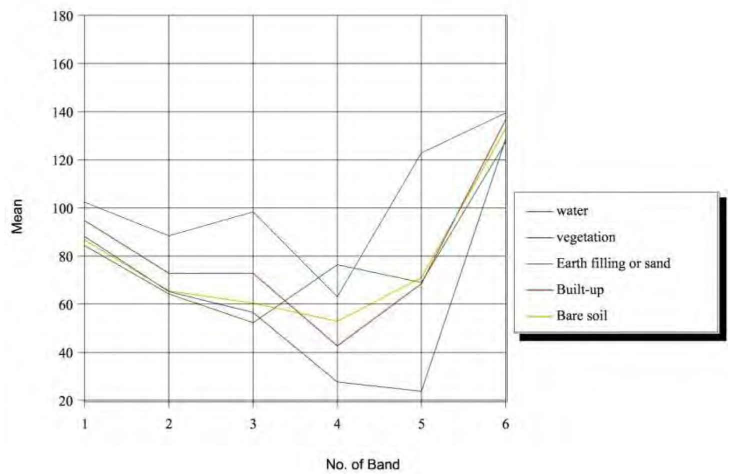
Signature mean graph (1989)



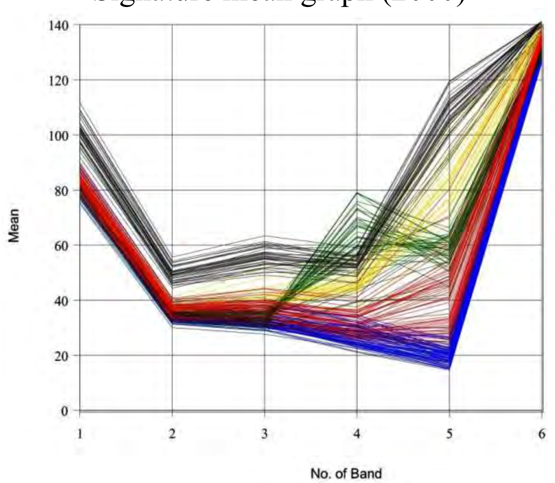
Combine Signature mean graph (1989)



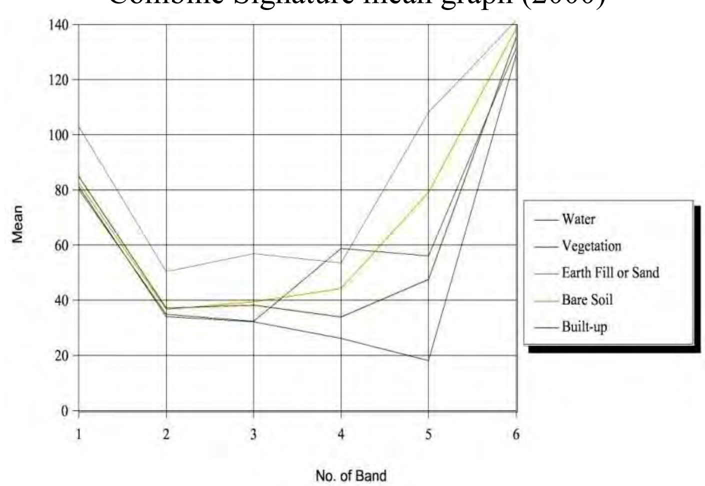
Signature mean graph (2000)



Combine Signature mean graph (2000)



Signature mean graph (2010)



Combine Signature mean (2010)

Fiqure 4.7: Signature mean graph according to different band

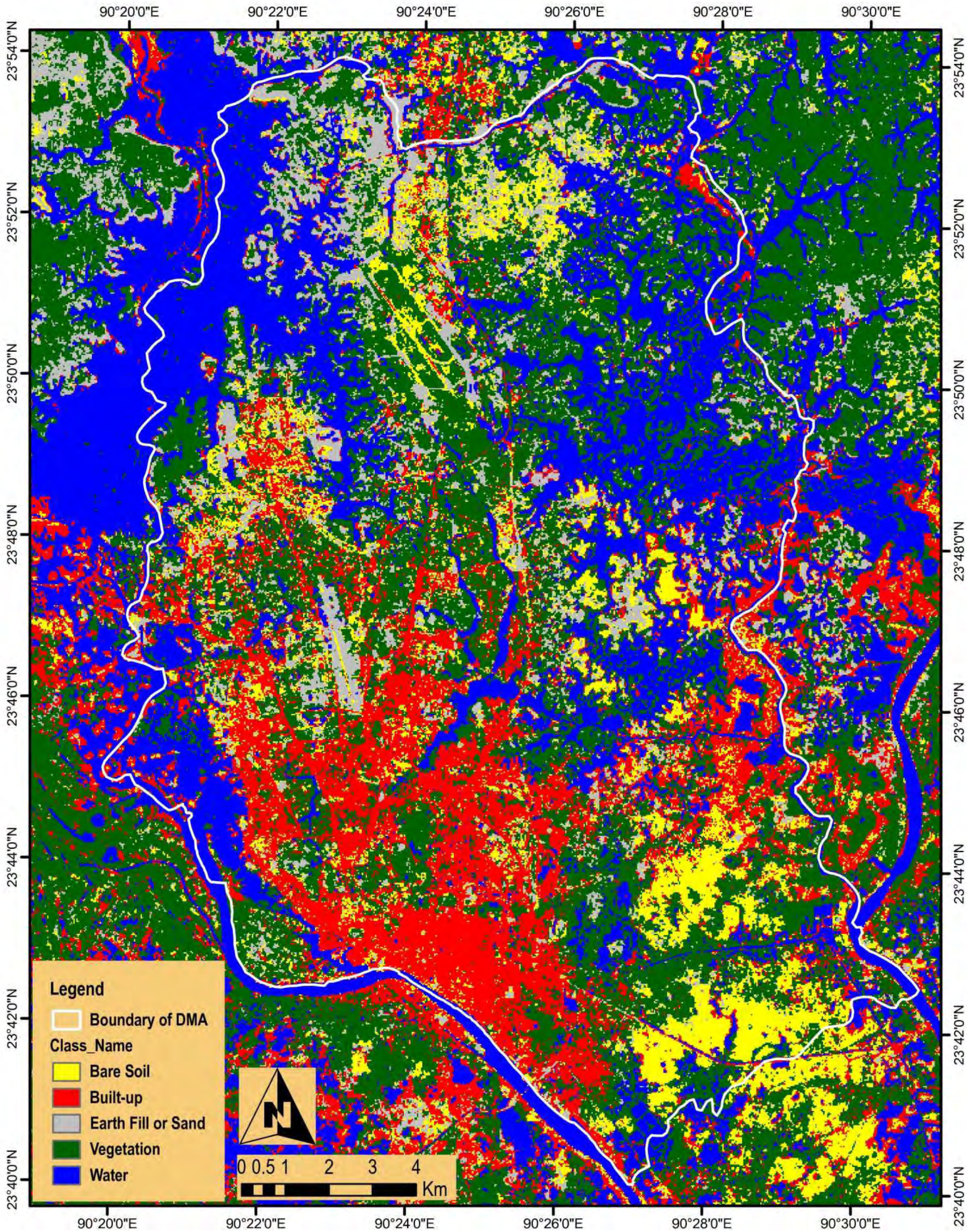


Figure 4.8: Land Cover Map of Dhaka Metropolitan Area(DMA), 12th January 1989

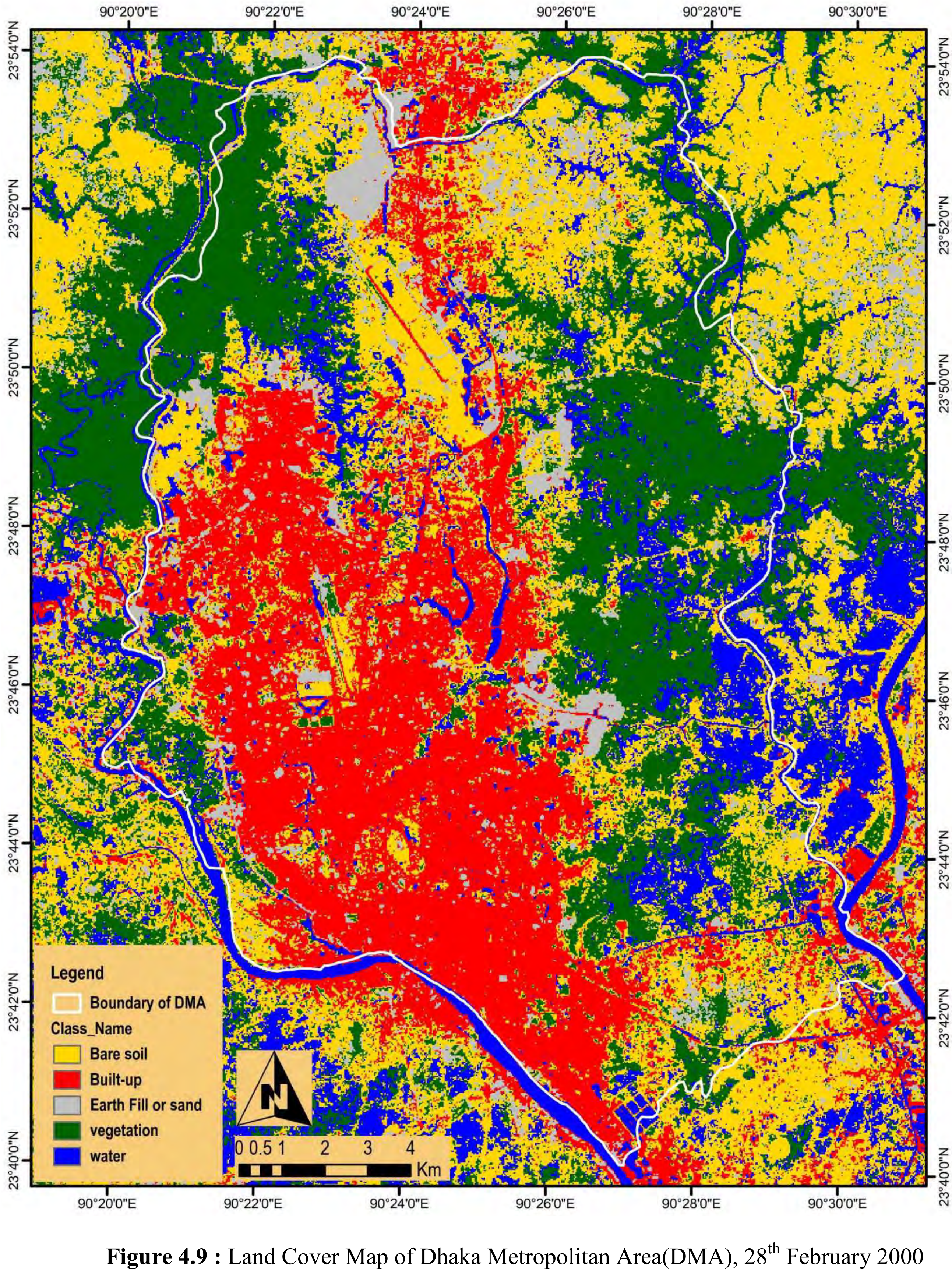


Figure 4.9 : Land Cover Map of Dhaka Metropolitan Area(DMA), 28th February 2000

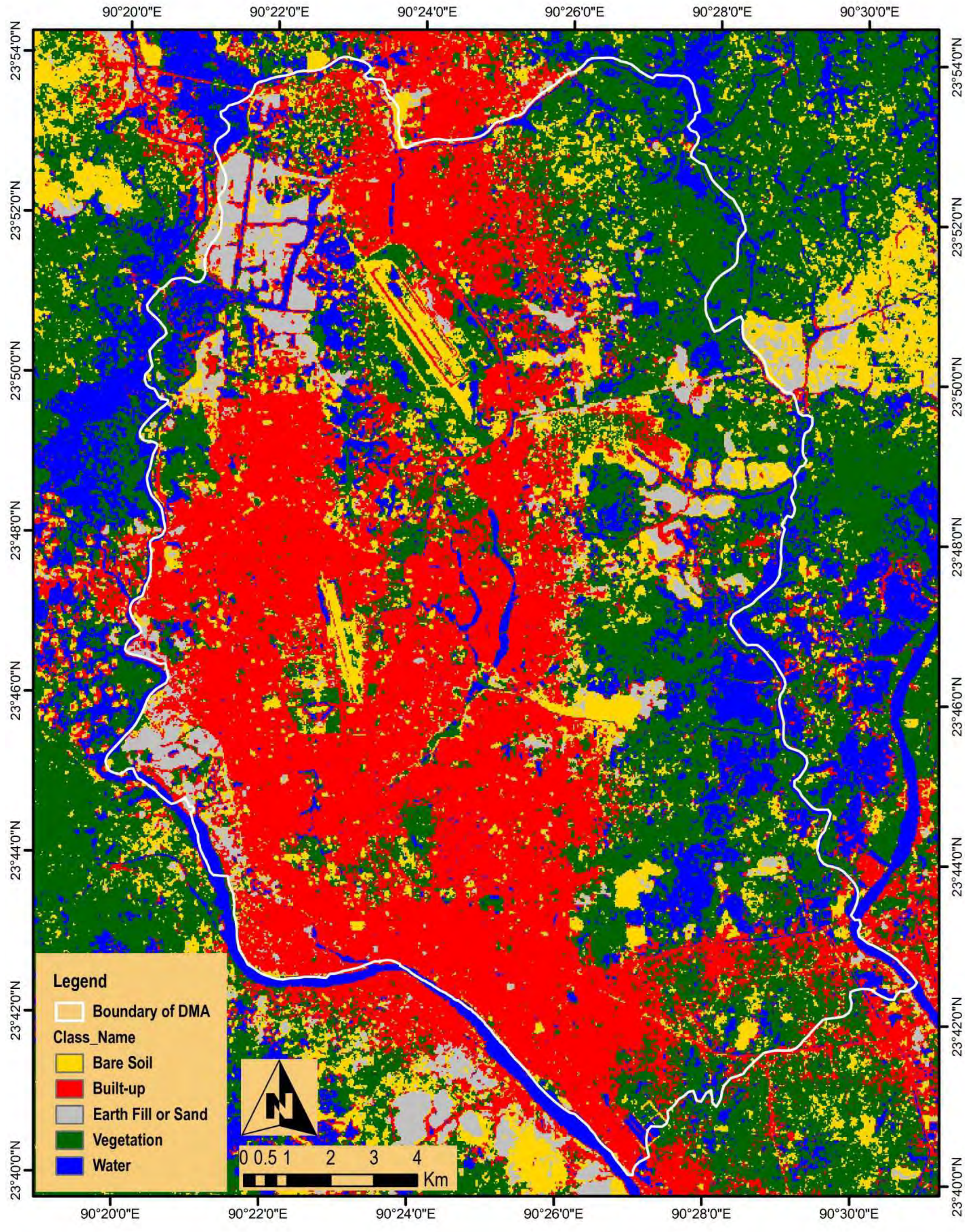


Figure 4.10 : Land Cover Map of Dhaka Metropolitan Area(DMA),30th January 2010

4.1.2.4 Error estimation

The map accuracy is derived from the signature error matrix on the base of reference data. The map accuracy is given in the Table 4.2. From the table it is found that the selected signatures are

Table 4.3: Signature Error estimation

Year 1989						
Classified Data	Reference Data					
	Water (%)	Vegetation (%)	Earth fill (%)	Built-up (%)	Bare soil (%)	Row Total
Water	99.91	0.03	0.00	0.00	0.00	28618
Vegetation	0.06	98.64	0.00	0.00	2.68	5981
Built-up	0.02	0.00	99.74	0.00	0.85	3411
Earth Fill	0.00	1.33	0.00	98.71	0.73	470
Bare soil	0.01	0.00	0.26	1.29	95.73	801
Column Total	28641	6023	3408	389	820	39281
Year 2000						
Classified Data	Reference Data					
	Water (%)	Vegetation (%)	Earth fill (%)	Built-up (%)	Bare soil (%)	Row Total
Water	97.13	0.00	0.00	0.01	0.00	6829
Vegetation	0.16	98.77	0.00	0.00	0.38	10927
Earth fill	0.00	0.31	100.00	0.00	0.00	1941
Built-up	0.46	0.00	0.00	97.70	0.44	10924
Bare soil	2.26	0.93	0.00	2.29	99.17	6996
Column Total	7030	11027	1907	11119	6534	37617
Year 2010						
Classified Data	Reference Data					
	Water (%)	Vegetation (%)	Earth fill (%)	Built-up (%)	Bare soil (%)	Row Total
Water	99.66	0.00	0.00	0.00	0.29	11593
Vegetation	0.07	98.76	0.00	0.18	0.40	3716
Earth fill	0.00	0.00	99.56	0.00	0.18	1584
Built-up	0.00	1.24	0.44	99.82	0.16	1181
Bare soil	0.28	0.00	0.00	0.00	98.97	7249
Column Total	11612	3723	1578	1118	7292	25323
Map accuracy (%)						
1989		**2000**		**2010**		
99.60%		98.28%		99.32%		

not overlapped with other signature. At least 95% of the each class data are accurate for all year. The overall accuracy is about 99.60% for 1989, 98.28% for 2000 and 99.32% for 2010.

4.2 Land surface temperature (LST) map preparation

The classified satellite images are converted into land surface temperature (LST) using the calibration of spectral radiance of remote sensing. Following sub-steps are adopted:

4.2.1 Conversion of the image digital number (DN) to spectral radiance

Landsat TM/ETM+ image pixels are converted to units of absolute radiance using equation no 5 and 6 (NASA, 2008). For conversion of Image digital number (DN) to spectral radiance (L_λ), some data is needed to calculate Spectral radiance (L_λ) form the equation 5 and 6 which is shown in Table 4.4.

Table 4.4: Conversion of the image digital number (DN) values to spectral radiance

Value	Year		
	1989(TM)	2000 (ETM+)	2010 (TM)
$QCAL_{MIN}$	1	0	1
$QCAL_{MAX}$	255	255	255
QCAL	Image Digital Number	Image Digital Number	Image Digital Number
L_{MAX}	15.303	17.040	15.303
L_{MIN}	1.238	0.000	1.238

Source: Meta files of Landsat TM/ETM+ Image, USGS.

4.2.2 Spectral radiance to black body temperature

Satellite Brightness temperature or black body temperature is derived from spectral radiance by the equation no 7 which is mentioned in the chapter 2 (NASA, 2008; Zhang *et al*, 2008).

4.2.3 Emissivity correction to calculate Land Surface Temperature (LST)

Emissivity is not same for all LCA. So emissivity (ε) correction is needed to calculate LST. The LST is derived from the equation no 8 which is discussed early in the chapter 02. For this study, a simple grouping for LCA, that is, ε = 0.95 for vegetative areas and ε = 0.92 for non-vegetative areas (Weng, 2001; Nichol at *al*, 1994) are used to calculate LST. Derived LST map of different years are shown in Figure 4.7, 4.8 and 4.9. In the below the table show the statistical information of LST over the period of 1989 to 2010 is shown in Table 4.5.

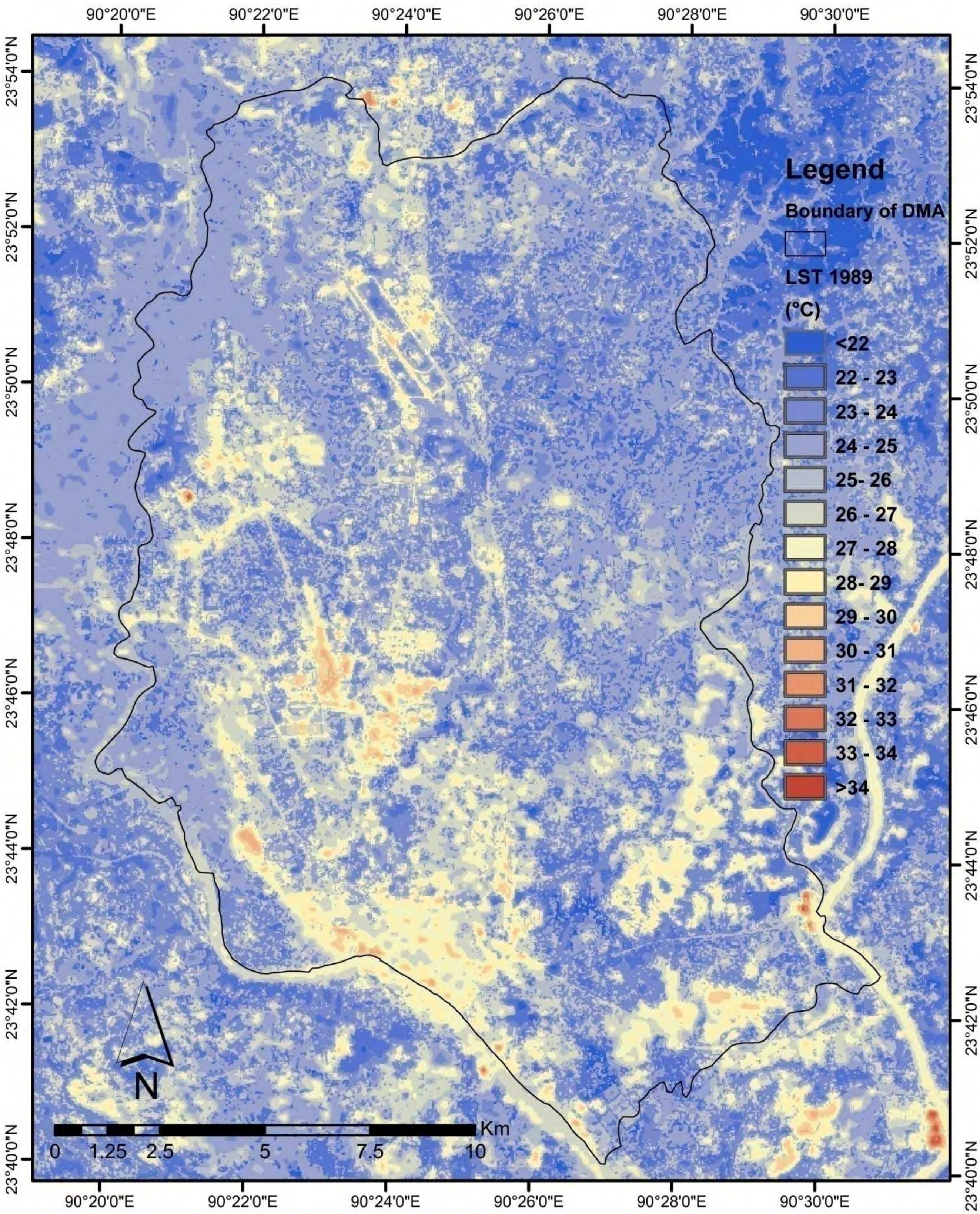


Figure 4.11: Land Surface Temperature map of DMA, 12th January 1989

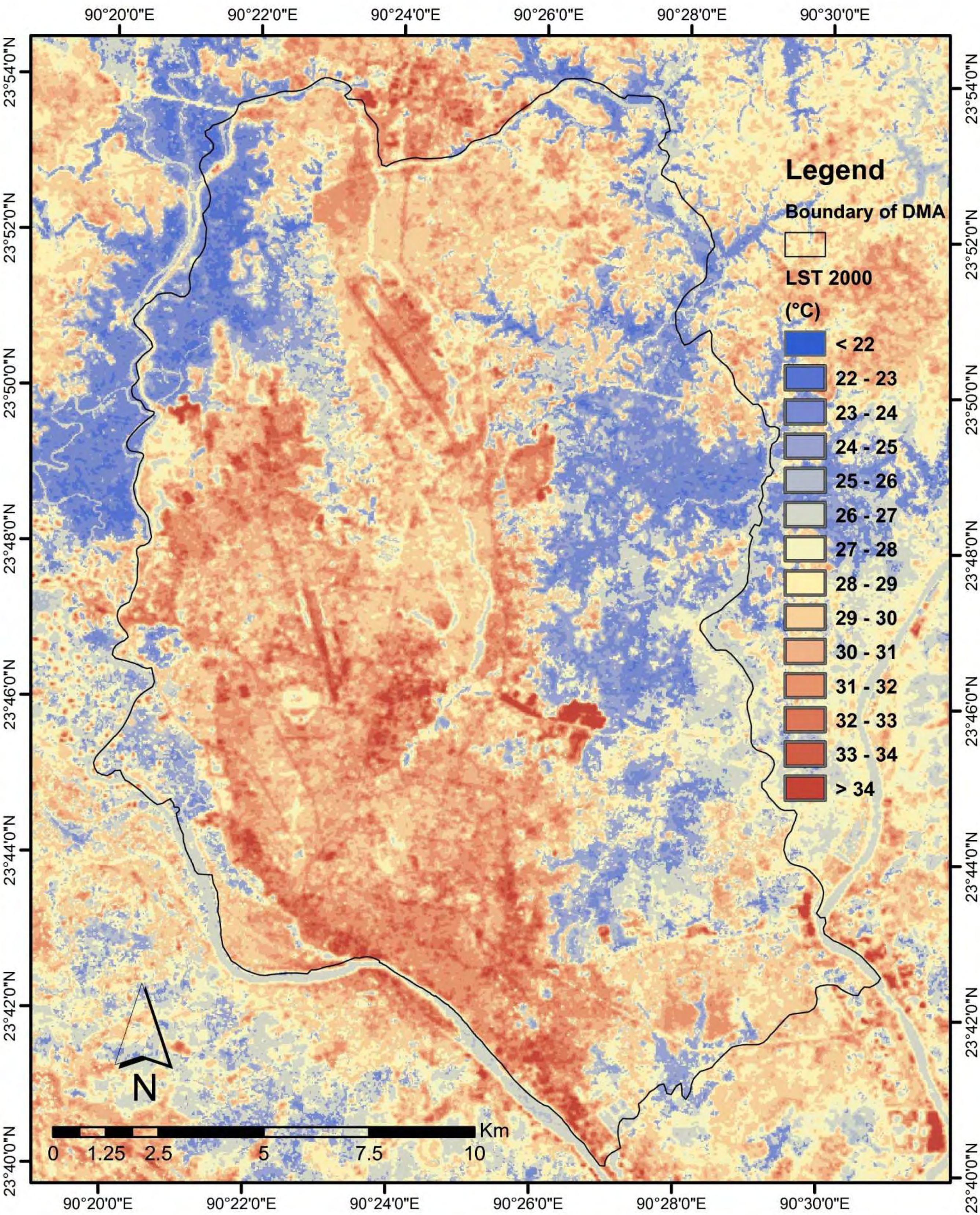


Figure 4.12: Land Surface Temperature map of DMA, 28th February 2000

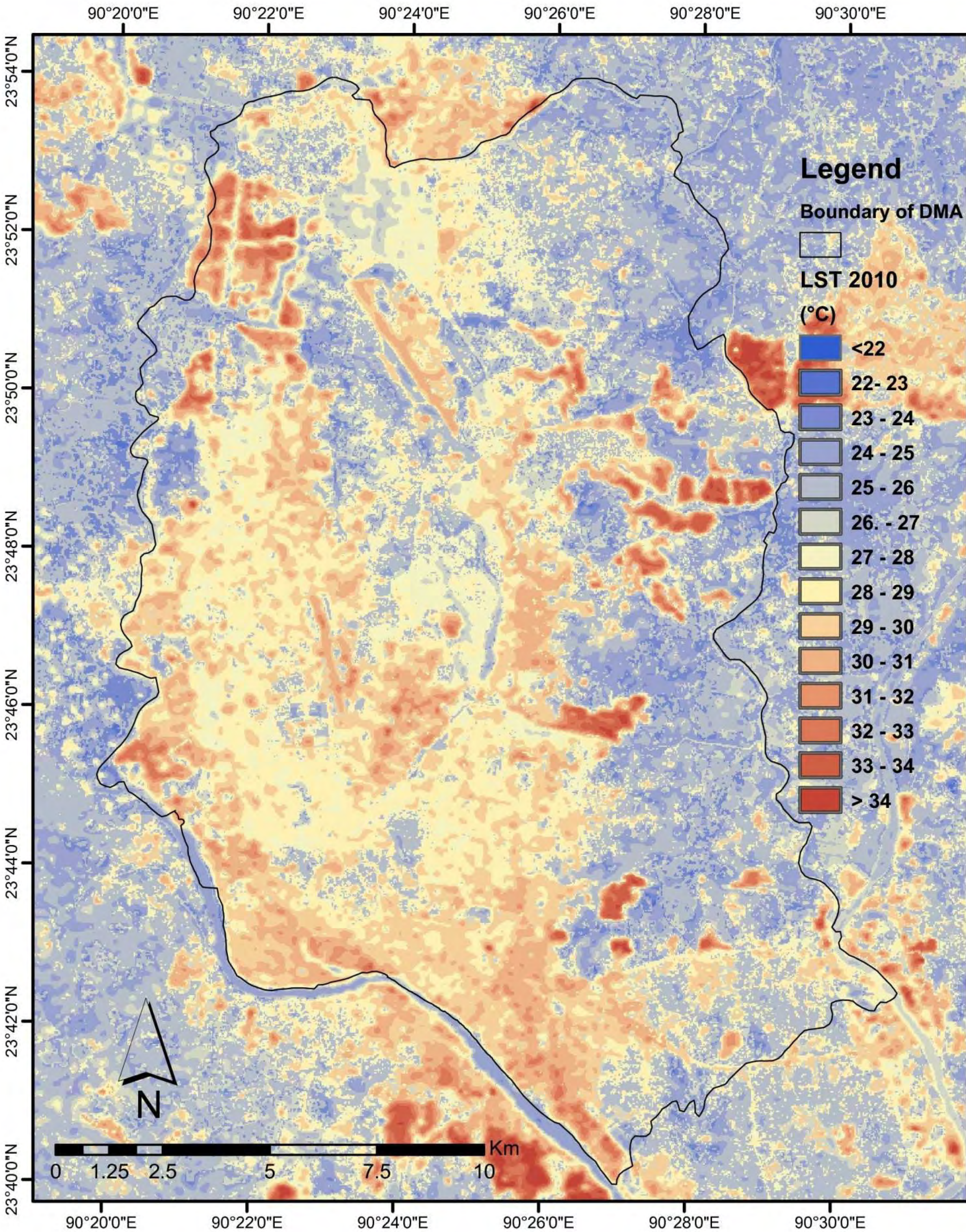


Figure 4.13: Land Surface Temperature map of DMA, 30th January 2010

Table 4.5: Statistical information of LST

Year	Minimum(°C)	Maximum(°C)	Average(°C)	Standard deviation
1989	20.42	33.97	24.74	1.671
2000	22.02	39.47	28.26	2.441
2010	21.82	36.13	26.81	2.139

The maximum LST is 39.47 °C in the year 2000 where lowest LST (20.42°C) is found in 1989. the average LST of this three periods are 24.74, 28.26 and 26.81 which are not abrupt.

4.3 NDVI and NDBI map preparation

LST may be varied for the same LC type for existing of the vegetation as well as impervious land. Density of vegetation and impervious area are derived in following steps.

4.3.1 Normalized Difference Vegetation Index (NDVI) map

The density of vegetated area can be depicted using Normalized Difference vegetation index (NDVI). NDVI of different years are derived using the equation no 1 from the Landsat TM/ETM+ images which is discussed earlier in the chapter 2.

Figure 4.10, 4.11 & 4.12 represents the NDVI of different years. The index value of three different years is shown in the Table 4.6. It is found from the table that the range of the index value is different. In the year 1989 the highest value of NDVI is 0.65. Whereas the lowest NDVI value (0.36) is found in year of 2000. Highest index value with positive mean 0.155 means the density of the vegetation land is more in 1989(Shown in Figure 4.10). On the other hand, in 2000 lowest index value with negative mean -0.087 means low density of vegetation land and scattered (shown in Figure 4.11). In 2010, positive mean 0.057 with low standard deviation 0.092 means also low density of vegetation land but distributed (shown in Figure 4.12).

Table 4.6: The range, mean and standard deviation of NDVI value

Year	Range of NDVI	Mean	Standard deviation
1989	-0.63 to 0.65	0.155	0.139
2000	-0.41 to 0.36	-0.087	0.131
2010	-0.27 to 0.50	0.057	0.092

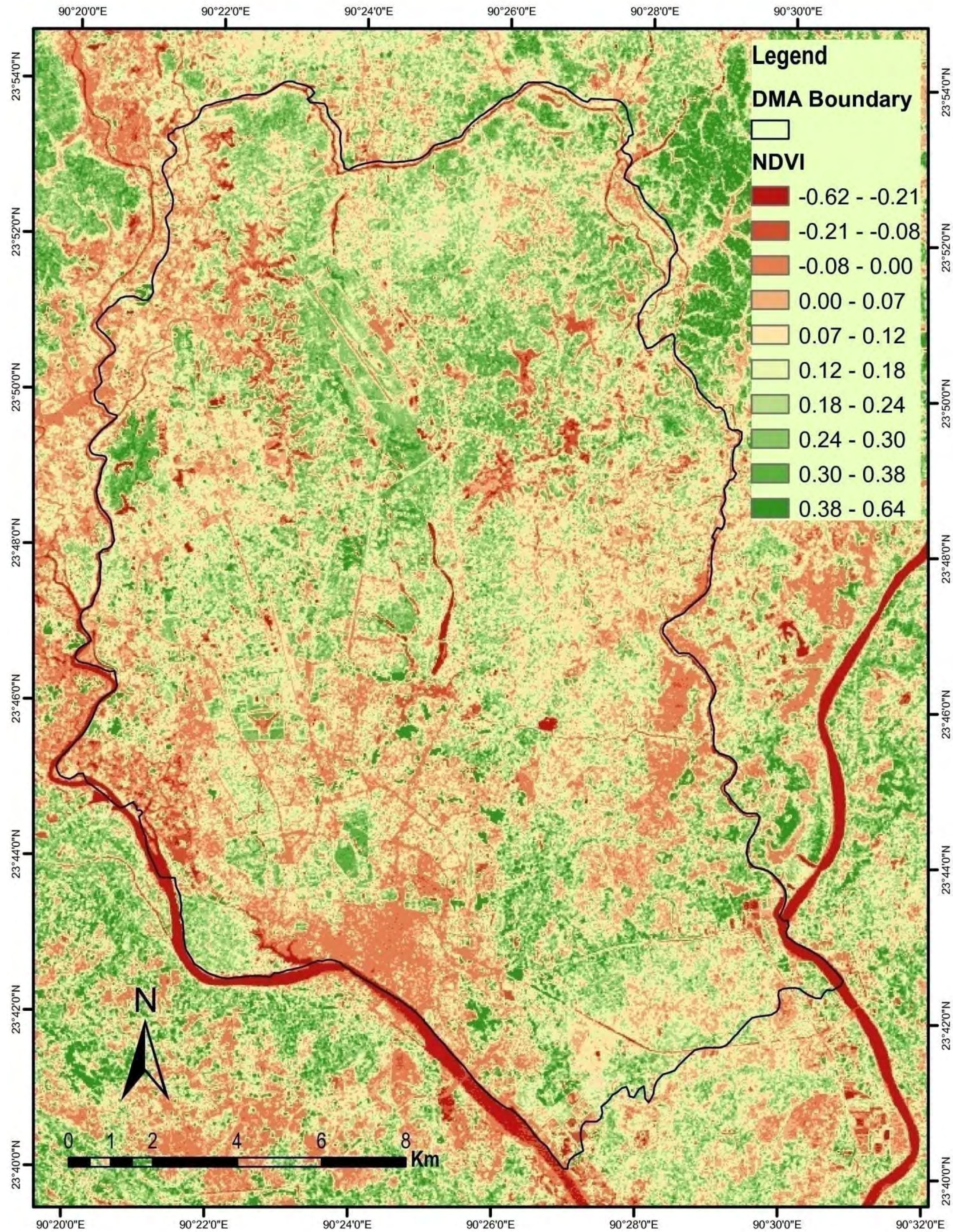


Figure 4.14: Normalized Difference Vegetation Index (NDVI), 12th January 1989

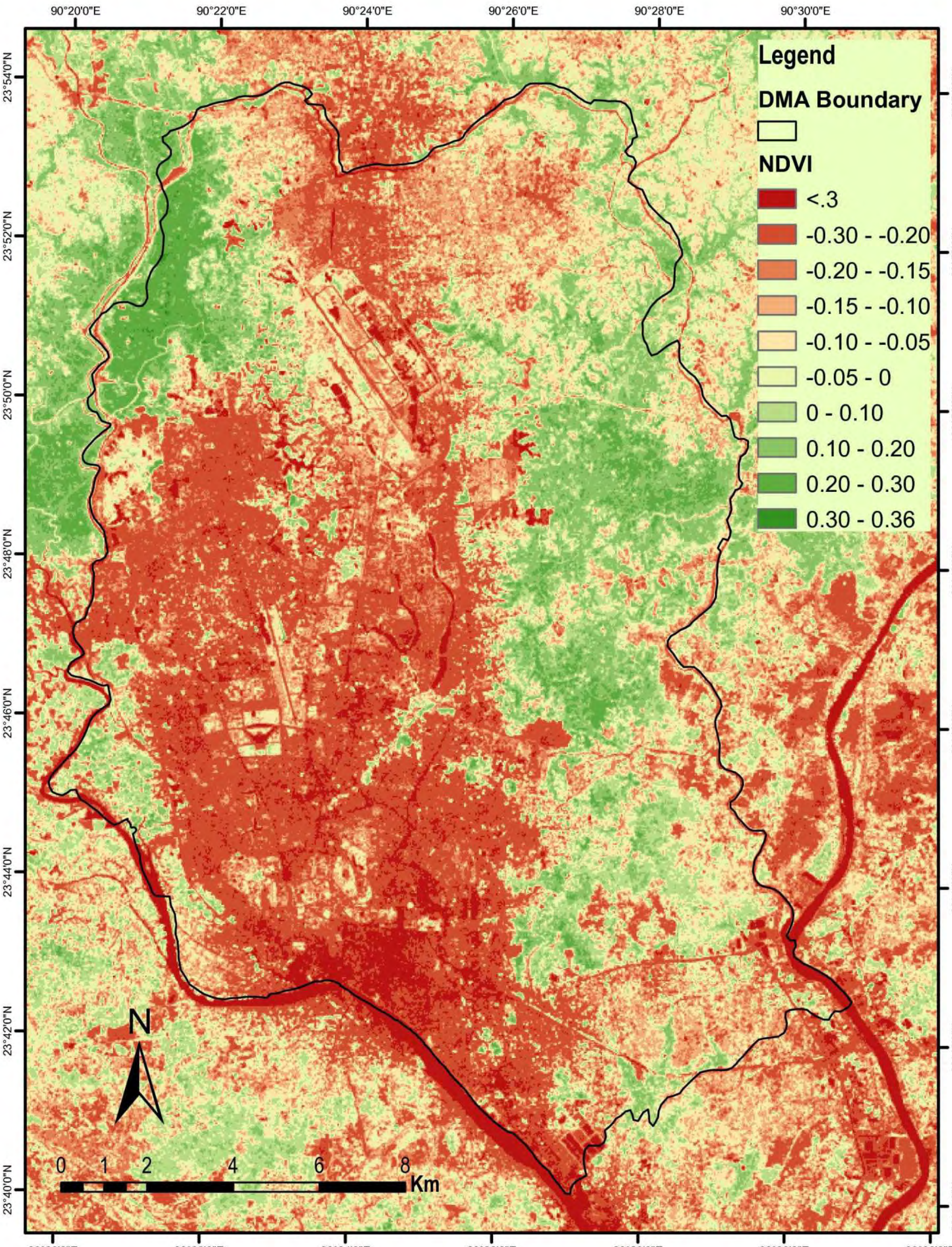


Figure 4.15: Normalized Difference Vegetation Index (NDVI), 28th February 2000

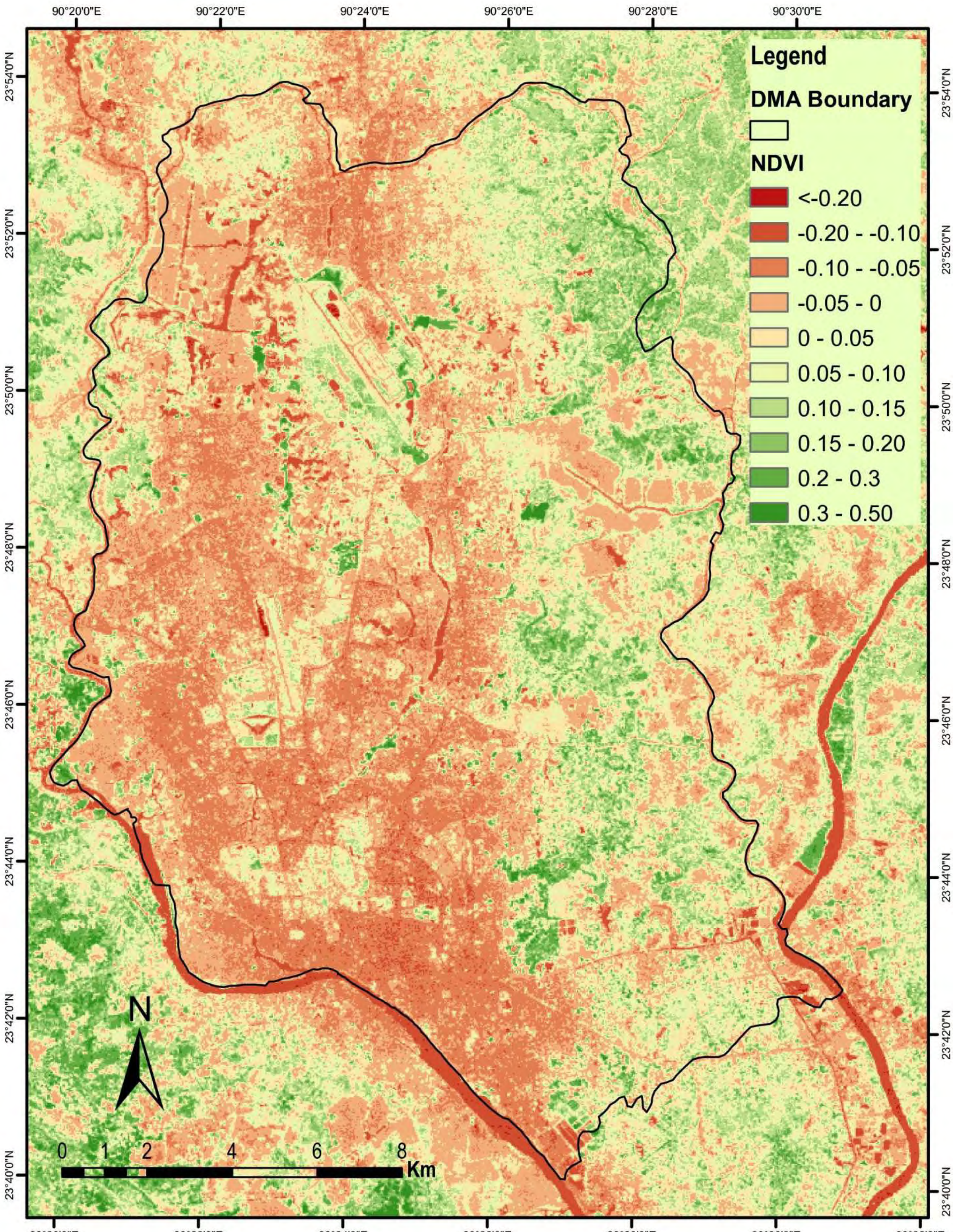


Figure 4.16: Normalized Difference Vegetation Index (NDVI), 30th January 2010

4.3.2 Normalized Difference Built-up Index (NDBI) map

Built-up area as well as impervious surface can be measured by Normalized Difference Built-up Index (NDBI). NDBI of different years are derived using the equation no 2 form the Landsat TM/ETM+ images.

From the figure 4.13, 4.14 and 4.15 are represent the NDBI of different year. The statistical information of NDBI is summarized in the Table 4.7. Compare to ground truth data of different year to the NDBI image; it is found that about 0.1 to 0.3 value of the NDBI represent the built-up area. Greater than 0.3 values represents category of earth fill or sand and bare soil land cover. Form the table and figure it is also found that the mean value of year 2000, NDBI is higher (0.112) than others and its standard deviation is 0.122. Greater positive mean indicates that the amounts of bare soil, earth fill or sand and built-up area are more in this year.

Table 4.7: The range, mean and standard deviation of NDBI value

Year	Range of NDBI	Mean	Standard deviation
1989	-0.698 to 0.554	0.069	0.143
2000	-0.459 to 0.502	0.112	0.122
2010	-0.488 to 0.588	0.087	0.137

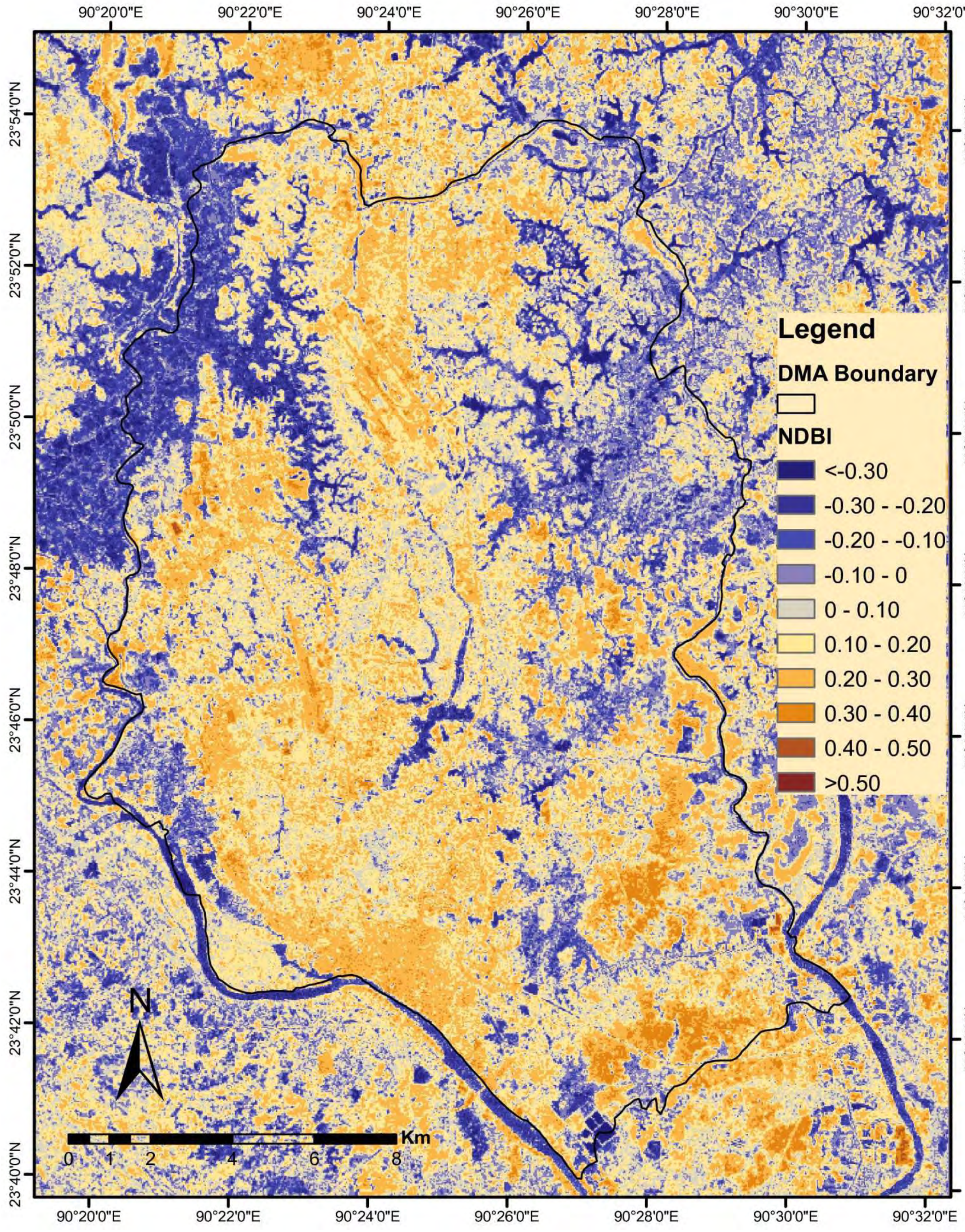


Figure 4.17: Normalized Difference Built-up Area (NDBI), 12th January 1989

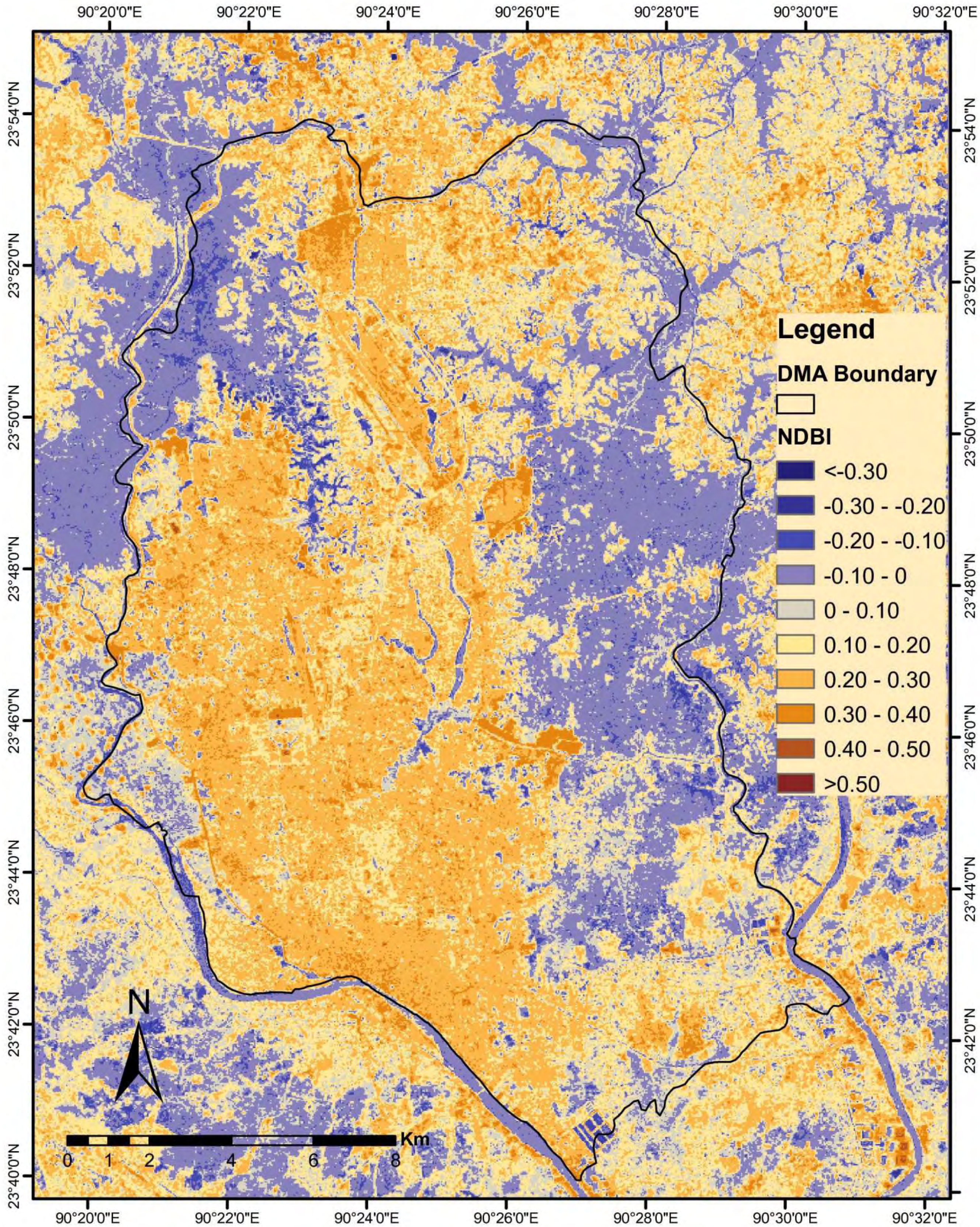


Figure 4.18: Normalized Difference Built-up Area (NDBI), 28th February 2000

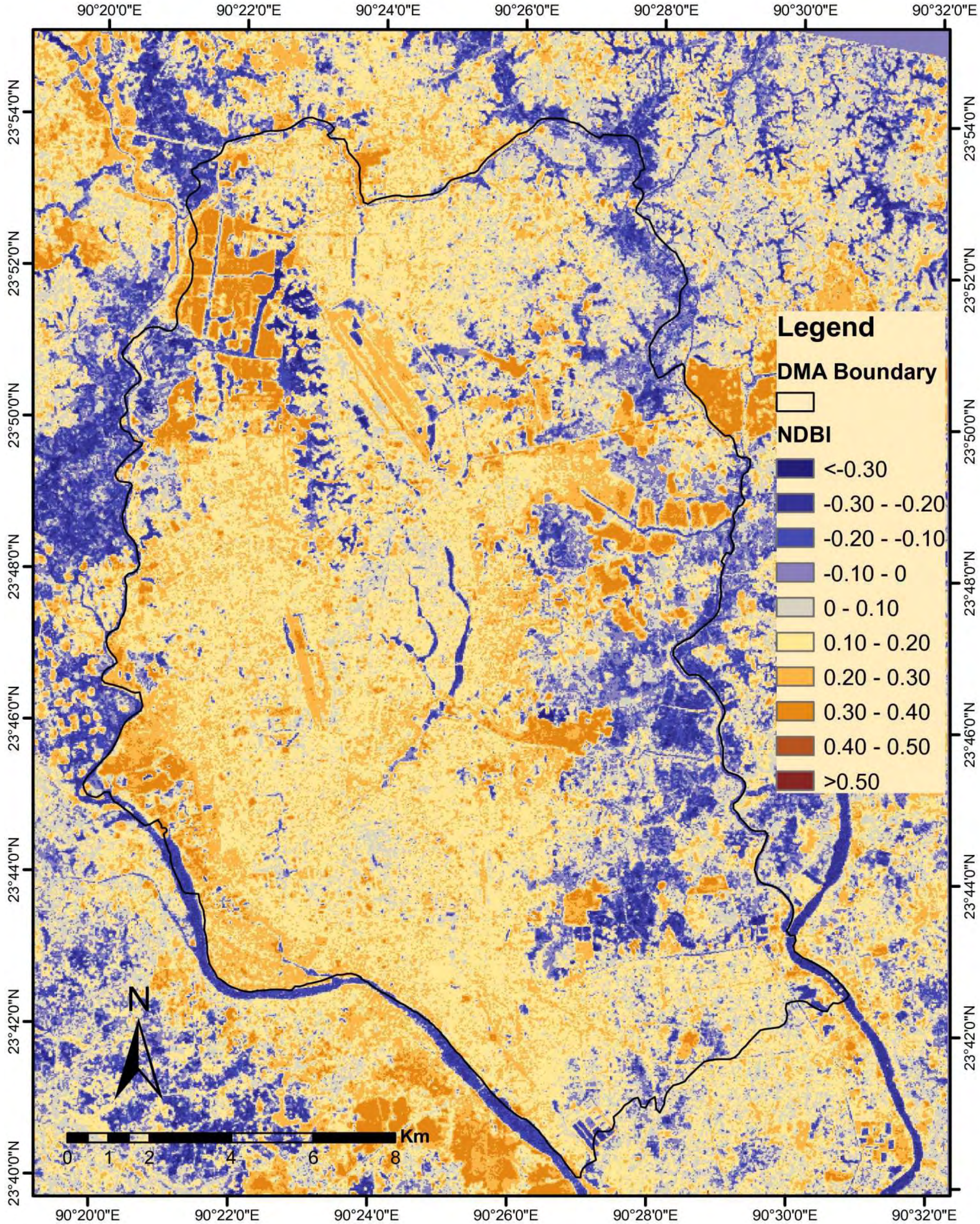


Figure 4.19: Normalized Difference Built-up Area (NDBI),30th January 2010

CHAPTER 05

SPATIAL DATA ANALYSIS

The land cover area (LCA) of Dhaka Metropolitan Area (DMA) has been changed day by day because of rapid growth of urbanization. How land surface temperatures (LST) have been changed due to the change of LCA of Dhaka metro area (DMA) over the different period of time is described in this chapter.

5.1 Land cover area (LCA) change

In the earlier the land cover area (LCA) classification map has been prepared over different period using the method of supervised classification. In the Table 5.1 how the land cover area areas have been changed during the period of 1989 to 2010 is summarized according to its area. In 1989 the mentionable LCA are vegetation and water body and it is 105.86 and 76.46 km^2 respectively whereas only 59.75 km^2 is found as Built-up area. In 2000, both vegetation and water bodies are decreased to 70.56 and 19.57 km^2 respectively and the Built-up area is increased to 96.00 km^2. But the scenario is changed in 2010; the vegetation and water bodies are increased slightly such as 5.82 % and 5.17 % respectively. It may be happened because of seasonal variation. The image of year 2000 and 2010 are taken in the month of February and January respectively. As a result water and vegetation areas are more dried up in 2000 than 2010. For this reason water and vegetation areas have been found slightly increased.   But the growth of Built-up area remains the same increasing rate.

Table 5.1: Land cover area (LCA) change in DMA (1989 to 2010)

Land cover area types	**Year**			**Land cover area change (1989 to 2010)**		
	1989 (km^2)	**2000 (km^2)**	**2010 (km^2)**	**1989-2000 (%)**	**2000-2010 (%)**	**1989-2010 (%)**
Water	76.46	19.57	35.38	-18.59	5.17	-13.42
Vegetation	105.86	70.56	88.38	-11.53	5.82	-5.71
Built-up	59.75	96.00	130.68	11.85	11.33	23.18
Earth fill or sand	30.72	32.55	15.18	0.60	-5.68	-5.08
Bare soil	33.21	87.32	36.37	17.68	-16.65	1.03
Total Area	306.00	306.00	306.00	--	--	--

5.1.1 Visual interpretation of Land cover areas (LCA) change

How the different land cover area types is being changed during the period of 1989 to 2000 and 2000 to 2010 are shown in Figure 5.1 and 5.2 respectively.

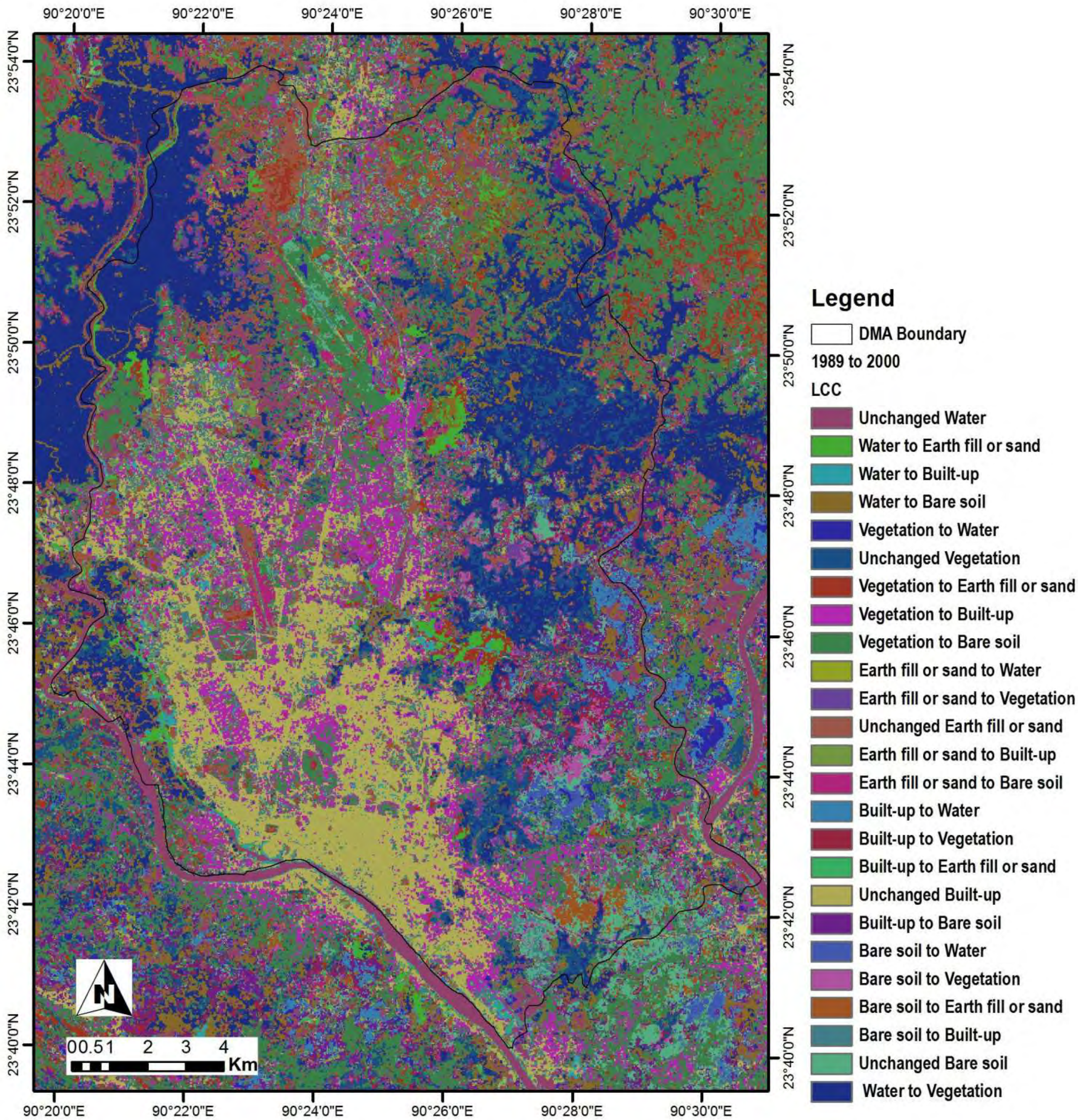


Figure 5.1: Land cover area change from 1989 to 2000

In the Figure 5.1 and 5.2, it is found the river channel and previous Built-up areas are almost in unchangeable situation. On the other hand almost all other types of LCA have been changing to others land cover areas types. Mentionable amount of water bodies' area have been changed into Earth fill or sand for development in the northern and eastern part of DMA during the period of 2000 to 2010. In this period, mentionable Built-up areas also have been developed in the north part of the city in shown in Figure 5.2 (Earth fill A & B, build-up C).

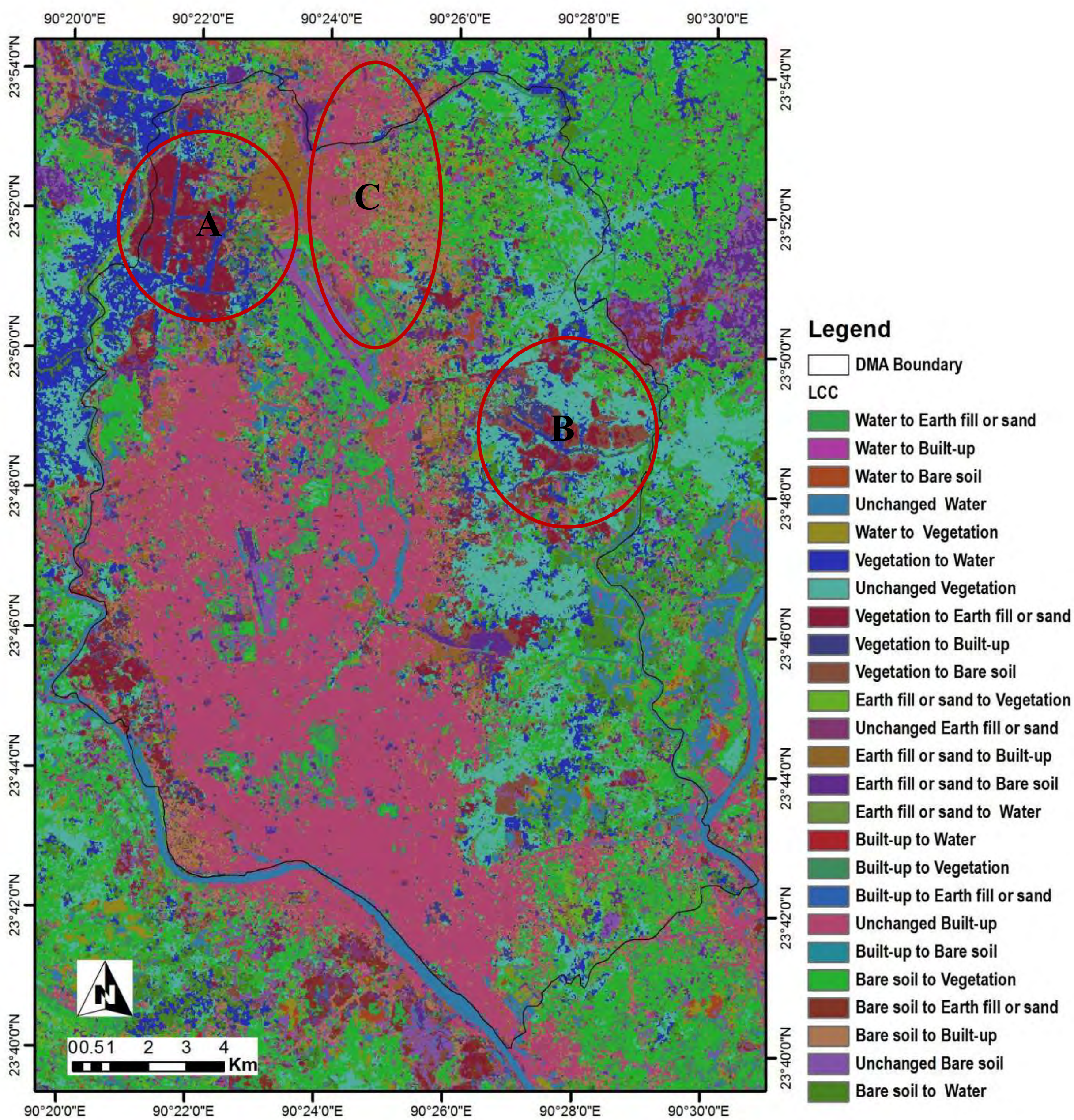


Figure 5.2: Land cover area change from 2000 to 2010

The total scenario of changing land cover area has been shown in the Figure 5.3 during the period of 1989 to 2010. The figure illustrates the decreasing water land into different land cover area type shown as different colors. The water body is decreased in 13.42% of total area where as built-up area is increased in 23.18%. Transition of built-up area is depicted in Table 5.2.

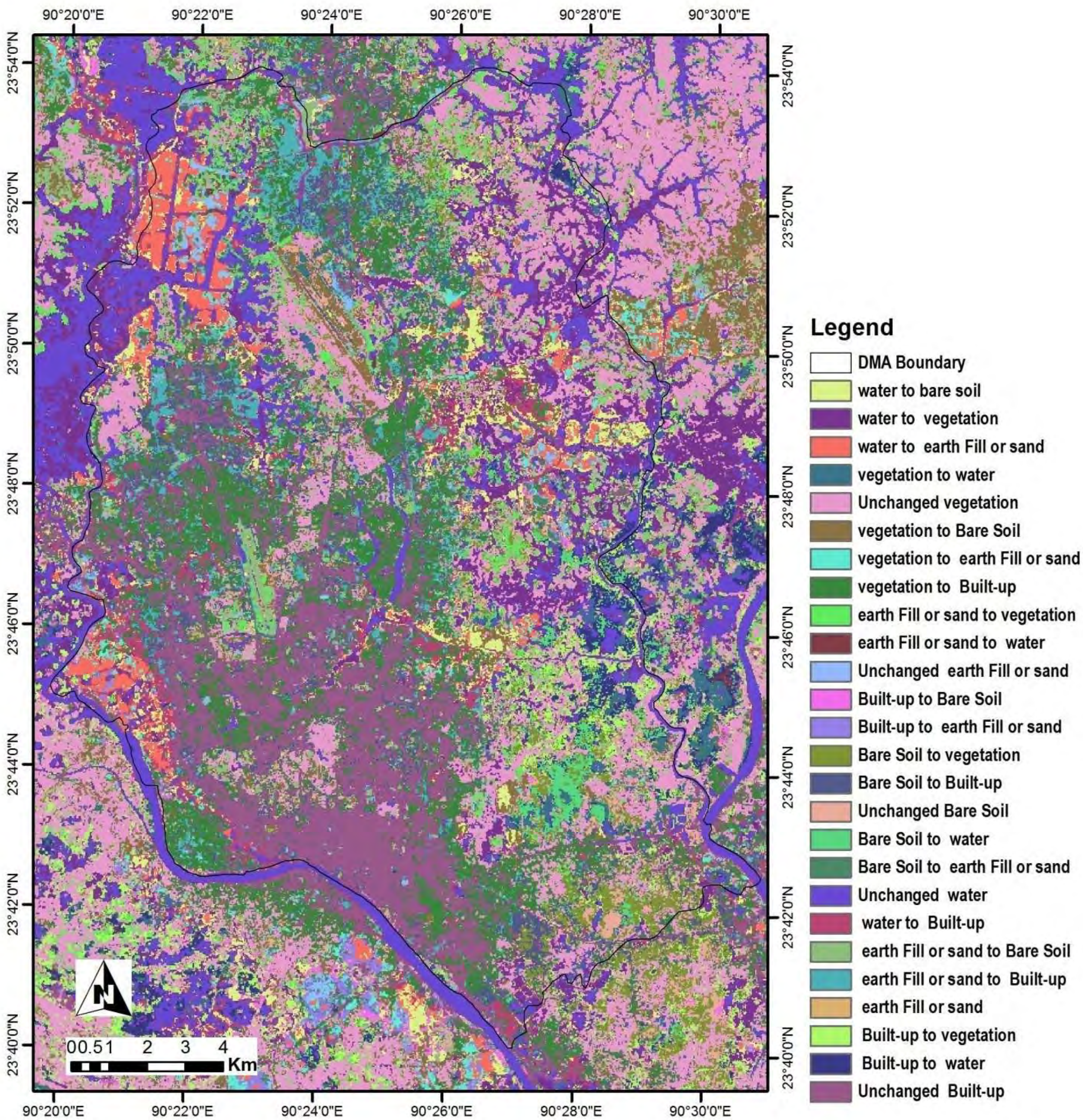


Figure 5.3: Land cover area change from1989 to 2010

5.1.2 Transition of Built-up area

Figure 5.4, 5.5 and 5.6 depict how built-up area has been grown up during the period of 1989 to 2010. 30.36 km² and 11.07 km² of vegetation and bare soil lands respectively have been turned into built-up area during the year 1989 to 2000. In this decade highest amount of vegetation land has been converted into built-up area in the south and east portion of the city shown in Figure 5.4 as green color. Mentionable 22.02 km² and 11.78 km² area of bare soil and earth fill or sand respectively have been changed into built-up area in the north portion of the city during the year 2000 to 2010 is also represented in Figure 5.5 as dark ash and yellow color. Figure also indicates that outer skirt built-up area is increased in this decade. Whereas the previous built-up area almost remain unchanged during this period of time. The total built-up area is increased to 130.68 km² in 2010. The overall scenario of the conversion of built-up area from 1989 to 2010 has been shown in Figure 5.6.

Table 5.2: Conversion of land cover area types into built-up area in DMA (1989 to 2010)

Land cover area types	1989 (Km²)	1989 to 2000 (Km²)	2000 to 2010 (Km²)
Water to Built-up	--	4.97	2.38
Vegetation to Built-up	--	**30.36**	8.35
Unchanged Built-up	--	43.29	**86.15**
Earth fill or sand to Built-up	--	6.32	**11.78**
Bare soil to Built-up	--	11.07	22.02
Total Built-up Area	59.75	96.00	130.68

5.1.3 Trend of changing land cover area

Graph 5.1 draw the attention to the trend of land cover areas type changing. All types of land cover area's growth rate are changeable in either negative or positive rate except built-up area. Only built-up area is increasing in a constant positive rate. In the Graph 5.1, a linier trend line is added and an equation is also derived for the future estimation of built-up area. The co-relational value, r^2 of this equation is 0.999. Value of r^2 indicates that the variable of this linear equation is highly co-related.

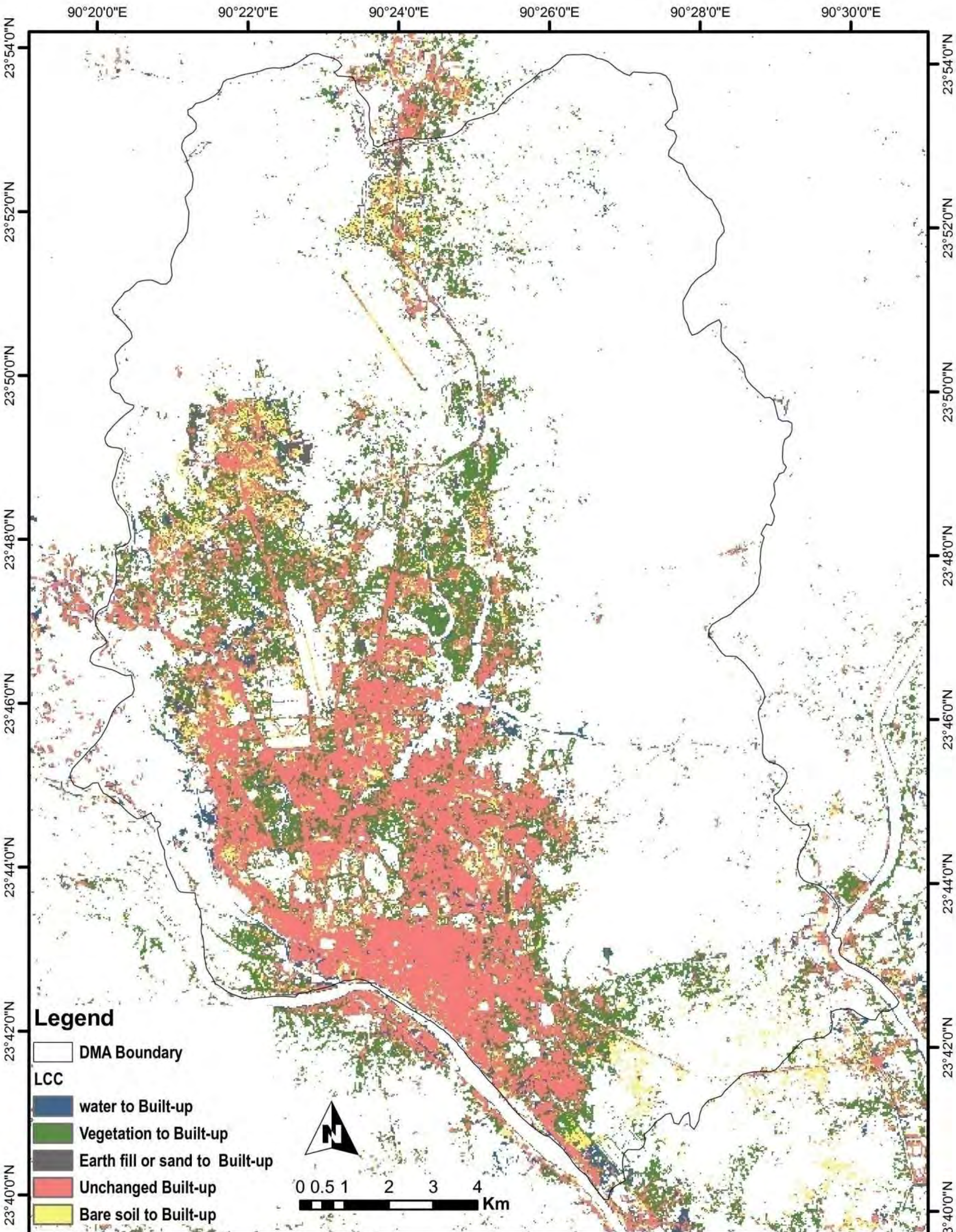


Figure 5.4: Conversion of other LCA into Built-up area from 1989 to 2000

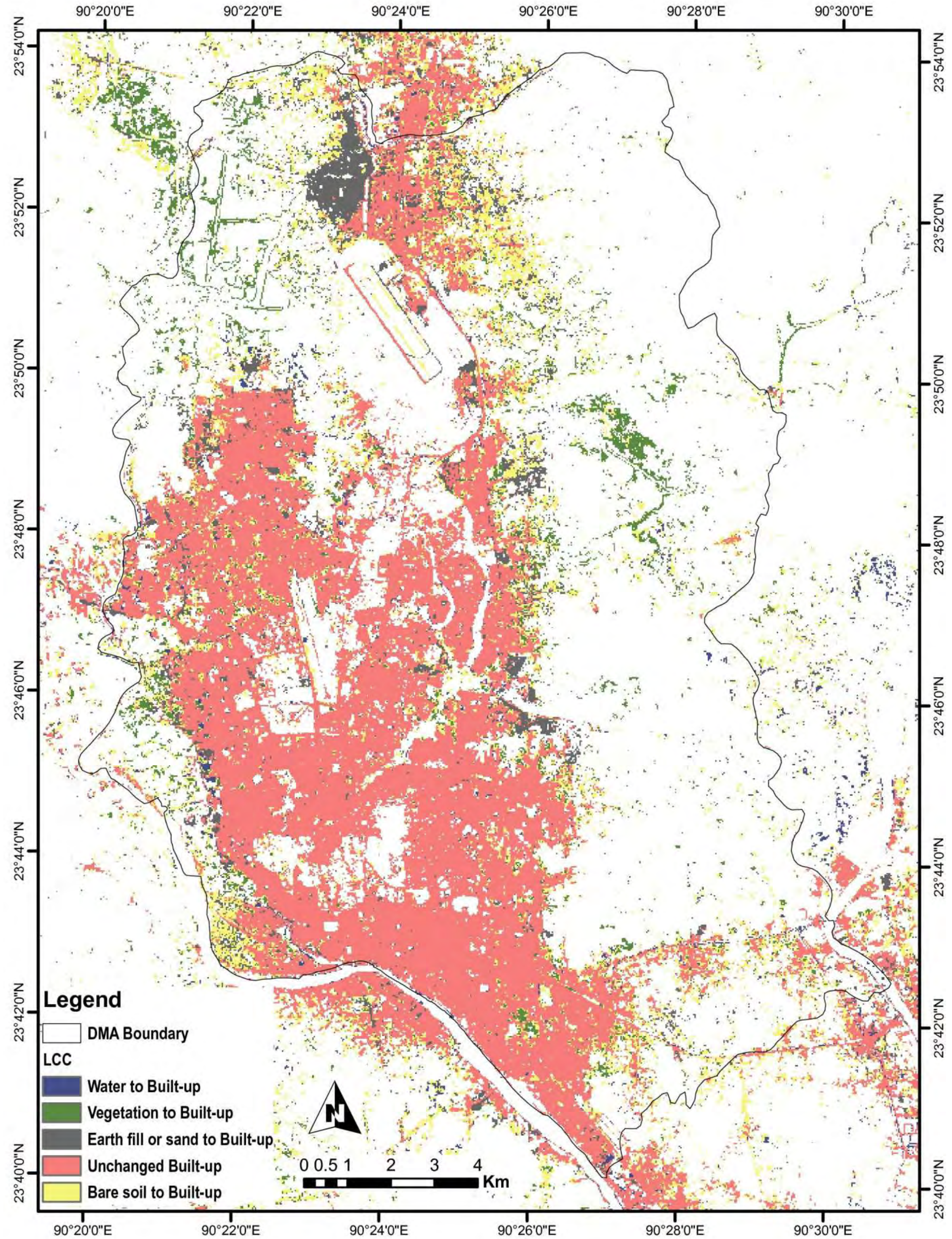


Figure 5.5: Conversion of other LCA into Built-up area from 2000 to 2010

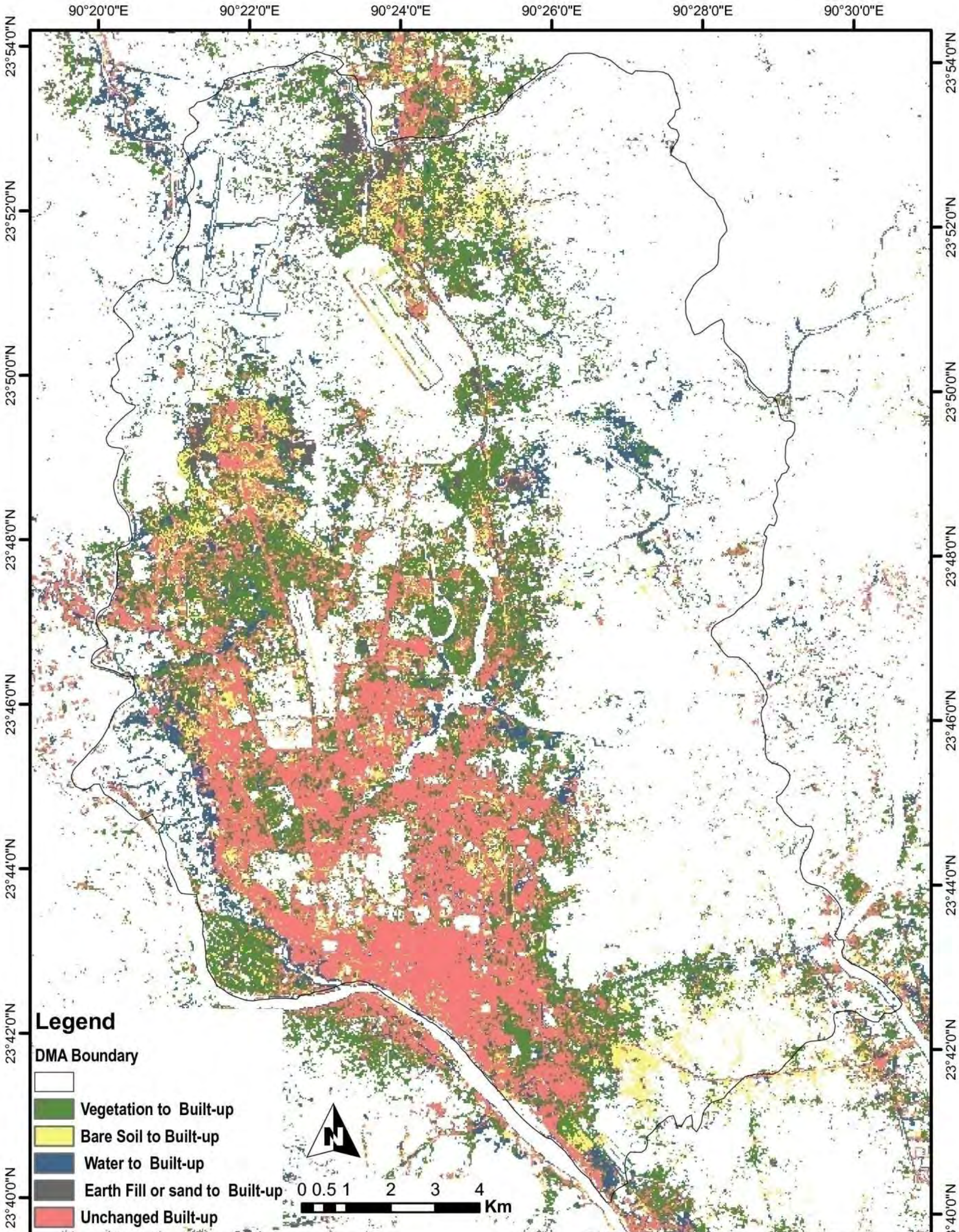
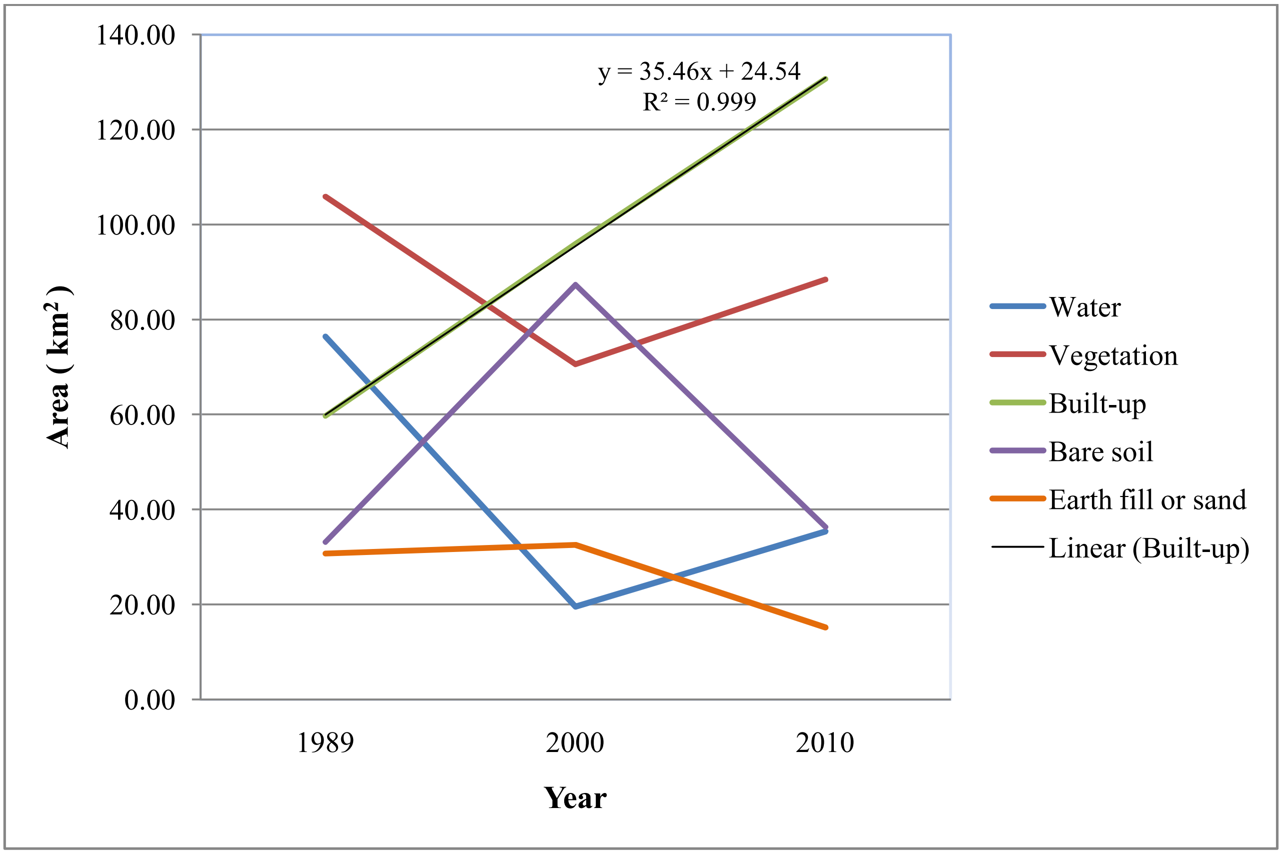


Figure 5.6: Conversion of other LCA into Built-up area from 1989 to 2010

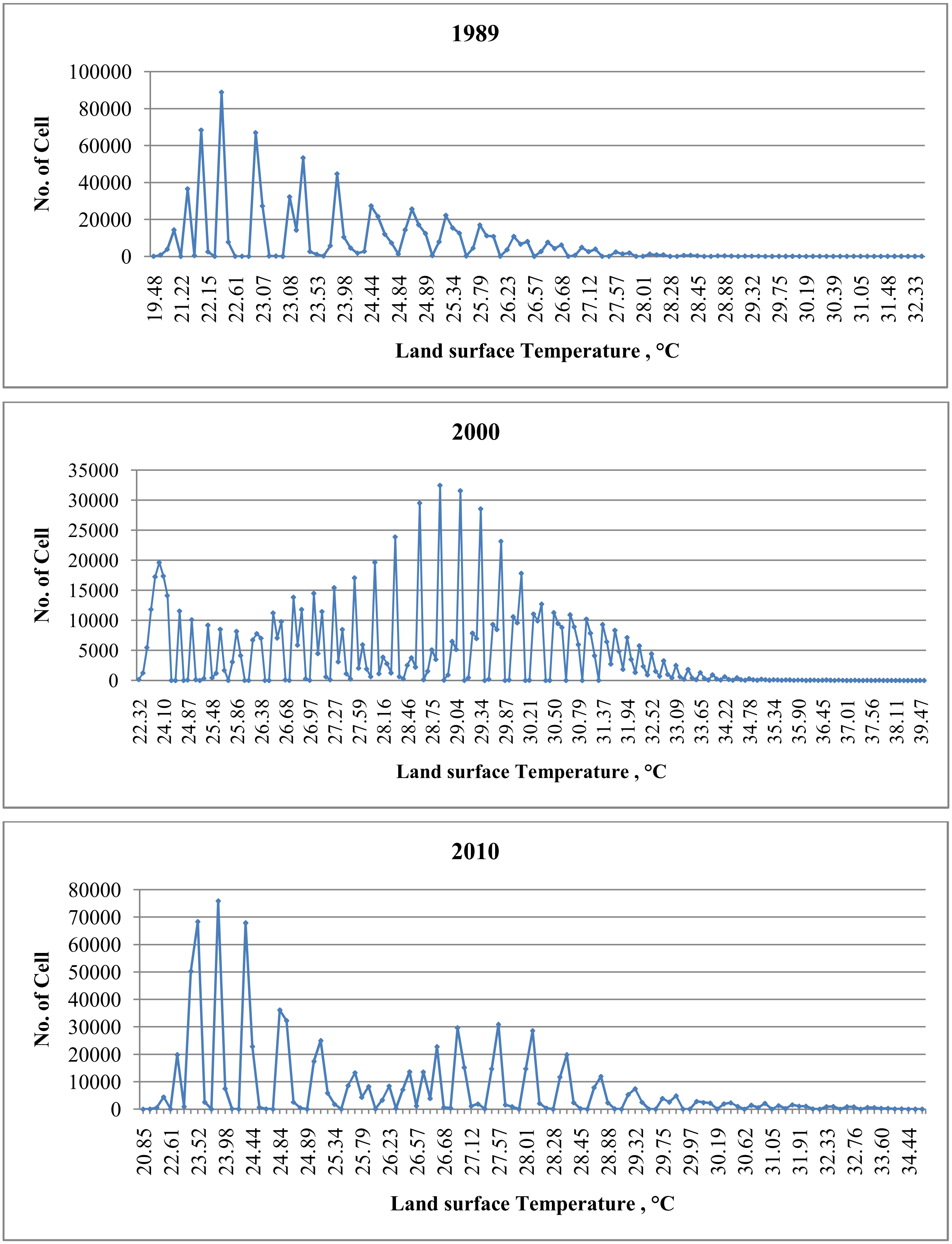


Graph 5.1: Trend of land cover area change over 1989 to 2010

5.2 Land surface temperature (LST)

Land surface temperature (LST) has been derived from the thermal band of Landsat TM /ETM+ using calibration of spectral radiance of remote sensing. Maximum, minimum and mean of calibrated LST and air temperatures are shown in Table 5.3. Air temperatures are collected from Bangladesh meteorological department. It should be mentioned that the LST has been calculated in different year in different day. So LST may differ with the air temperature. It is found from Table 5.3 that the mean LST of year 2000 is higher than other years LST.

The LST distribution of different year has been shown in the Graph 5.2. It is found form the Graph most of the cell value is less than 24 °C and the value is normal distribution in 1989. So the LST is uniformly distributed from the mean LST value. But other years are shown different scenario in the graph. In the year of 2000 most of the cell is between the LST ranges of 27-30 °C.



Graph 5.2: Land surface temperature (LST) distribution of different periods

In 2010, the density of LST is found in two portion of the graph, between 22-24 °C and 26-28°C. So the LST value is not uniformly distributed. So there is several cluster area which have high LST value and others cluster which have low LST value. It can be concluded that the character of the LST is changed according to the spatial changing and its value is increasing day by day.

Table 5.3: Derived LST & air temperature

Representative year	LST			Air Temperature		
	Minimum (°C)	Maximum (°C)	Mean (°C)	Minimum (°C)	Maximum (°C)	Mean (°C)
12-01-1989	20.42	33.97	24.74	9.40	21.70	15.55
28-02-2000	22.02	39.47	28.26	15.30	27.80	21.55
30-01-2010	21.82	36.13	26.81	11.00	27.10	19.05

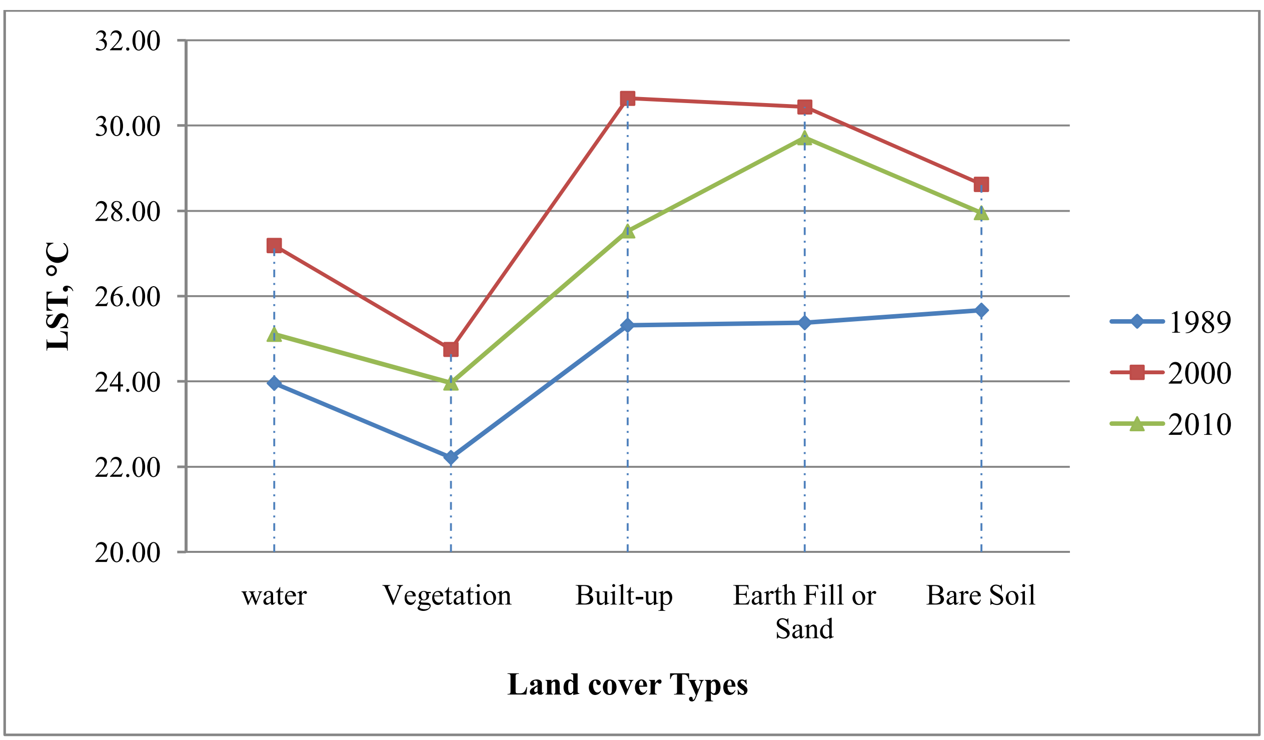
Source: Bangladesh Meteorological Department, 2011

5.3 Relationship of LST and LCA

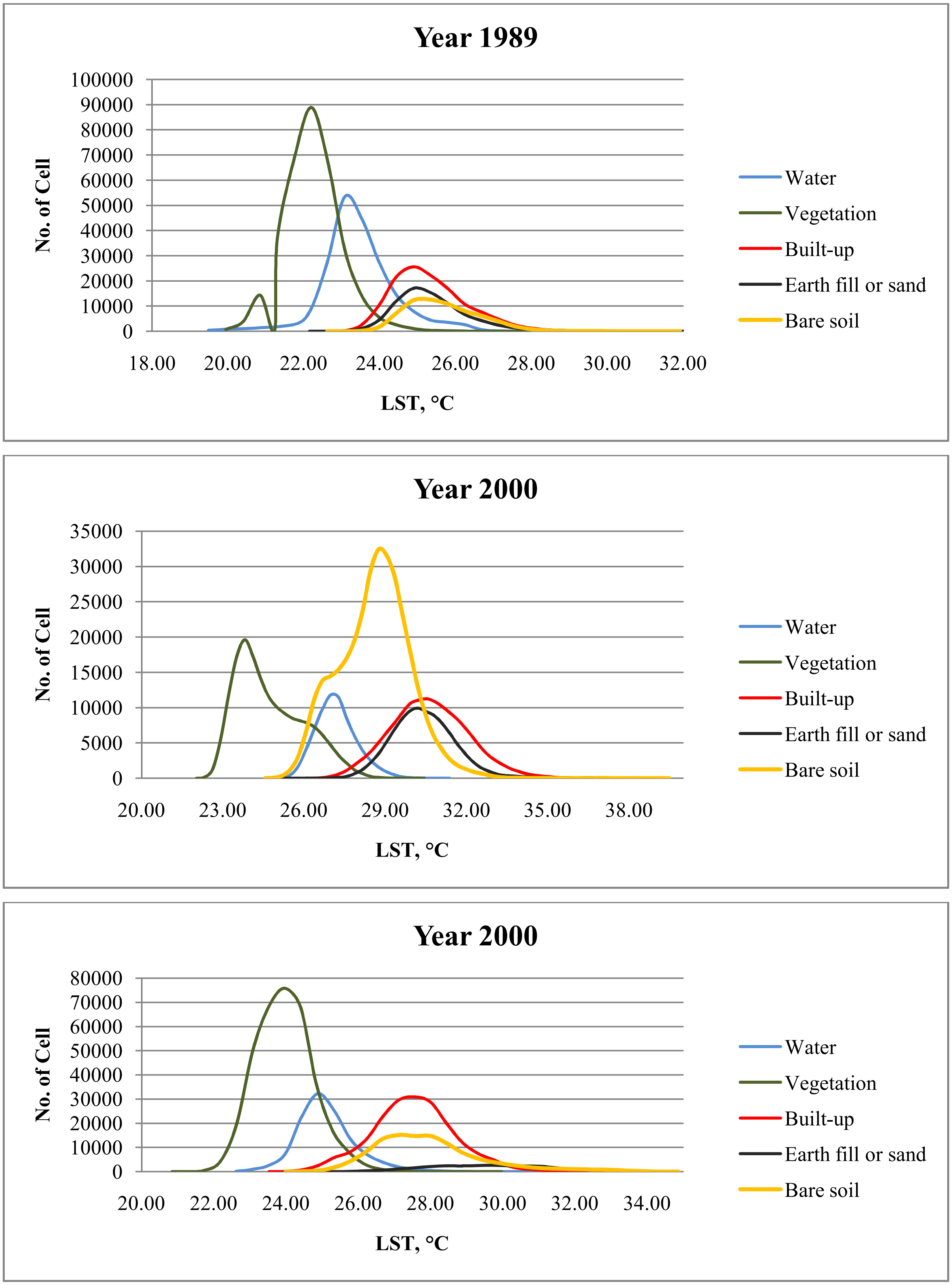
The LST can be changed for pattern and density of land cover area (LCA). The spectral resolution of the Lansat TM/ETM+ images are 30m. So 900m² areas do not contain the same kind of LCA property. So, the LCA types for the pixel of Landsat image have been determined by the greater percentage of LCA. For this reason, LST are varied for same type of LCA. Table 5.4 contents the minimum, maximum and mean data of LST of different LCA over the period of 1989 to 2010. Form the table it is found that the character of the LST changing with LC is almost same for the period of 1989, 2000 and 2010. The maximum temperature is **39.47** °C of Bare soil in 2000 and the minimum temperature is **20.42** °C of vegetation in 1989. The difference of mean LST for each LCA from Water is minimum in 1989 but higher in 2000. The LST of Built-up is about 3.46 °C higher than the water in 2000. The mean LST of different year are plotted in the Graph 5.3 where the relationship between the LCA and LST is established. From the graph, the LST line of the year, 1989 shows almost a liner line among built-up, earth fill or sand and bare soil. But the vegetation has lower LST value than other categories. In 2000 the line of LST is abrupt and the built-up LCA retains more heat than other land cover area classes. The mean

Table 5.4: Derived mean land surface temperature (LST) distribution according to land cover area over the period of 1989 to 2010

Year	Land cover area type	LST, °C			
		Maximum	Minimum	Mean	Difference from Water
1989	Water	30.19	21.22	23.96	0.00
	Vegetation	30.39	**20.42**	22.22	-1.75
	Built-up	31.48	22.61	25.32	1.36
	Earth Fill Or Sand	33.97	22.15	25.38	1.42
	Bare Soil	31.91	22.61	25.67	1.71
2000	Water	31.37	24.87	27.19	0.00
	Vegetation	30.43	22.02	24.76	-2.43
	Built-up	37.83	26.08	**30.65**	3.46
	Earth Fill Or Sand	38.65	24.57	**30.44**	3.25
	Bare Soil	**39.47**	24.57	28.62	1.43
2010	Water	31.91	22.61	25.11	0.00
	Vegetation	29.97	21.82	23.97	-1.14
	Built-up	32.76	23.53	27.53	2.42
	Earth Fill Or Sand	**36.47**	24.44	29.72	4.61
	Bare Soil	34.86	23.98	27.96	2.85



Graph 5.3: Relationship between land cover area (LCA) and land surface temperature (LST)



Graph 5.4 : LST of classified LCA in the periods of 1989 to 2010

LST of Built-up is **30.65**°C which is highest LST in the table. Whereas the second highest heat contains the earth fill or sand type land cover area and its mean LST is **30.44**°C. Bare soil and water are the other land cover areas which are 28.62 and 27.19°C respectively. In the year 2010 the LST character is found different than 2000. Earth fill or sand land cover area type is the highest temperature which is **29.72**°C. But vegetation land has the low LST value. How this LST of LCA has been changing over the period shown in the Graph 5.4. It is concluded from the above discussion that LST of vegetation value is always lower than other categories of LCA and Built-up or Earth fill or sand have the higher LST than others.

5.4 Visual interpretation of LST change of DMA

The LST changing with LCA can be illustrated visually compare two classified images of LCA and LST. The Visual interpretation of LST changing of DMA is discussed in the below.

5.4.1 Visual interpretation of LST and LCA, 1989

It is found from the Figure 5.7 that almost area of DMA is low LST and it is lower than **22 °C.** In somewhere of DMA area, LST also is found more than **28 °C.** Now comparing higher LST area with the LCA map, it is found that earth fills or sand areas of the inner city have higher LST (point out as A in Figure 5.7). The water channel and the vegetation area can be visually identified in the LST map by its pattern compare to LCA Map and it is found comparatively low LST value. As in 1989 most of the LCA is vegetation and water (Shown in Table 5.1), the mean LST is found low in this year. Besides the LCA where LST is greater than **27 °C**, is almost built-up area found in LCA map and some built-up area shows low LST due to the existence of vegetation and water body's areas (point out as B & C in Figure 5.7).

5.4.2 Visual interpretation of LST and LCA, 2000

It is easily to separate visually the differences of LST from the Figure 5.8 compare to LCA map. It is found from the figure that water bodies and vegetation land have the lowest LST and it is less than about 26°C. The highest LST is found in the earth fill of sand area which is water area in 1989. The LST of grownup built-up area is about 28 to 33 °C. In early this chapter LCA of year 2000 is described how water and vegetation land has been converted into built-up area and the pattern and density of LST map of this year prove that the LST of DMA is increased than the year 1989 because of grownup built-up area.

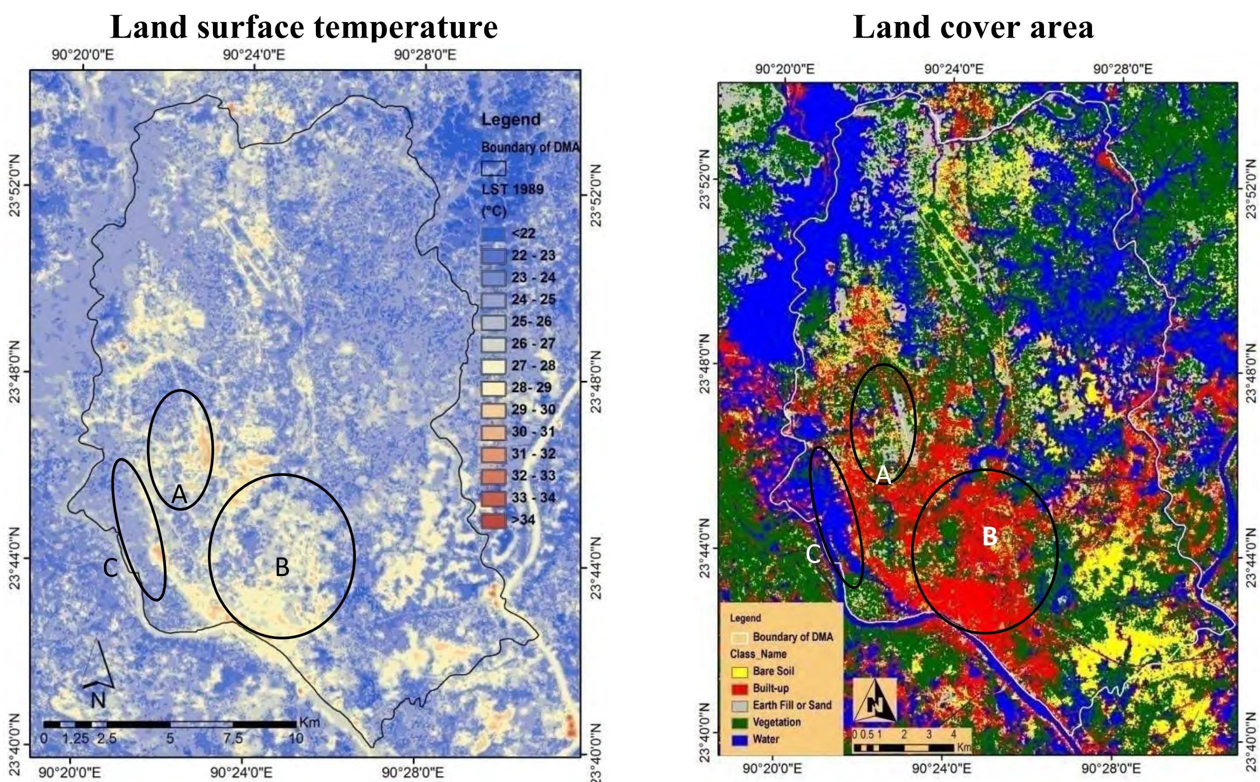


Figure 5.7: Visual Interpretation of LST with respect to LCA transition, January 1989

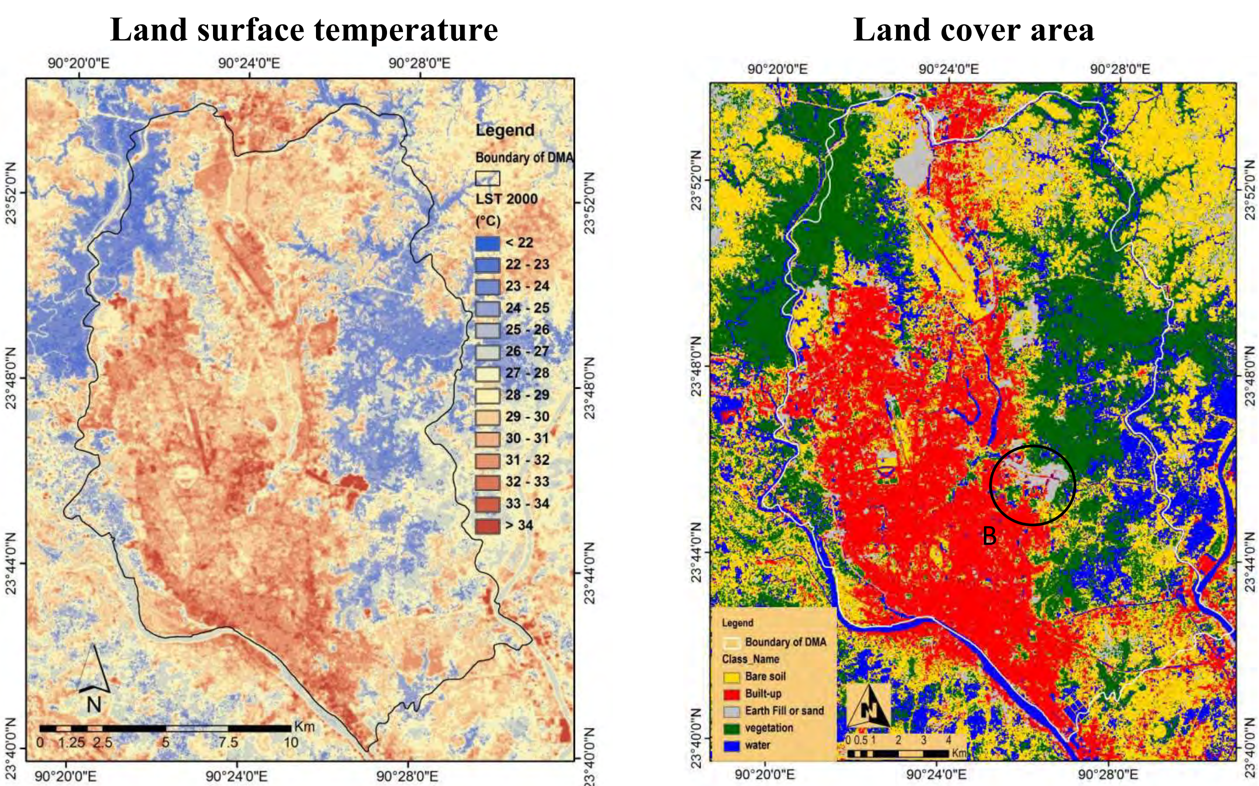


Figure 5.8: Visual Interpretation of LST with respect to LCA transition, February 2000

5.4.3 Visual interpretation of LST and LCA, 2010

It is also easy to separate visually different LCA from the LST map of year 2010. But in 2010 the LST of Built-up areas do not represent same LST for large and smooth area shown in Figure 5.9. As early in this chapter it is found the Built-up area is increasing in the same growth rate (Graph 5.1), the density of the built-up area is increased. For that reason the character of LST map is found different in the built-up area. Even some vegetated land area is found the same LST as in built-up area (point out as A in figure 5.9) because of pattern and density of grownup built-up area. The LST map also draws attention that the categories of earth fill or sand and bare soil area have the more LST than any other LCA. It should be mentioned that the high LST of earth fill or sand area has been converted from category of water bodies for future development. A category of bare soil is converted from earth fill or sand (point out as B in Figure 5.8& 5.9) and it is also transited into Built-up area soon.

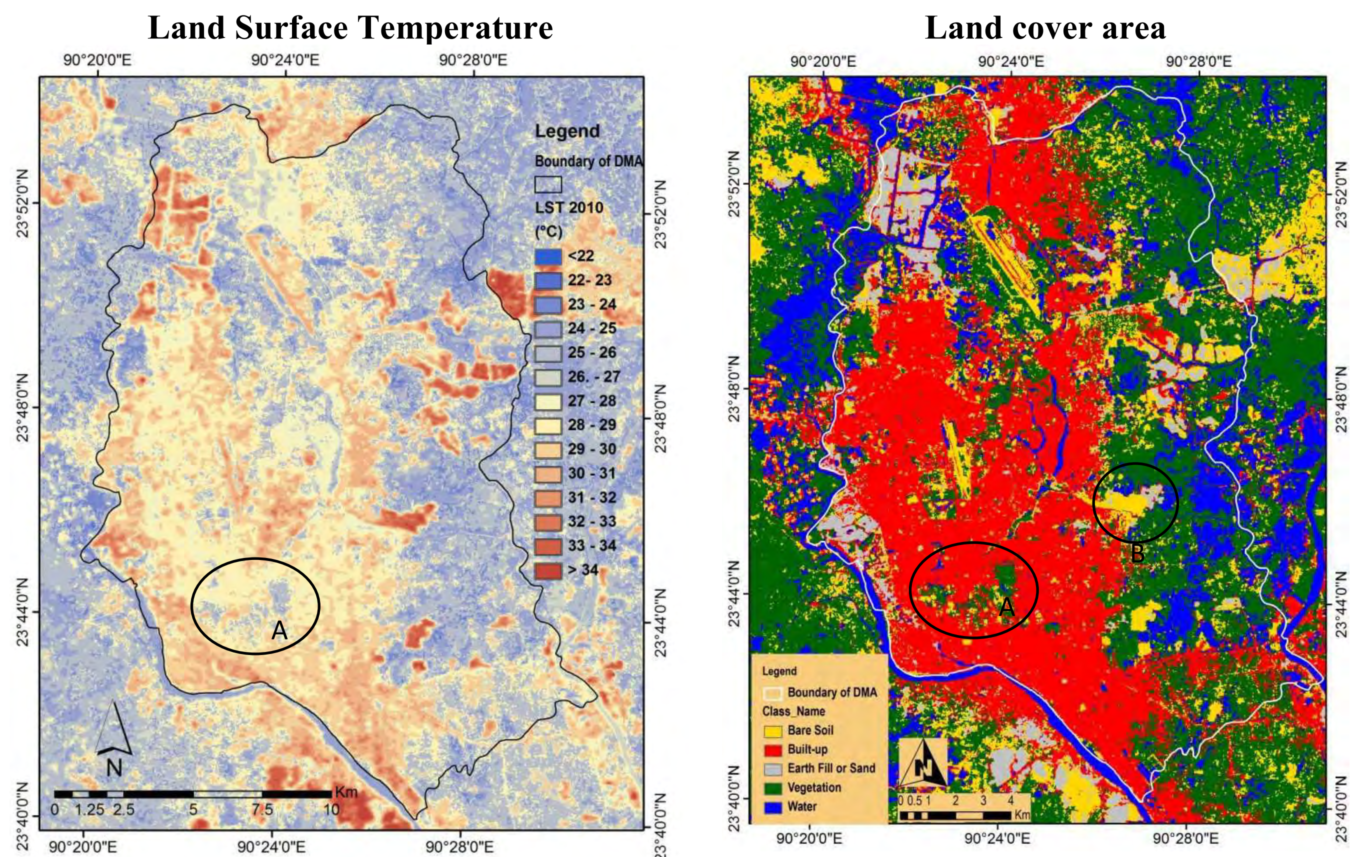


Figure 5.9: Visual Interpretation of LST with respect to LCA transition, January 2010

It is clear from the visual interpretation that unplanned grownup built-up area is one of the causes of increasing LST of DMA over the period of time and it is also affect the other land cover area is found in LST map of year 2010.

5.5 LST Differences with Changing Land cover area

Figure 5.10, 5.11 and 5.12 represent more than 8 °C temperature differences in the period of 1989 to 2000. The mean LST of 2000 is higher than 1989 (Table 5.4) and the pattern of this LST differences distribution map indicates that the land cover area (LCA) changing is one of the cause of LST increasing. The differences of LST distribution map of year 2000-2010 represent totally different scenario shown in Figure 5.11. Because, the mean LST of year 2000 is higher than 2010 and it is about 1.45 °C (see Table 5.3). So, the differences of LST changing should be found negative. But in the Figure 5.11 it is found that still some places are found positive value of LST changing in the north and east corner of the DMA pointed out as red color. The red color portion of figure 5.11 is category of earth fill or sand types LCA which have been shown in Figure 5.2 (point out as A & B). Without land cover area changing, there is no physical change found in those areas. So it is clear that the land cover area is one of the causes of changing LST.

The figures also represent how the LST of DMA area is increasing. In period of 1989 to 2000 the differences of LST is lower and scattered than the period of 2000 to 2010 shown in Figure 5.10 and 5.11. But in the period of 1989 to 2010 the high LST differences are found in the categories of built-up and earth fill or sand area as smoothly concentrated shown in Figure 5.12. Most of the lands are found high LST differences than the period of 1989 to 2000. So it is proved that the LST is increasing with the changing of LCA.

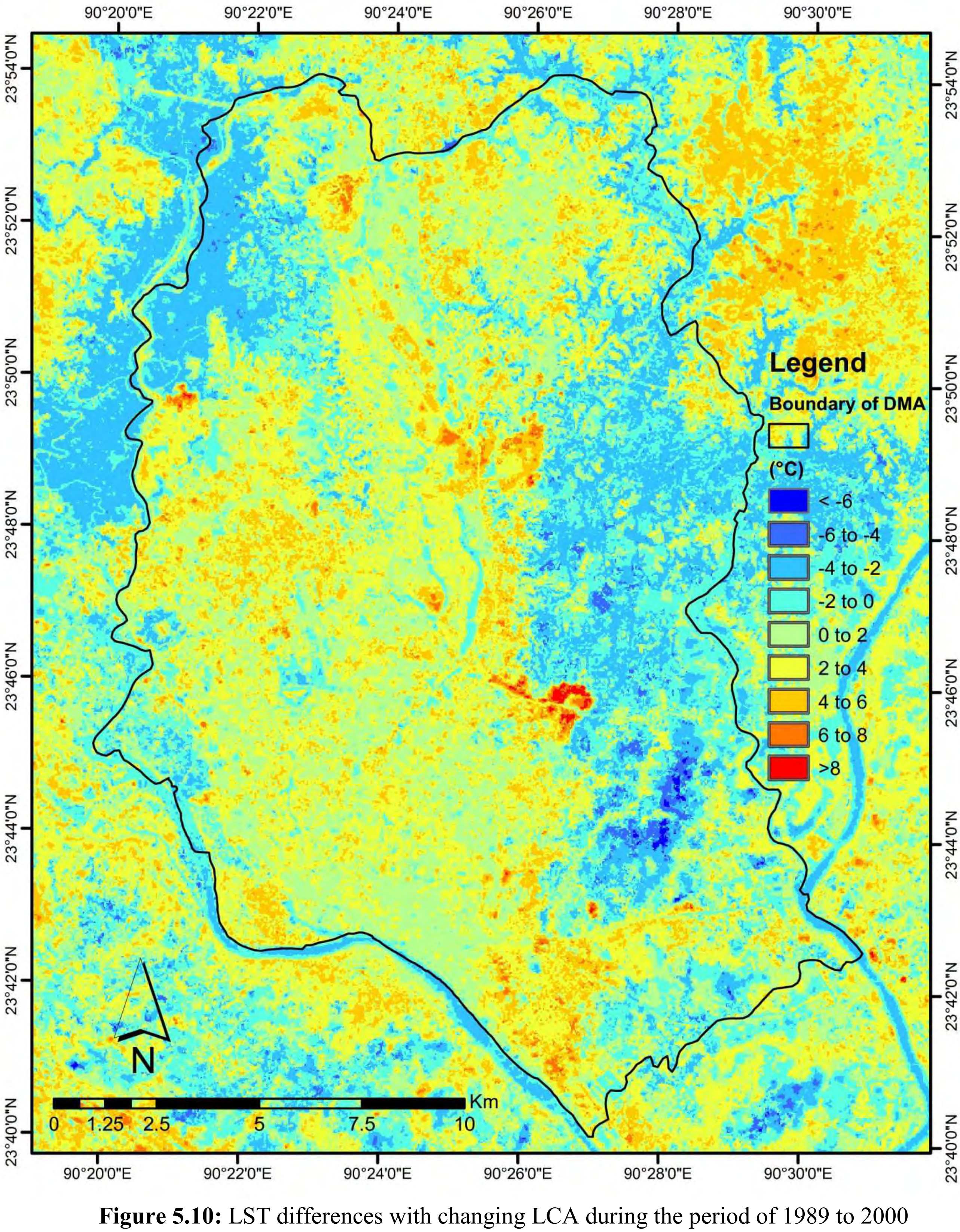


Figure 5.10: LST differences with changing LCA during the period of 1989 to 2000

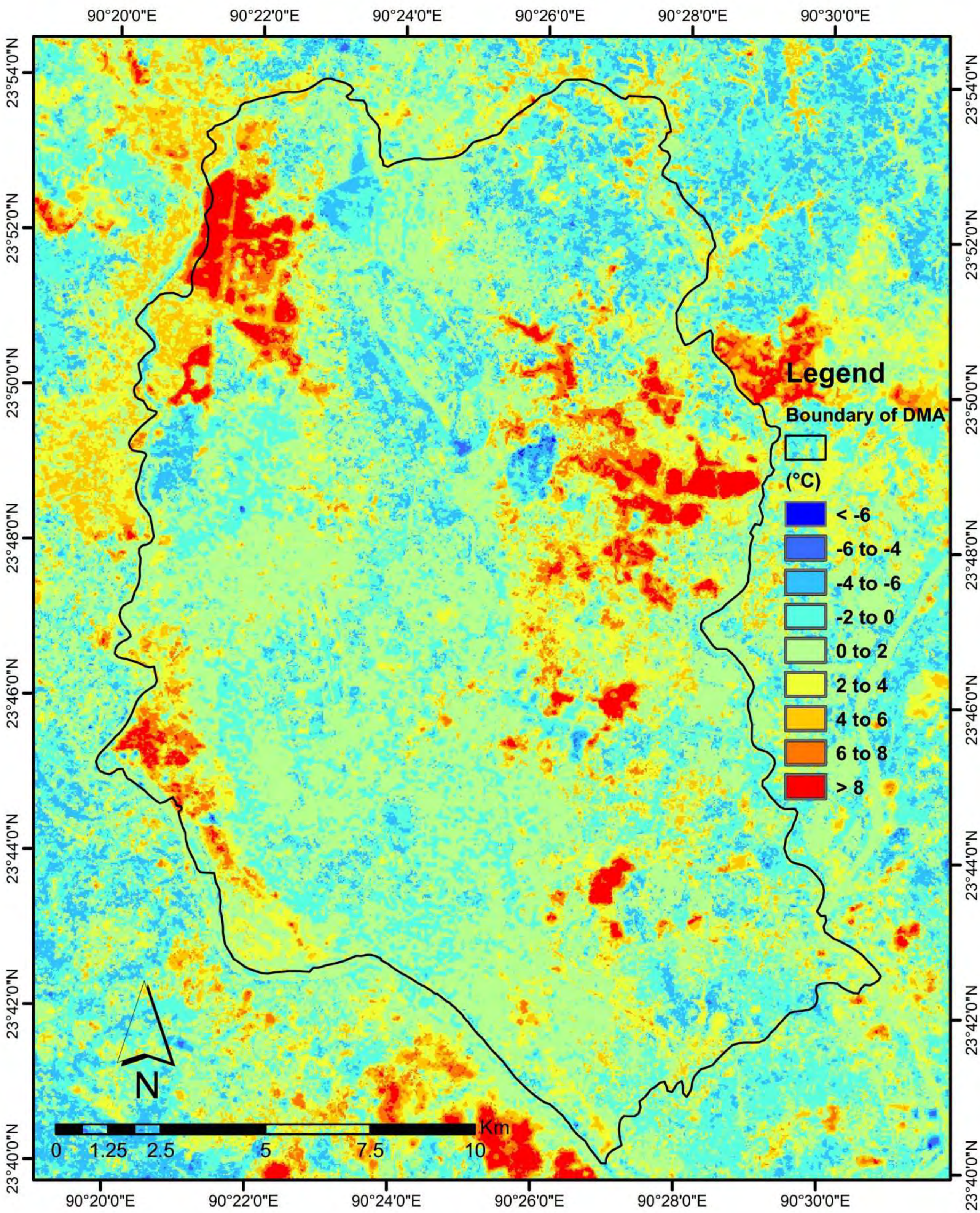


Figure 5.11: LST differences with changing LCA during the period of 2000 to 2010

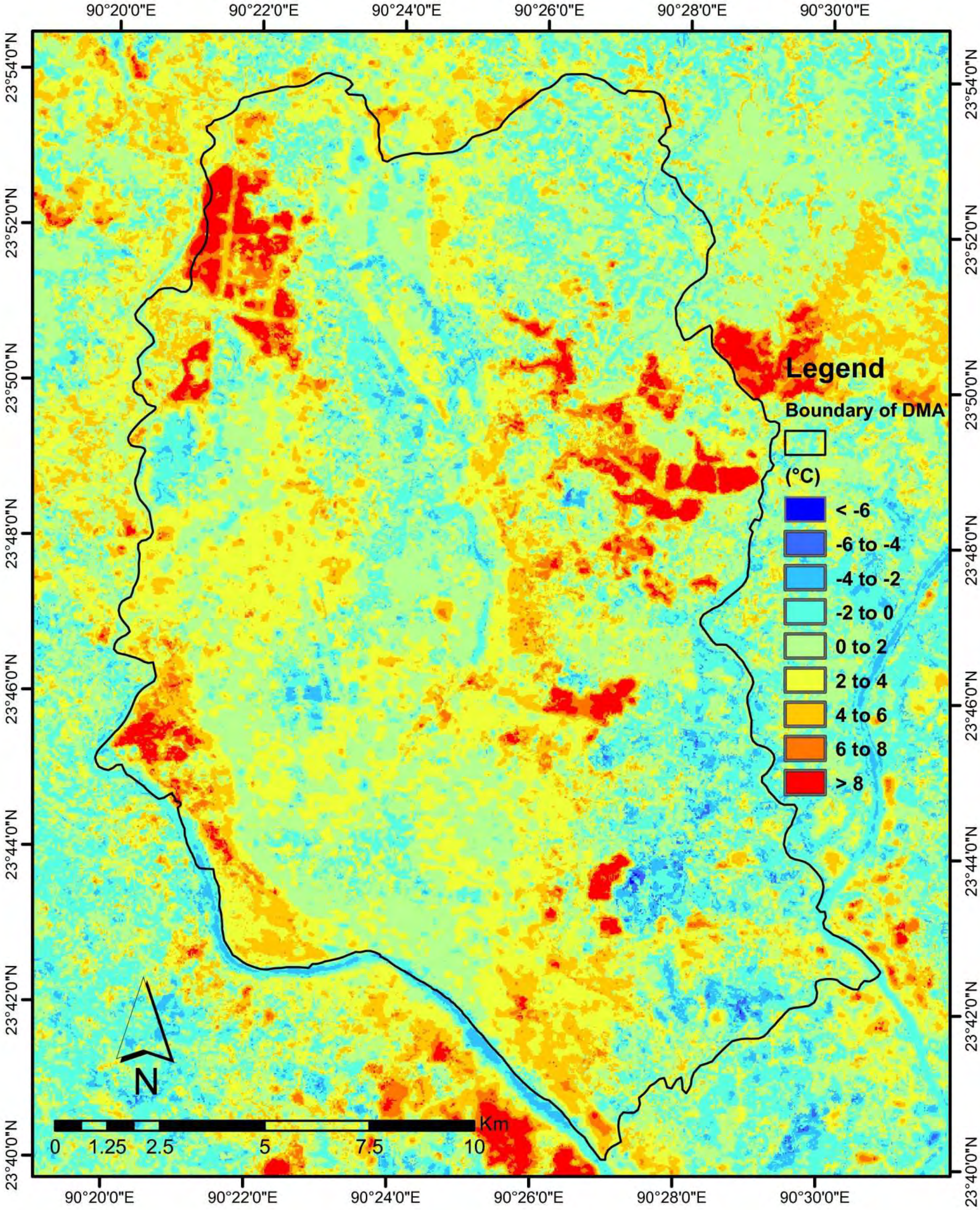


Figure 5.12: LST differences with changing LCA during the period of 1989 to 2010

CHAPTER 06

SPATIAL SIMULATION OF LST

How LST is changing with the LCA, NDVI and NDBI have been described with the simulated graph and map in this chapter. Land cover area (LCA) and Land surface temperature (LST) map have been shown in Figure 6.1 and 6.2.

6.1 Spatial simulation of LST and NDVI

The relationship of Normalized Difference Vegetation Index (NDVI) and LST of different period has been analyzed during the period of 1989 to 2010 shown in the simulated graph 6.1, 6.2 and 6.3. From those graph it is clear that the LST of different year is decreasing with the increasing value of NDVI. Increasing positive value of NDVI means the more dense vegetation area. So categories of vegetation land have low LST. From earlier in this chapter it is illustrated visually that some built-up area has low temperature due to the existence of vegetation. Now it is proved form the simulated graph that Vegetation affects on LST.

Graph 6.1 represents that the positive NDVI value is about 0.65 which is high value. So the vegetation density of this year is found high. Besides the density of positive NDVI value indicates that the more probability of available of vegetation. Graph 6.2 represents that the positive NDVI value is about 0.35 which is low value. So the density of vegetation of this year found low. Form the simulated graph it is found that the density of the cell value is more in the Negative portion of NDVI value. So it indicates that the less probability of available of vegetation in the study area. From the graph 6.3 it is found that the value of NDVI is about 0.5 which is high value. So in this year the density of vegetation is found high. But the density of the cell value is found between the NDVI ranges of -0.1 to 0.15 in the simulated graph which indicate that the distribution of vegetation is low density. The vegetation maps of different years are shown previous chapter 04 in the Figure 4.10, 4.11 and 4.12. The simulated line of the all graph is downward with the increasing value of NDVI which indicates the LST is negatively correlated with the NDVI. Besides it is found from the simulated curve how much healthy vegetation is present in the study area.

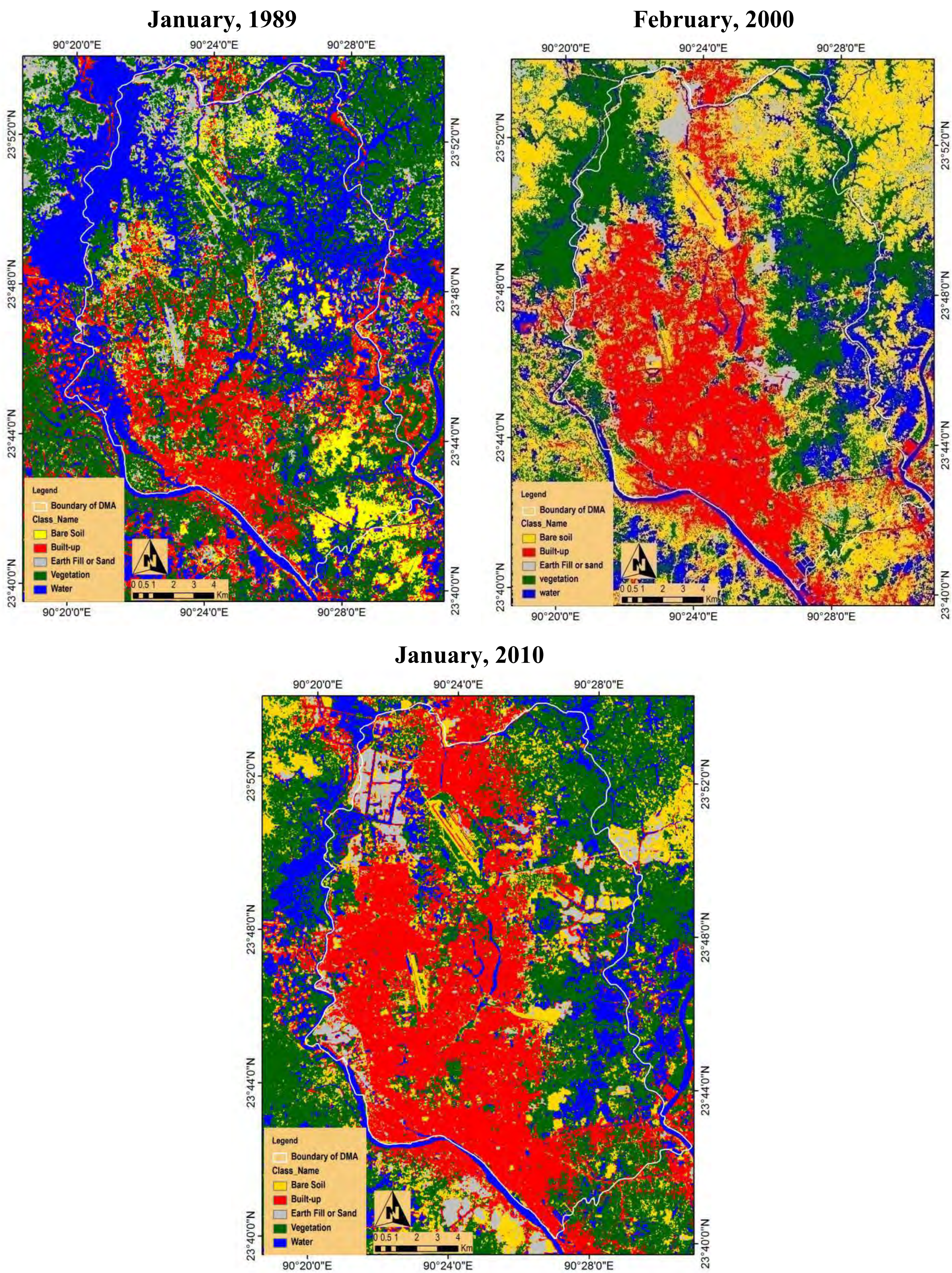


Figure 6.1: Land cover area (LCA) over the period of 1989 to 2010

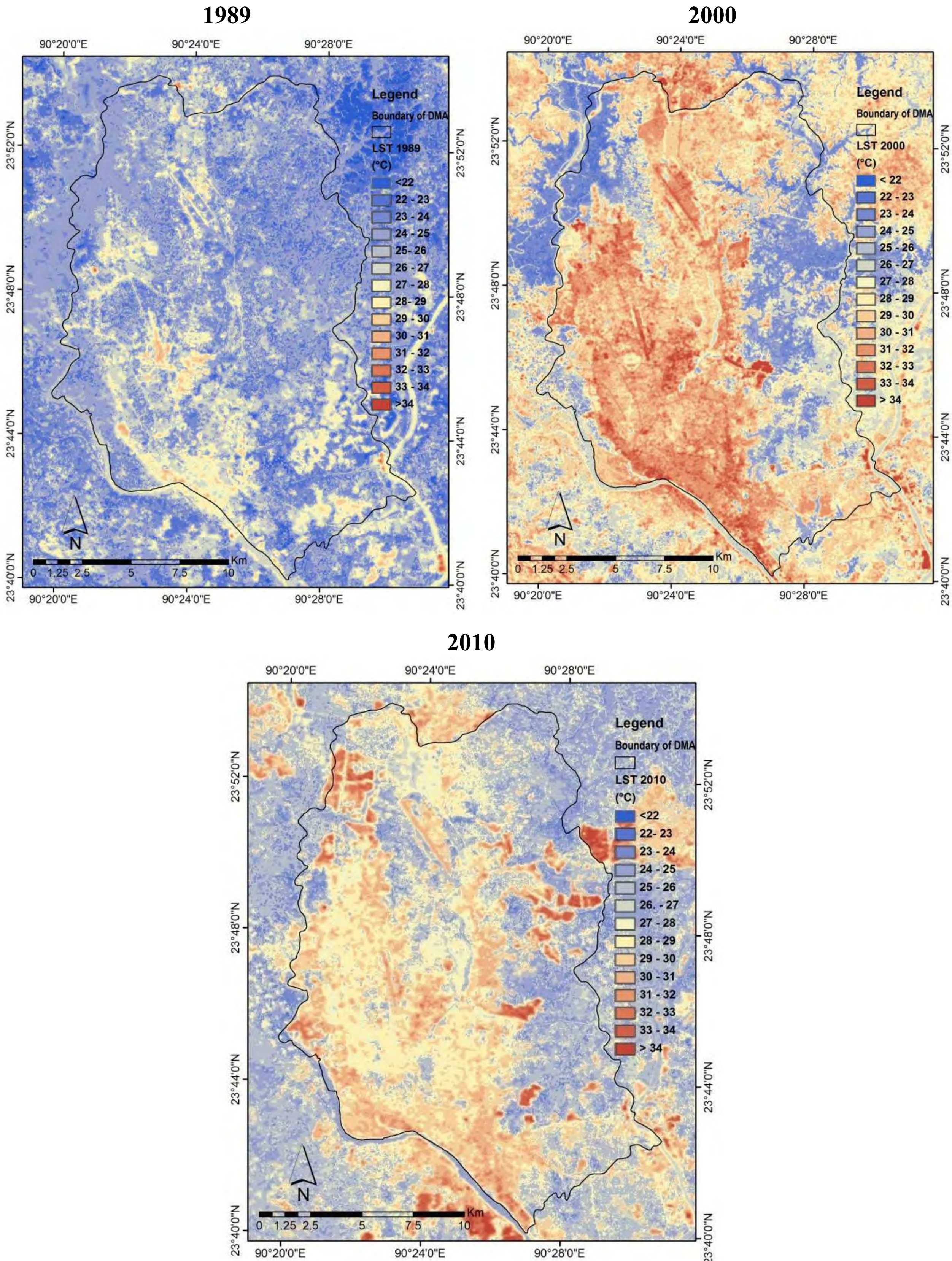
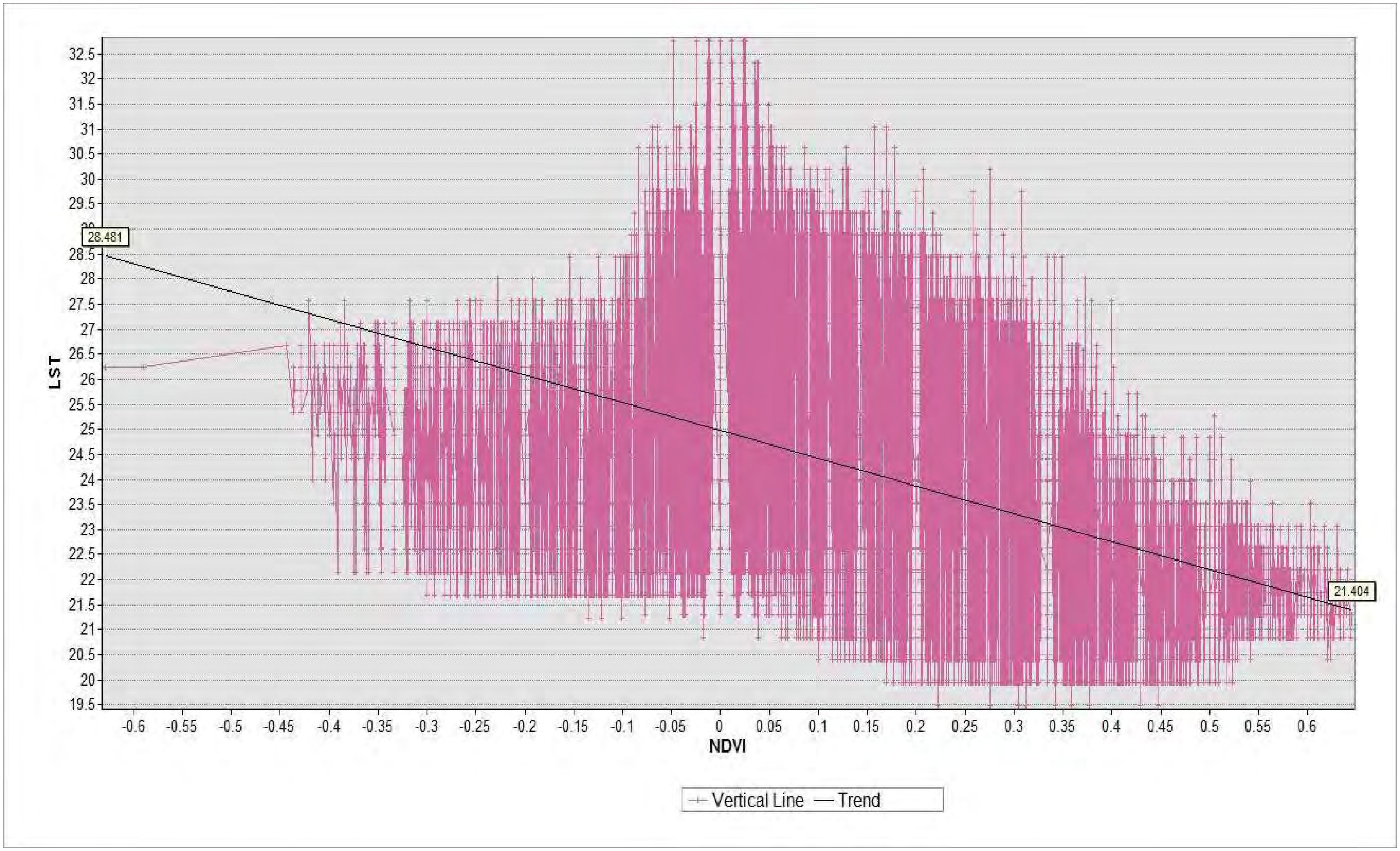
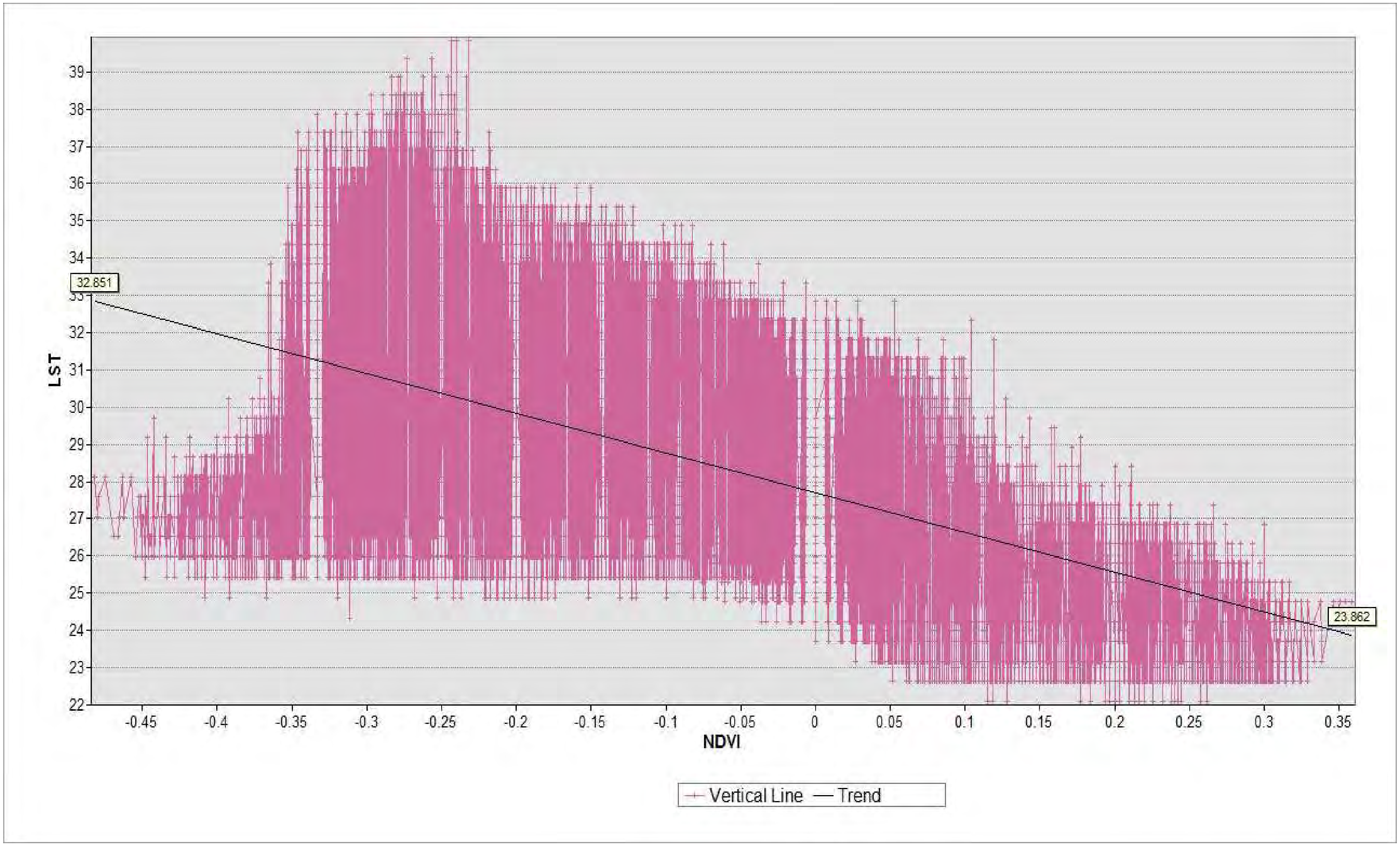


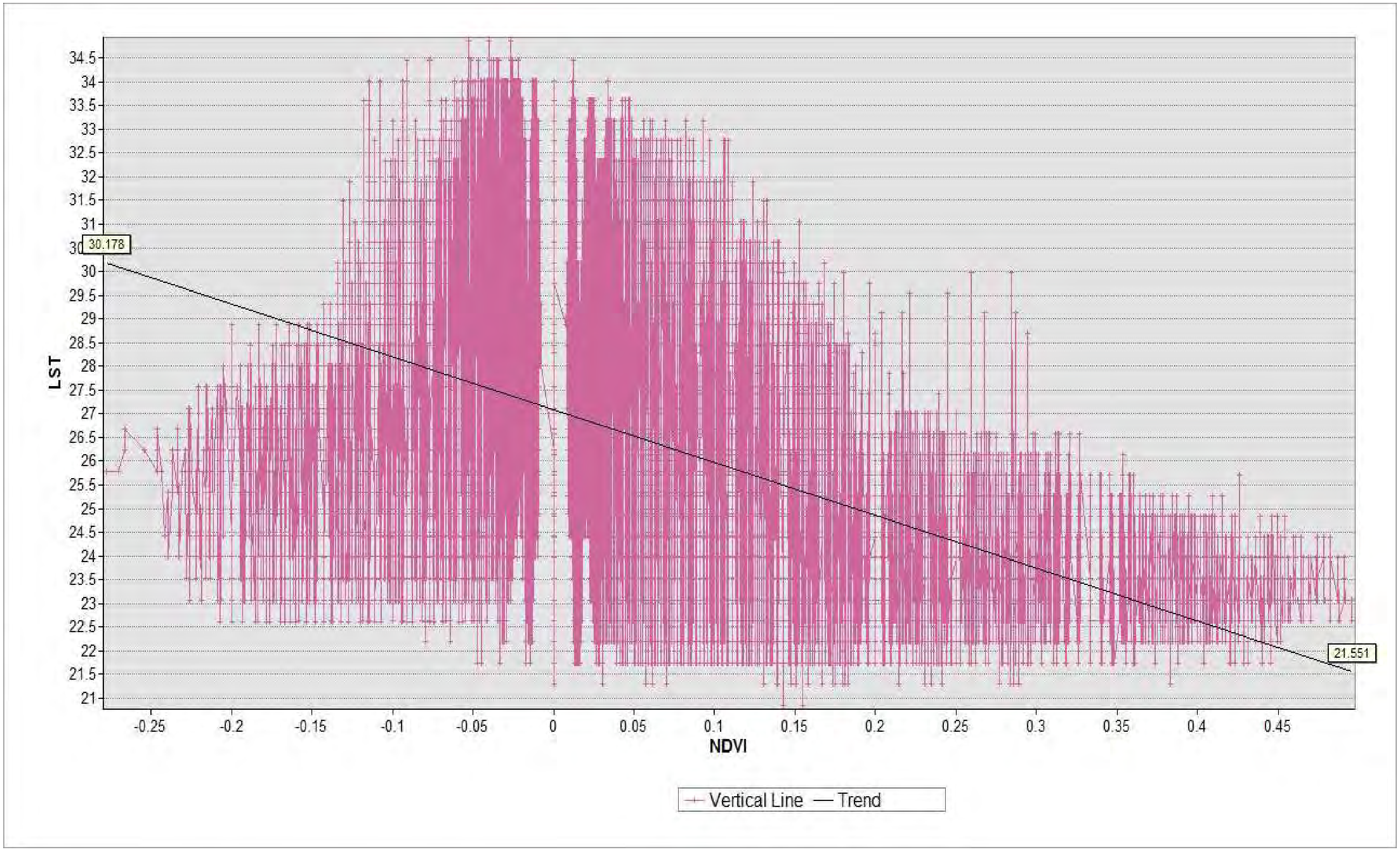
Figure 6.2: Land surface temperature (LST) over the period of 1989 to 2010



Graph 6.1: Simulated graph of NDVI and LST, 1989



Graph 6.2: Simulated graph of NDVI and LST, 2000



Graph 6.3: Simulated graph of and LST, 2010

6.2 Spatial simulation of NDBI and LST

The relationship of the Normalized Difference Built-up Index (NDBI) and LST is analyzed in the simulated graph 6.4, 6.5 and 6.6. Form those graph it is found that the LST is increasing with the increasing value of NDBI. Generally positive value of NDBI represents the Built-up area, bare soil and earth fill or sand. Higher positive value represents categories of the earth fill or sand and bare soil land. From the Graph 6.4 it is found that built-up cell vule is between the rage of -0.15 to 0.23 and the LST trend line is less slopy than other simulated NDBI graph. In the graph 6.5 and 6.6 shows more sloppy treand line and the desity of NDBI value increase between the rage of 0.1 to 0.35. generally the rage of 0.1 to 0.35 is sensitive for Built-up area. so it can be conculed that LST is incresing with the grownup Built-up area.

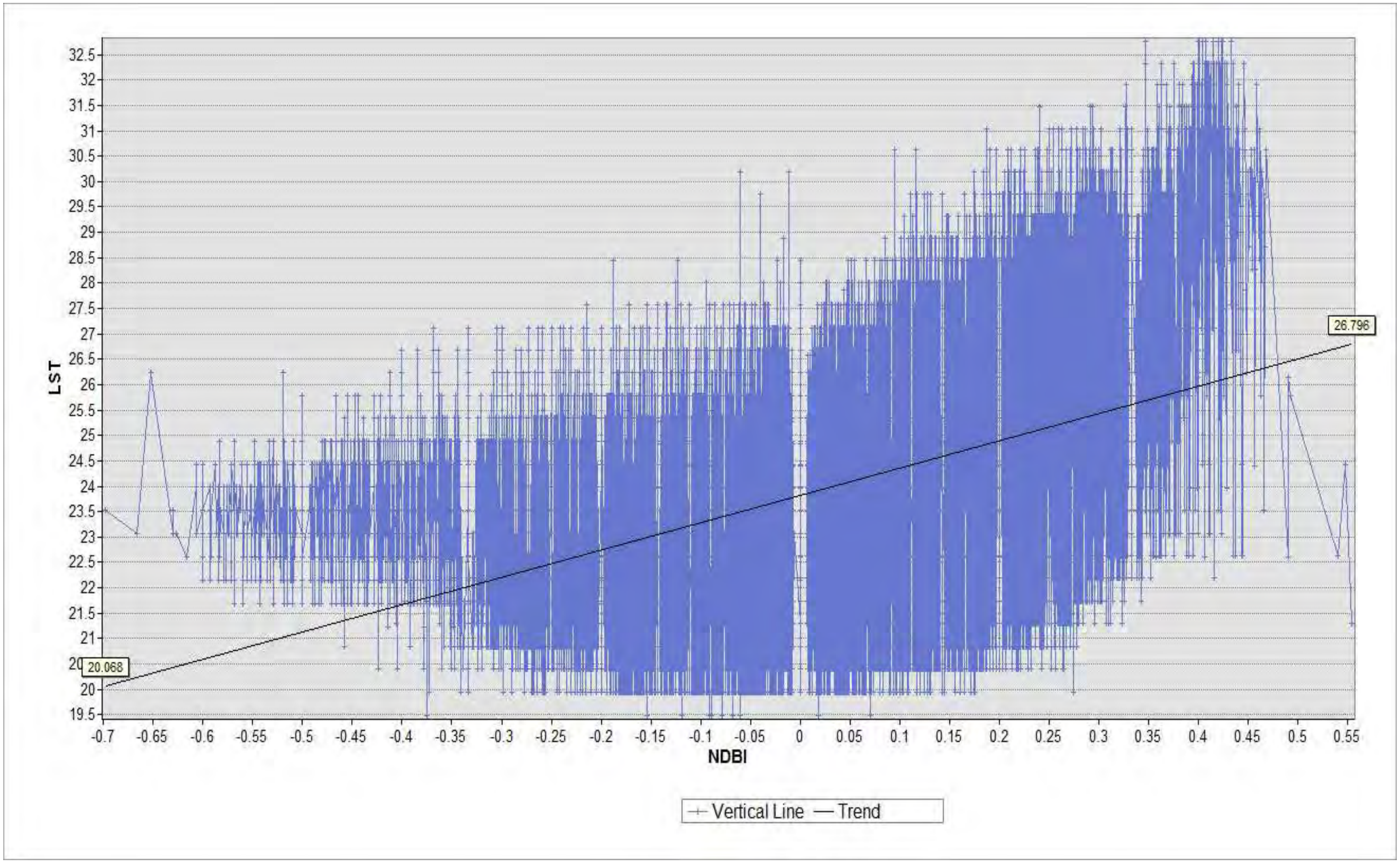
6.3 Simulated Graph of LST and LCA

LST variation according to Categories of LCA has been shown in Graph 6.7, 6.8 and 6.9. In the graph the different LST has been plotted according to each LCA types. The graphs represent that each LCA has different LST value and the characteristic of the LST changing with LCA value can be illustrated in those Graphs.

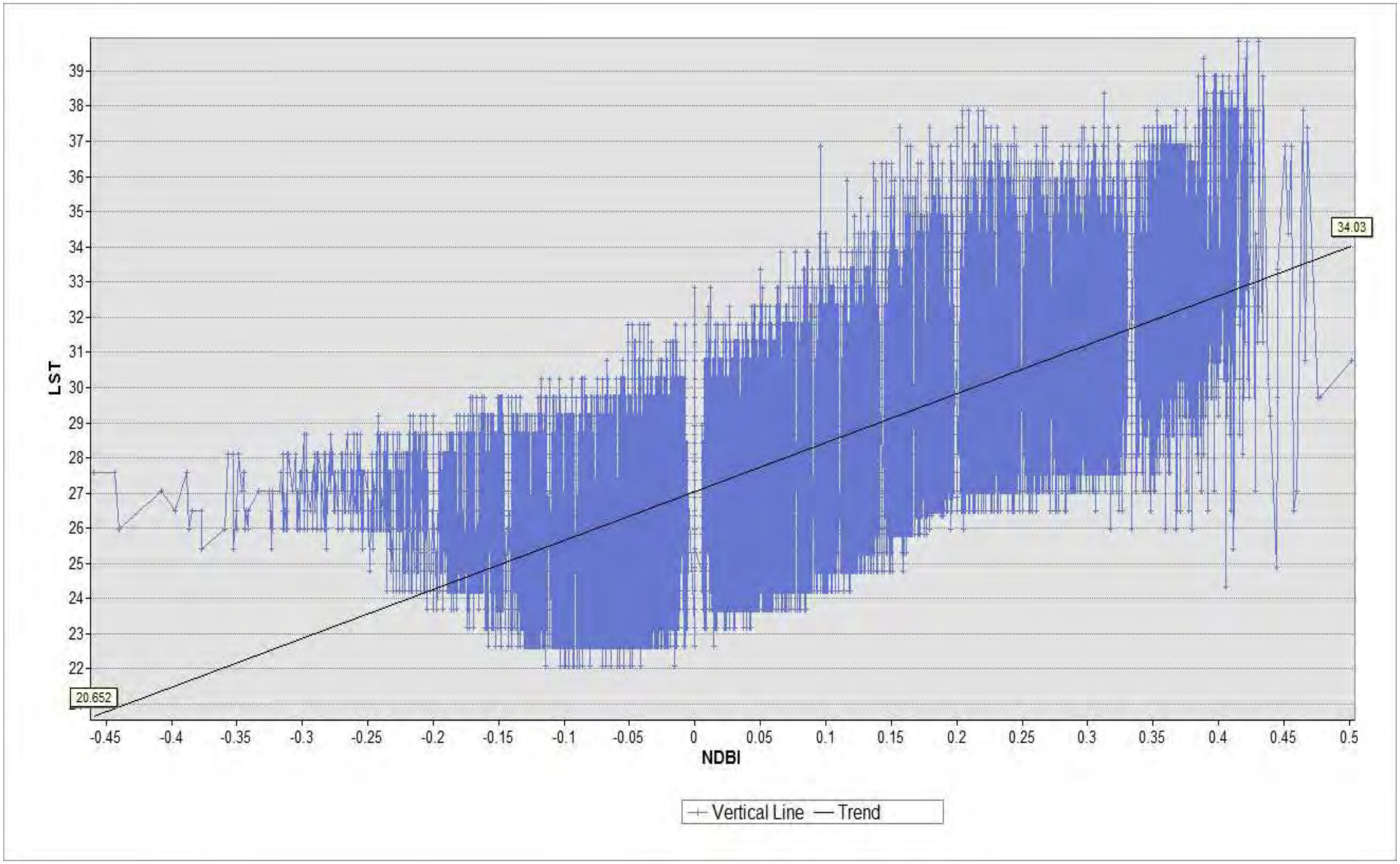
In the graph 6.7, the different categories of LCA show how LST is changing in this period. As for example LST value of bare soil starts from 32 °C but other bare soil does not show the same LST value. the LST of bare soil is changing with different Cell value shown in the graph.

The simulated line of the LST represents that the vegetation has the low LST but all vegetation are not same kind. Some vegetation show lower LST value means the leaf are more reflective or evaporators. The average Built-up area is grater LST value though the earth fill or a sand category has highest. Because it storage more heat than others material. So the material property is a factor for LST value.

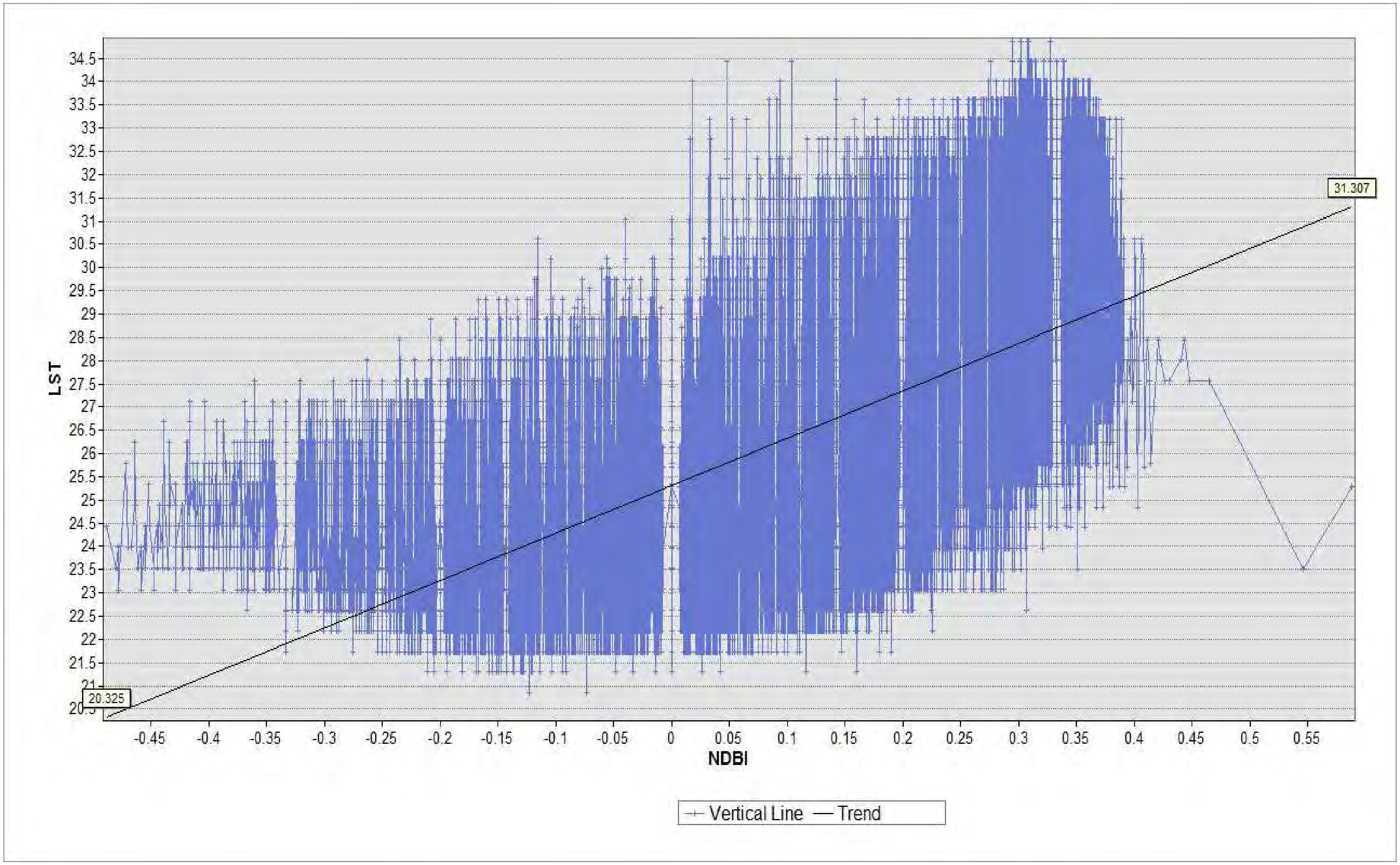
The trend of LST has been derived over the period of 1989 to 2010 is shown in the simulated Graph 6.10. The simulated graph represents that the LST is increasing. A liner equation of LST changing has been derived from the simulated graph which correlation value, R^2 is 0.08.



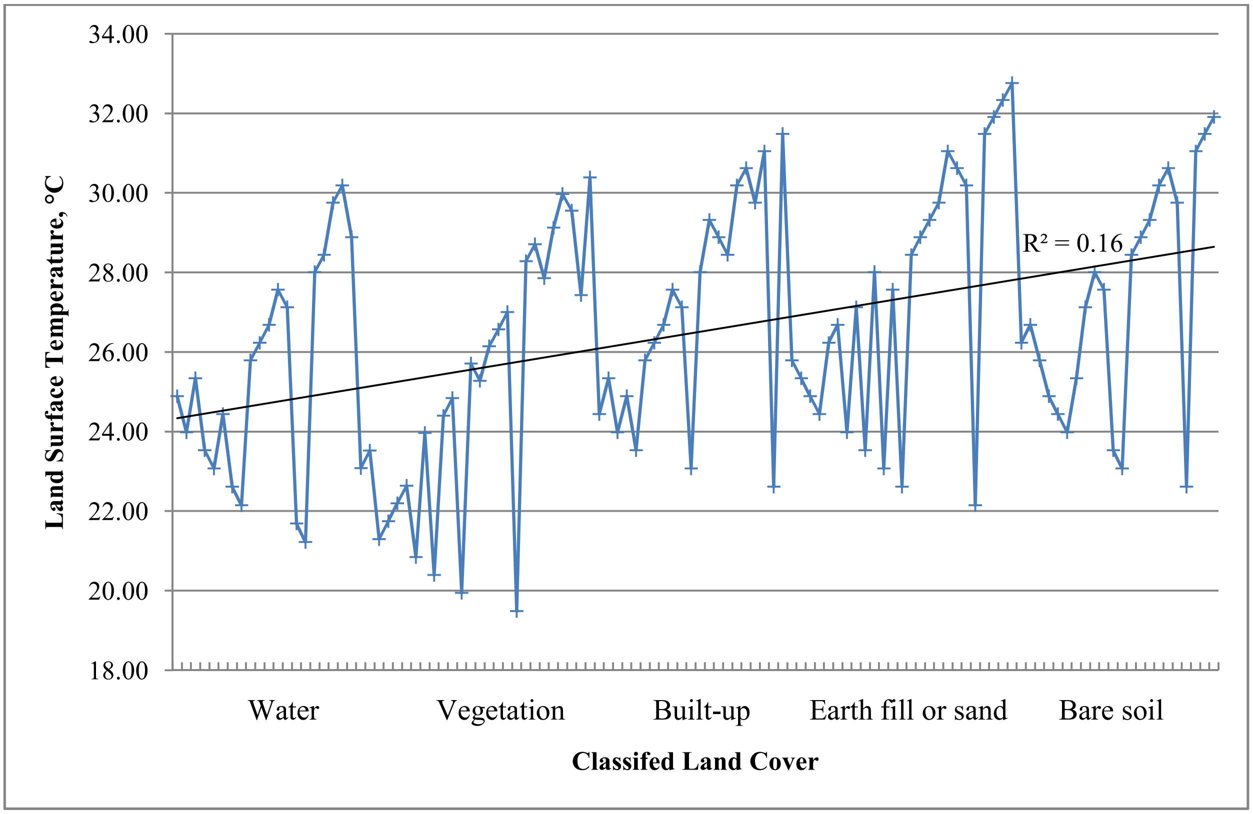
Graph 6.4: Simulated graph of NDBI and LST, 1989



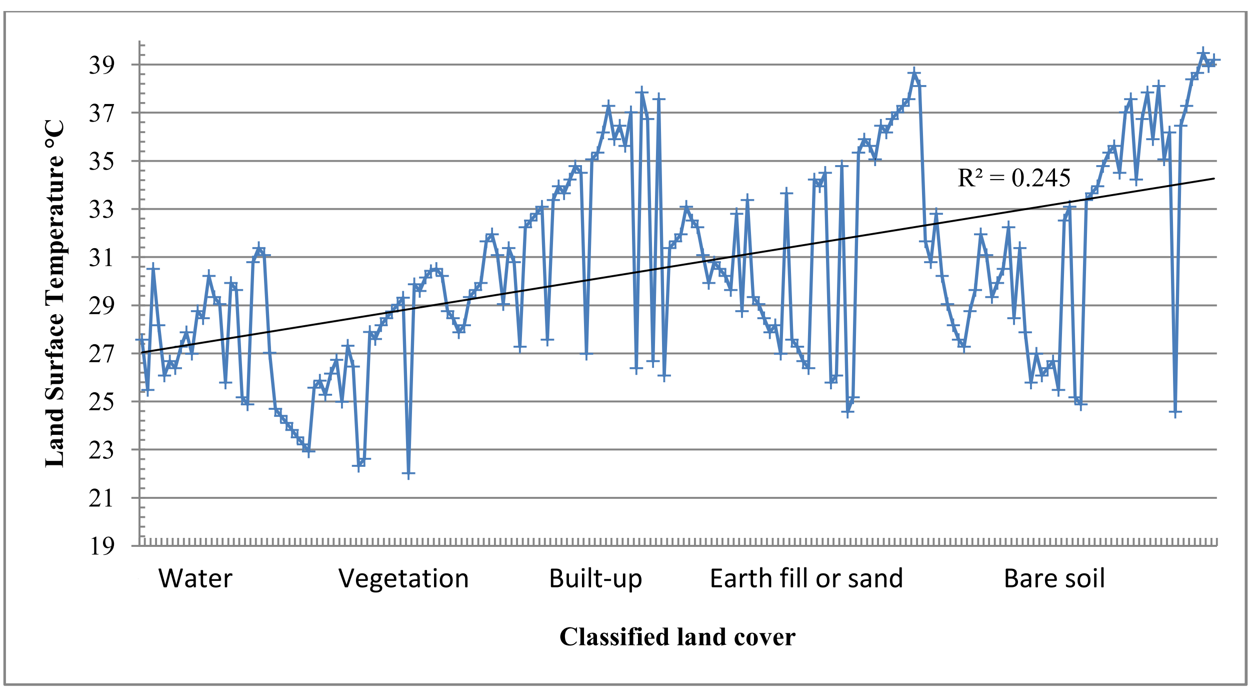
Graph 6.5: Simulated graph of NDBI and LST, 2000



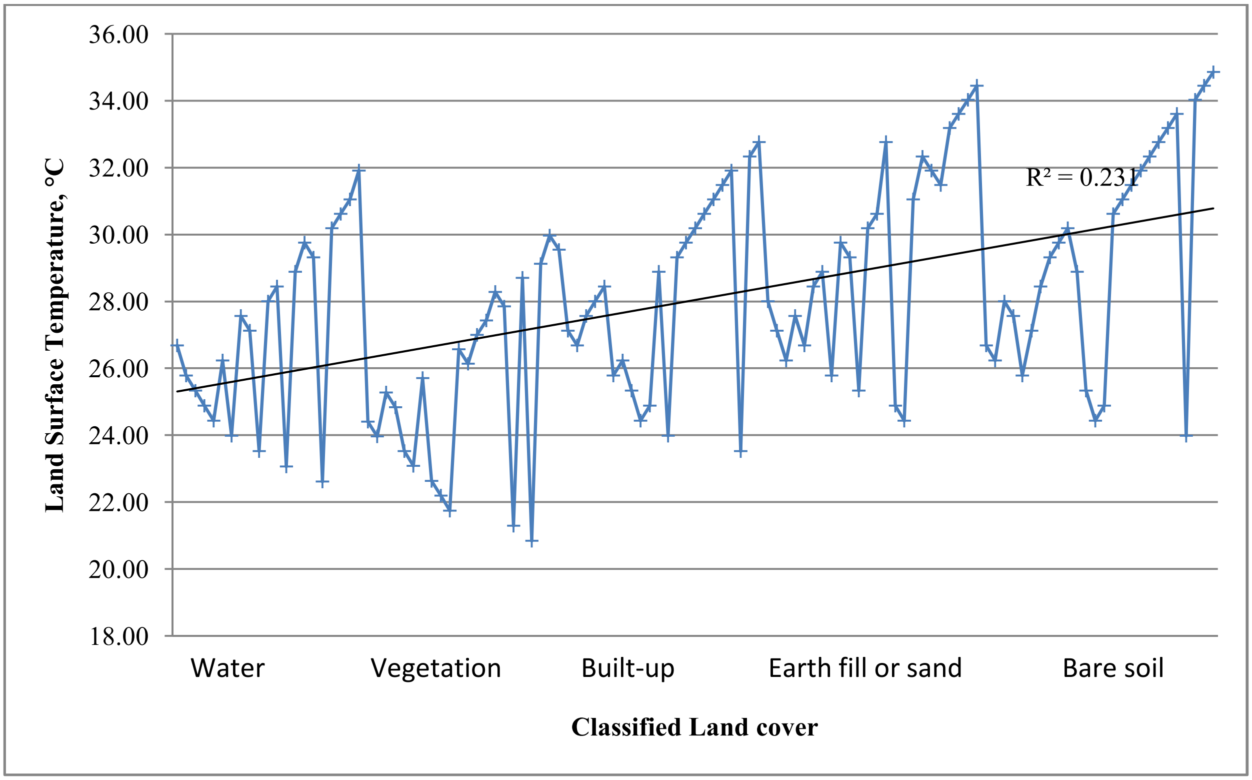
Graph 6.6: Simulated graph of NDBI and LST, 2010



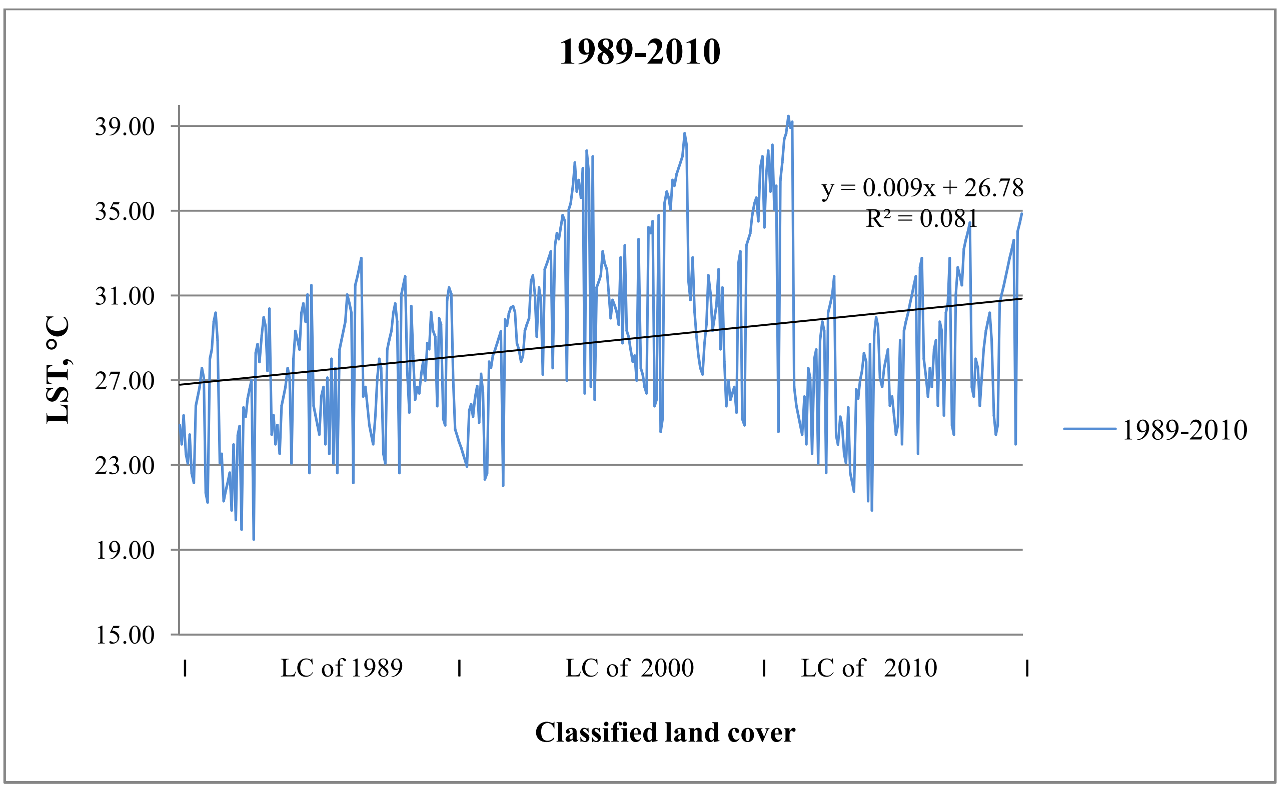
Graph 6.7: LST and LCA simulated curve, 1989



Graph 6.8: LST and LCA simulated curve, 2000



Graph 6.9: LST and LCA simulated curve, 2010



Graph 6.10: Trend of LST over the period of 1989 to 2010

6.4 Impacts of the LST changes on climate

The density of LST map has been simulated using the Kernel density estimation method shown in the Figure 6.3, 6.4 and 6.5. Greater values of densely LST areas represent more heat stress area. The density of LST simulated maps have been produced according to the *Thana* (Police station) boundaries. From the simulated maps the low and high density of LST areas can be determined and priority base areas can be selected for mitigation measurement of heat stress.

Greater values of density of LST are found little portion in year 1989 from the simulated map. Around 30 to 32°C is found in Tejgaon, Lalbagh, Kotwali, Sutrapur, Hazaribagh and Motijheel. Most of the urban area is below 28°C. Both Tejgaon and Hazaribagh are basically industrial built-up area of DMA. On the other hand Lalbagh, kotowali and sutrapur are compact residential built-up area. Motijheel is also compact commercial built-up area. So it is found that greater values of LST density are in the built-up area shown in Figure 6.3. In the year 2000 and 2010, scenario of the density LST map has been totally changed. With the increasing of built-up area of DMA, the density of LST is increased in the built-up areas shown in Figure 6.4 and 6.5. In the outer side of the DMA, water or vegetation types of LCA have been filled up with sand for future development. Those areas are also found greater value of LST density which also effect on the surrounding LST value. So it is proved that the LST is increasing and changing LCA such as urban development is one of the causes of this increasing LST.

This increasing LST value is adversely affect on the climate. Abrupt rainfall is also the cause of increasing temperatures (Trenberth and Shea, 2005). Heat stroke, heat exhaustion and heat cramps are the effects of high LST. People can fall victim to heat stroke, heat exhaustion and heat cramps in the area where the density of LST value is greater. The vulnerable heat spot area where the LST density is greater than 32°C is shown in the Figure 6.3, 6.4 and 6.5.

From the research it is found that vegetation and water types of LCA are decreasing day by day with the increasing LST value. It is adversely affect on biodiversity. Vegetation and water bodies help to reduce the temperature of the area. More over it protects different type of species which is important to ecosystem. If this scenario is going on that way, the environmental condition of the DMA is degraded very soon.

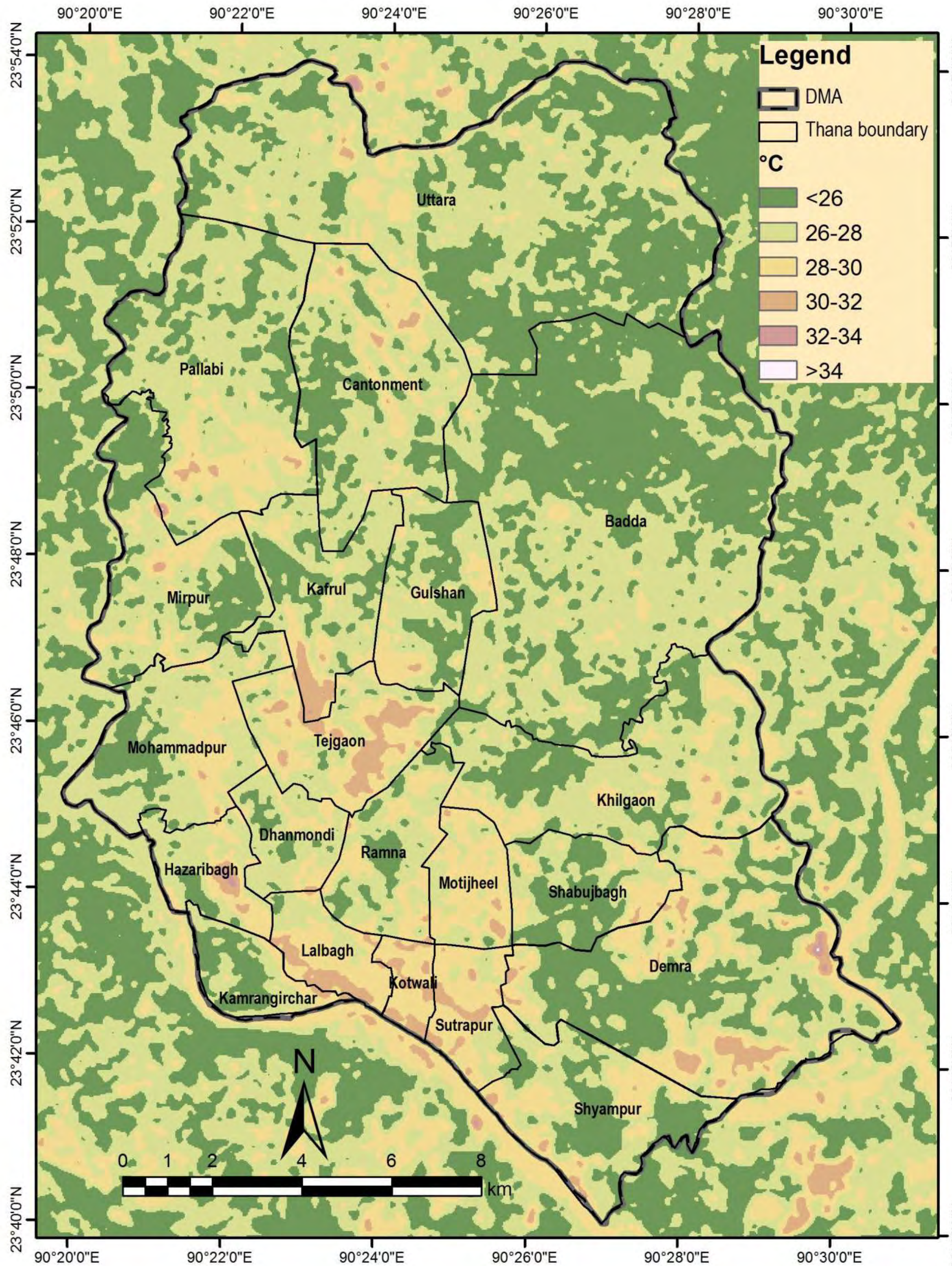


Figure 6.3: Thana boundary wise density simulated map of LST, January 1989

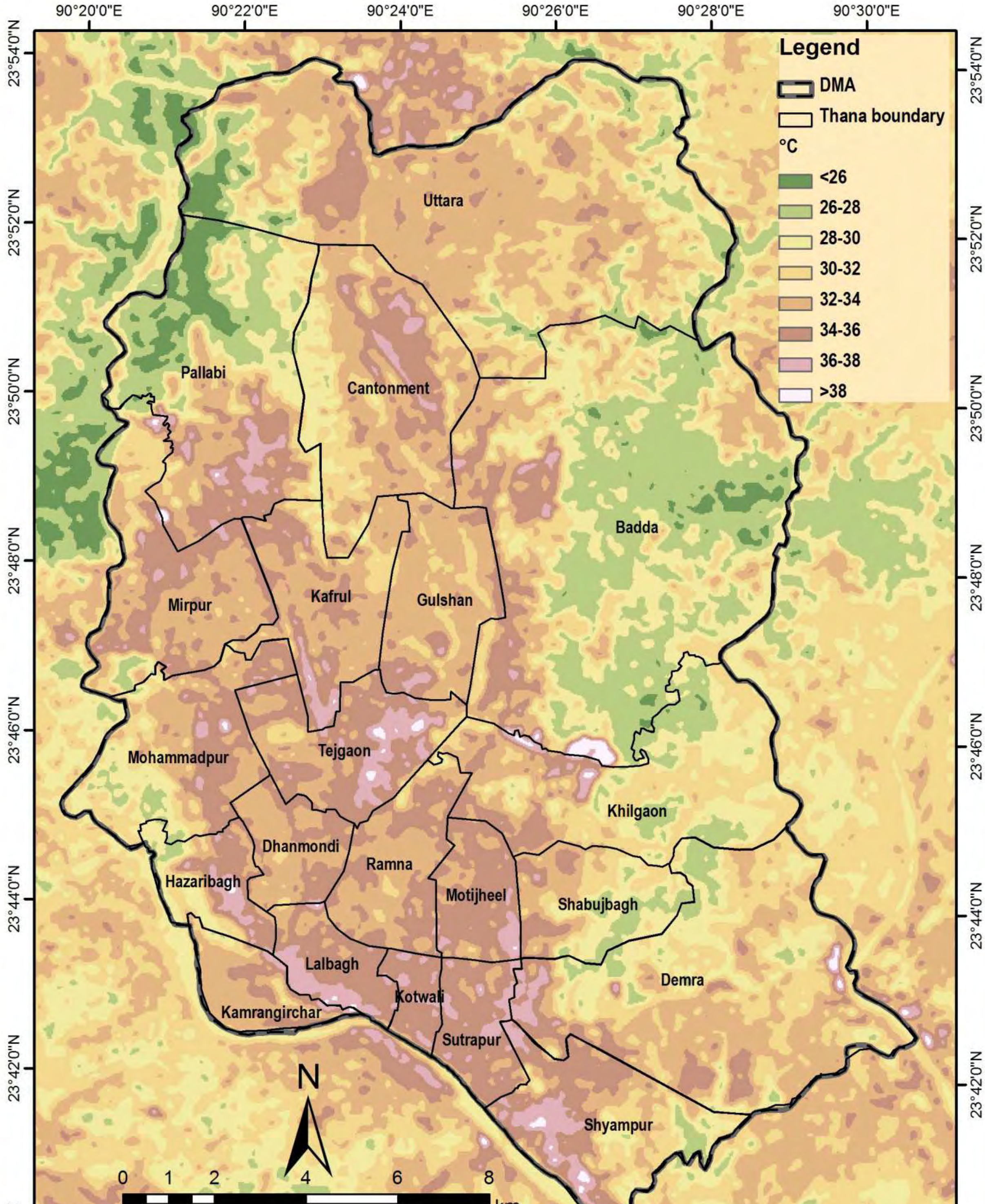


Figure 6.4: Thana boundary wise density simulated map of LST, February 2000

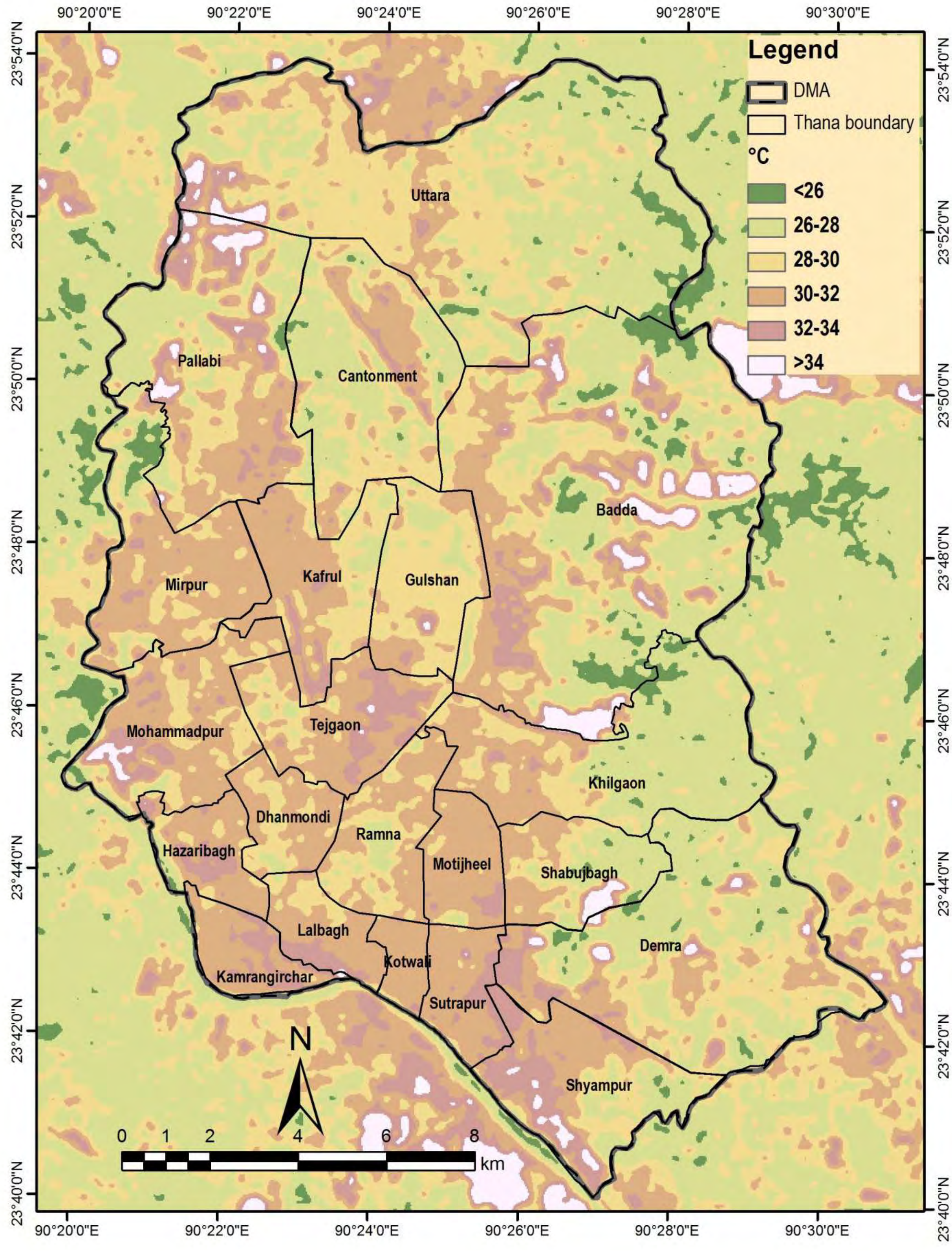


Figure 6.5: Thana boundary wise density simulated map of LST, January 2010

CHAPTER 07
FINDINGS OF THE RESEARCH

7 Major findings:

The major findings according to the research objective are given in the followings.

7.1 Findings from studying the association among urban development, changing of LCA and LST

1. From the study it is found that land cover areas (LCA) of DMA have changed rapidly during the period of 1989 to 2010. During this period the water land areas is decreasing by -13.42%. On the other hand, built-up areas are grown up by 23.18% in a constant growth rate.

2. From the visual analysis it is found that the built-up areas are increasing in centre of the city during the period of 1989 to 2000. It is also observed that the highest amounts of vegetation land areas (30.36 km^2) are converted into built-up areas during in this period.

3. It is clear from the visual analysis that the water land areas (having low LST value) is converted first into earth fill or sand / bare soil (having high LST value) and it is converted into built-up area . Due to this conversation, LST is continuously increasing.

4. Some built up areas are found with low LST value than the other built-up areas. From the visual interpretation, it is realized that the surrounding areas of DMA are either water bodies or vegetation. Therefore it is found that vegetation and water bodies can reduce the LST of the city.

5. It is found from the association study of the LCA and LST that LST is changing due to the change in LCAs.

6. Average LST of different years is different because of air temperature. In 2000 Highest LST is found where LST is low in 1989.

7.2 Findings from determining LST changes over different LCA in Dhaka city over different time-periods using remote sensing and spatial techniques of GIS

1. The average LST is correlated with the LC changing. Land of Vegetation category also affects the LST which is analyzed by correlating LST with NDVI. In 2000 the highest average LST of built-up areas is found because of low vegetation density (NDVI< 0.0). Where the LST of built-up comparatively lower than other types because of better vegetation density (NDVI < 0.2) in 2010.

2. It is found from visual interpretation that LST is depending on changing LCAs. The LST value has been increasing with the expansion of urban development such as built-up areas and earth fill or sand categories of land. Earth fills or sand has the highest LST found from the analysis.

3. Though the average LST of the year 2000 is greater than that of the year 2010, some land cover areas are found more LST in the year 2010 than the year 2000. So it is proved that LST is increasing day by day because of changing Land cover.

4. From the density estimation of LST map, it is found that density of higher LST of the study area is increasing during the period of 2000 to 2010 as well as high density of LST found in the Built-up and earth fill or sand categories land such as urban development.

5. The relationship between LST and NDBI proved that LST is increasing with the density of built-up land cover.

7.3 Findings from examining the impacts of the LST changes on climate of Dhaka using GIS-based spatial simulation

1. LST variation with the changing LCA is found from the simulated Curve over the period of 1989 to 2010. From the simulated curve it is found that LST change depends on LCA properties and LST is increased for each LCA than previous period.

2. LST value is gradually increased in this study area over this period found from the simulated curve which will effect on human health, air quality, increase energy demand and aquatic ecosystem health.

3. From the Kernel density estimation method, density of LST is found in the Figure 6.3, 6.4 and 6.5. More LST density is found from the built-up areas and earth fill or sand type categories of land. LST density is increased in the built-up area during the period 2000 to 2010. It was also found that Same LCA has different density of LST. It may be the cause of vegetation density of the cell, property of the LCA material, urban geometry, anthropogenic heat.

CHAPTER 08

RECOMMENDATIONS AND CONCLUSIONS

8.1 Recommendations

Recommendation 1:

It is found from the research that The LST value is highly positively correlated with the built-up areas. As built-up areas are growing up (23.18%) at a constant high growth rate from vegetation and water bodies, it should be controlled by land use planning. The detail area plan of DMA has already been published where the land use zoning and the other development has been defined. The authority should take necessary steps to control this undesirable development.

Recommendation 2:

The materials of the built-up area are almost concrete building and paved road. High priority areas of LST will be determined from the LST map and modifications to improve the solar reflectance of roofs in these areas. To reduce LST Cool Roof or green roof can be the better solution. Cool roofs are built with materials that give them high albedo and high emissivity in order to minimize the absorption of solar radiation and to maximize the release of outgoing long wave radiation (Van & Cohen, 2008) which will reduce the surface temperature. Green roofs are contained vegetation areas situated on built structures. In the same way to reduce LST of paved area, cool pavement option, increase solar reflectance by permeable concrete and turf pavers (Environmental Protection Agency, 2008) can be the better solution.

Recommendation 3:

Urban developments in DMA have resulted in a landscape predominantly characterized by the replacement of vegetation with hard, impermeable surfaces such as built-up area. The loss of green space in urban areas contributes significantly to LST increased through two mechanisms. Firstly, loss of green space results in reduced rates of evapotranspiration. Due to the reduction in the quantity of latent heat being converted into sensible heat through this process (Ordonez & Duinker, 2012), the overall cooling effect of vegetation will be diminished. Furthermore, the loss of shading from vegetation, particularly large trees, will result in an increase in the temperatures of the surfaces below. To reduce this effect the amount of green space in the DMA should be increased. Mechanisms to enhance green space may include planting programs, naturalization procedures and conservation of the park or open spaces. Besides The LST differences shown in LST map largely occurs due to planning practices that do not hold developers accountable for either preserving or planting trees and vegetation in order to conserve green space. In order to conserve the vegetation, the authority of DMA should modify the Official Plan and development guidelines to include measures that more stringently protect existing trees and encourage low impact development.

Recommendation 4:

Form the LC and LST map it is found that the surrounding area and the inner city have lots of wetland and water bodies which is low LST value. as from the LCC map it is found that the water bodies is continuously filled with sand, a official guideline should be made to stringently protect the existing water bodies. Otherwise the aquatic ecosystem is also hampered.

Recommendation 5:

From the Kernel density estimation map, it is found that LST is too high in some of the built-up areas. It may be the cause of urban geometry. Urban geometry means of the pattern of urban structure. Priority areas should be determined and a guideline should be made from the LST density map.

8.2 Conclusions:

Due to the rapid growth of population Dhaka city is developing day by day without proper planning, rules and regulation. Agricultural land, water bodies, vacant land, open spaces have been converted to built-up area such as concrete building, paved road, paved surface etc. As a result the Land surface temperature is increasing day by

day which is also building up Urban Heat Island effects (UHIE). The research is focused on the impacts of urban development on land cover areas (LCA) and land surface temperature (LST) in DMA. The results show LCA is changing continuously due to urban development. As a result natural covers have been turn into impervious surface and simulated graph represents that LST is increasing due to change of LCA.
LST is changing with not only the LCA transition but also due to other factors such as presence of vegetation and water bodies, urban geometry. As the growth rate of built-up area of DMA is too high, it is important to control this growth rate. Otherwise the LST value is increasing day by day and it adversely affects on micro climate. This can also negatively affect our economy of the country.

Therefore, some recommendations have been given on the basis of findings of the research which may reduce LST value of DMA. As the measures are selected on the preliminary assessment of these research findings, further study can be taken to reduce this LST value. However, if the rate of this changing of LST is going on in this rate, it is difficult to face the future unexpected natural hazards and lose the livable environment for living beings.

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Appendix A

Demographic feature

Table A1: Thana wise population distribution and area of the Dhaka metropolitan area (DMA)

SI No.	Name of the Thana	Area (km²)	Population census	Population census	Population census
			13-03-91	22-01-01	15-03-11
1	Adabor [split from Mohammadpur]	3.1	...	...	203,989
2	Badda [Badda]	21.7	...	...	536,621
3	Bangshal [split from Kotwali]	2	...	...	186,952
4	Biman Bandar [Airport]	14.5	...	5,079	10,626
5	Cantonment	8.6	...	117,464	131,864
6	Chak Bazar [split from Lalbagh]	1.2	...	...	156,147
7	Dakshinkhan [split from Uttara]	18.7	...	...	255,931
8	Darus Salam [split from Mirpur]	4.4	...	...	159,139
9	Demra	22.3	...	...	226,679
10	Dhanmondi	3.8	...	...	147,643
11	Gendaria [split from Sutrapur]	3.6	...	...	137,721
12	Gulshan	7.1	...	...	253,050
13	Hazaribagh [Hazaribagh]	5.3	...	127,370	185,639
14	Jatrabari [split from Demra]	10.7	...	...	443,601
15	Kadamtali [split from Shyampur]	7.5	...	...	370,895
16	Kafrul [Kafrul]	6	...	...	396,182
17	Kalabagan [split from Dhanmondi]	1.7	...	...	118,660
18	Kamrangir Char [Kamrangir Char]	3.7	...	...	93,601
19	Khilgaon	14	...	...	327,717
20	Khilkhet [split from Badda]	21.6	...	...	130,053
21	Kotwali	0.8	...	...	62,087
22	Lalbagh [Lalbagh]	2.2	...	...	369,933

Source: BBS,1991; BBS,2001 & BBS, 2010

SI No.	Name of the Thana	Area (km^2)	Population census 13-03-91	Population census 22-01-01	Population census 15-03-11
23	Mirpur	7.4	...	...	500,373
24	Mohammadpur	6.6	...	...	355,843
25	Motijheel	3.7	...	...	210,006
26	New Market [split from Dhanmondi]	1.3	...	...	49,523
27	Pallabi	9.4	...	...	596,835
28	Paltan [split from Motijheel]	1.4	...	...	59,639
29	Ramna	3.9	...	...	200,973
30	Rampura [split from Khilgaon]	2.8	...	...	224,079
31	Sabujbagh	6.5	...	291,207	376,421
32	Shah Ali [split from Mirpur & Pallabi]	4.9	...	...	115,489
33	Shahbagh [split from Ramna]	3.7	...	...	68,140
34	Sher-E-Bangla Nagar [split from Tejgaon, Kafrul & Mohammadpur]	5.2	...	...	137,573
35	Shyampur [Shyampur]	5.9	...	...	184,062
36	Sutrapur [Sutrapur]	2.6	...	...	211,210
37	Tejgaon	4.8	...	...	148,255
38	Tejgaon Industrial Area [split from Tejgaon & Gulshan]	2	...	...	146,732
39	Turag [split from Uttara]	23.3	...	...	157,316
40	Uttara	5.4	...	...	179,907
41	Uttar Khan [split from Uttara]	20.7	...	...	78,933
	Dhaka Metropolitan Area(DMA)	**306**	**4,173,626**	**6,482,877**	**8,906,039**

Source: BBS,1991; BBS,2001 & BBS, 2010

Table A2: Demographic Feature of Dhaka city, 1951- 2015

Year	Area (Sq. Km)	Population (Million)	% increase of population over preceding year	Density (Per Sq. Km.)
1951	85.45	0.4		4813.09
1961	124.45	0.7	74.76	5775.54
1974	335.79	2.0	187.76	6159.66
1981	509.62	3.4	66.32	6750.41
1991	1352.82	6.8	98.95	5059.16
2001	1352.82	10.7	56.51	7918.43
2011	1352.82	14.54	35.88	10,750
2015	1352.82	16.0	14.28	11,827

Source: BBS 1997, BBS 2003, Rabbani, 2010 & BBS, 2011

Appendix B
Derived data of LCA and LST

Table B1: Derived data of LST according to classified LCA in 1989

ROWID	VALUE	COUNT (No. of Cell)	B6_1989 (DN Value)	Classified LCA [1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
0	1	32193	130	2	19.54	24.11
1	2	14243	131	2	19.97	24.56
2	3	11117	131	4	19.97	26.84
3	4	15405	130	4	19.54	26.38
4	5	17089	129	4	19.11	25.92
5	6	12003	128	4	18.67	25.46
6	7	21642	128	3	18.67	25.46
7	8	14319	129	1	19.11	25.92
8	9	22190	130	3	19.54	26.38
9	10	6622	132	4	20.40	27.30
10	11	8009	132	5	20.40	27.30
11	12	6169	133	5	20.83	27.75
12	13	4267	133	4	20.83	27.75
13	14	10818	131	5	19.97	26.84
14	15	12368	129	5	19.11	25.92
15	16	7255	128	5	18.67	25.46
16	17	44683	127	1	18.24	24.99
17	18	36514	126	2	17.80	22.28
18	19	68357	127	2	18.24	22.74
19	20	88833	128	2	18.67	23.20
20	21	4501	127	4	18.24	24.99
21	22	66979	129	2	19.11	23.65
22	23	1769	127	5	18.24	24.99
23	24	7900	130	1	19.54	26.38
24	25	10423	127	3	18.24	24.99
25	26	53332	126	1	17.80	24.53
26	27	27245	125	1	17.36	24.06
27	28	27296	128	1	18.67	25.46
28	29	12539	130	5	19.54	26.38
29	30	25599	129	3	19.11	25.92
30	31	2575	126	3	17.80	24.53
31	32	7719	124	1	16.92	23.59
32	33	17002	131	3	19.97	26.84
33	34	10774	132	3	20.40	27.30
34	35	7638	133	3	20.83	27.75
35	36	3993	134	5	21.26	28.21
36	37	2399	135	3	21.68	28.66

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_1989 (DN Value)	Classified LCA [1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
37	38	850	136	5	22.10	29.11
38	39	4874	134	3	21.26	28.21
39	40	2469	134	4	21.26	28.21
40	41	1092	126	4	17.80	24.53
41	42	211	125	3	17.36	24.06
42	43	2478	123	1	16.47	23.12
43	44	4438	131	1	19.97	26.84
44	45	807	136	4	22.10	29.11
45	46	1900	135	5	21.68	28.66
46	47	209	126	5	17.80	24.53
47	48	14288	125	2	17.36	21.82
48	49	5728	132	2	20.40	25.01
49	50	191	125	4	17.36	24.06
50	51	17	125	5	17.36	24.06
51	52	1292	135	4	21.68	28.66
52	53	3781	124	2	16.92	21.36
53	54	2709	133	2	20.83	25.46
54	55	1225	134	2	21.26	25.91
55	56	3549	132	1	20.40	27.30
56	57	44	124	4	16.92	23.59
57	58	696	123	2	16.47	20.89
58	59	2624	133	1	20.83	27.75
59	60	198	136	2	22.10	26.80
60	61	449	135	2	21.68	26.35
61	62	1221	136	3	22.10	29.11
62	63	568	137	4	22.53	29.56
63	64	282	138	4	22.95	30.01
64	65	92	139	4	23.37	30.46
65	66	68	135	1	21.68	28.66
66	67	29	140	4	23.78	30.90
67	68	573	134	1	21.26	28.21
68	69	421	122	1	16.03	22.65
69	70	334	137	5	22.53	29.56
70	71	165	138	5	22.95	30.01
71	72	111	139	3	23.37	30.46
72	73	229	138	3	22.95	30.01
73	74	522	137	3	22.53	29.56
74	75	72	137	2	22.53	27.24
75	76	29	138	2	22.95	27.68
76	77	93	139	5	23.37	30.46
77	78	63	141	5	24.20	31.35
78	79	26	141	3	24.20	31.35
79	80	45	142	5	24.62	31.79

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_1989 (DN Value)	Classified LCA [1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
80	81	20	142	3	24.62	31.79
81	82	27	143	4	25.03	32.23
82	83	28	142	4	24.62	31.79
83	84	56	140	3	23.78	30.90
84	85	11	141	4	24.20	31.35
85	86	78	140	5	23.78	30.90
86	87	4	121	1	15.58	22.17
87	88	16	139	2	23.37	28.12
88	89	10	143	3	25.03	32.23
89	90	13	124	3	16.92	23.59
90	91	4	123	4	16.47	23.12
91	92	9	122	2	16.03	20.43
92	93	2	124	5	16.92	23.59
93	94	2	142	2	24.62	29.43
94	95	4	143	2	25.03	29.87
95	96	20	144	4	25.44	32.67
96	97	30	143	5	25.03	32.23
97	98	29	145	4	25.85	33.11
98	99	33	146	4	26.26	33.54
99	100	12	147	4	26.67	33.98
100	101	3	141	2	24.20	29.00
101	102	13	136	1	22.10	29.11
102	103	5	137	1	22.53	29.56
103	104	1	140	1	23.78	30.90
104	105	2	141	1	24.20	31.35
105	106	1	138	1	22.95	30.01
106	107	2	144	2	25.44	30.30
107	108	2	146	2	26.26	31.16
108	109	8	144	5	25.44	32.67
109	110	1	145	2	25.85	30.73
110	111	2	140	2	23.78	28.56
111	112	4	144	3	25.44	32.67
112	113	3	145	5	25.85	33.11
113	114	2	147	2	26.67	31.59

Table B2: Derived data of LST according to classified LCA in 2000

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
0	1	1843	162	5	25.61	31.66
1	2	6432	161	4	25.34	31.37
2	3	4856	162	4	25.61	31.66
3	4	3494	163	4	25.89	31.94
4	5	5964	159	5	24.78	30.79

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
5	6	11274	158	3	24.50	30.50
6	7	449	166	5	26.71	32.80
7	8	622	167	4	26.99	33.09
8	9	1529	165	4	26.44	32.52
9	10	2353	164	4	26.16	32.23
10	11	7858	160	4	25.06	31.08
11	12	9576	156	4	23.95	29.92
12	13	4479	154	2	23.38	27.02
13	14	12694	157	5	24.22	30.21
14	15	8921	159	4	24.78	30.79
15	16	9469	158	4	24.50	30.50
16	17	9929	157	4	24.22	30.21
17	18	8481	155	4	23.66	29.63
18	19	31550	153	5	23.10	29.04
19	20	23863	150	5	22.25	28.16
20	21	17051	148	5	21.69	27.57
21	22	15416	147	5	21.40	27.27
22	23	32439	152	5	22.82	28.75
23	24	23138	155	5	23.66	29.63
24	25	1334	163	5	25.89	31.94
25	26	1000	166	4	26.71	32.80
26	27	4118	160	5	25.06	31.08
27	28	28536	154	5	23.38	29.34
28	29	17809	156	5	23.95	29.92
29	30	8822	158	5	24.50	30.50
30	31	930	164	5	26.16	32.23
31	32	3503	152	4	22.82	28.75
32	33	29503	151	5	22.54	28.46
33	34	8482	148	1	21.69	27.57
34	35	2724	161	5	25.34	31.37
35	36	19658	149	5	21.97	27.87
36	37	11538	146	2	21.11	24.69
37	38	14117	145	2	20.83	24.40
38	39	17367	144	2	20.54	24.10
39	40	19617	143	2	20.25	23.81
40	41	17249	142	2	19.96	23.51
41	42	3079	142	5	19.96	25.78
42	43	430	141	1	19.67	25.48
43	44	11057	157	3	24.22	30.21
44	45	13	158	1	24.50	30.50
45	46	403	168	4	27.26	33.37
46	47	6967	154	4	23.38	29.34
47	48	3872	150	1	22.25	28.16

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
48	49	14475	146	5	21.11	26.97
49	50	6720	143	5	20.25	26.08
50	51	11826	141	2	19.67	23.21
51	52	11225	144	5	20.54	26.38
52	53	4144	143	1	20.25	26.08
53	54	9778	145	1	20.83	26.68
54	55	7031	144	1	20.54	26.38
55	56	13834	145	5	20.83	26.68
56	57	5479	140	2	19.38	22.92
57	58	5157	153	4	23.10	29.04
58	59	5096	152	3	22.82	28.75
59	60	3769	151	3	22.54	28.46
60	61	1905	149	3	21.97	27.87
61	62	1204	141	5	19.67	25.48
62	63	8506	149	2	21.97	25.57
63	64	8151	150	2	22.25	25.86
64	65	9191	148	2	21.69	25.28
65	66	11462	147	1	21.40	27.27
66	67	2220	151	4	22.54	28.46
67	68	7793	151	2	22.54	26.15
68	69	5879	153	2	23.10	26.73
69	70	10098	147	2	21.40	24.98
70	71	5934	149	1	21.97	27.87
71	72	11792	146	1	21.11	26.97
72	73	642	149	4	21.97	27.87
73	74	1552	152	1	22.82	28.75
74	75	1252	150	4	22.25	28.16
75	76	41	146	4	21.11	26.97
76	77	2784	150	3	22.25	28.16
77	78	7863	154	3	23.38	29.34
78	79	2528	151	1	22.54	28.46
79	80	9323	155	3	23.66	29.63
80	81	10584	156	3	23.95	29.92
81	82	8349	162	3	25.61	31.66
82	83	7149	163	3	25.89	31.94
83	84	10201	160	3	25.06	31.08
84	85	45	157	1	24.22	30.21
85	86	462	154	1	23.38	29.34
86	87	340	169	4	27.53	33.65
87	88	922	153	1	23.10	29.04
88	89	6482	153	3	23.10	29.04
89	90	3098	155	2	23.66	27.31
90	91	9302	161	3	25.34	31.37

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
91	92	10909	159	3	24.78	30.79
92	93	7066	152	2	22.82	26.44
93	94	263	148	4	21.69	27.57
94	95	162	138	2	18.80	22.32
95	96	1248	139	2	19.09	22.62
96	97	705	165	5	26.44	32.52
97	98	1684	142	1	19.96	25.78
98	99	132	147	4	21.40	27.27
99	100	12	145	4	20.83	26.68
100	101	1127	157	2	24.22	27.88
101	102	2041	156	2	23.95	27.59
102	103	225	167	5	26.99	33.09
103	104	91	156	1	23.95	29.92
104	105	6	144	4	20.54	26.38
105	106	211	155	1	23.66	29.63
106	107	602	147	3	21.40	27.27
107	108	644	158	2	24.50	28.17
108	109	339	140	5	19.38	25.17
109	110	74	139	5	19.09	24.87
110	111	279	159	2	24.78	28.45
111	112	131	160	2	25.06	28.73
112	113	61	161	2	25.34	29.02
113	114	20	162	2	25.61	29.30
114	115	5770	164	3	26.16	32.23
115	116	4429	165	3	26.44	32.52
116	117	3270	166	3	26.71	32.80
117	118	2495	167	3	26.99	33.09
118	119	1126	148	3	21.69	27.57
119	120	1824	168	3	27.26	33.37
120	121	134	168	5	27.26	33.37
121	122	932	170	3	27.80	33.94
122	123	184	171	4	28.07	34.22
123	124	1316	169	3	27.53	33.65
124	125	629	171	3	28.07	34.22
125	126	301	173	3	28.61	34.78
126	127	99	169	5	27.53	33.65
127	128	76	170	5	27.80	33.94
128	129	448	172	3	28.34	34.50
129	130	278	146	3	21.11	26.97
130	131	221	174	3	28.88	35.06
131	132	253	170	4	27.80	33.94
132	133	121	175	3	29.15	35.34
133	134	48	173	5	28.61	34.78

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
134	135	47	178	3	29.95	36.18
135	136	9	182	3	31.02	37.28
136	137	67	177	3	29.69	35.90
137	138	36	179	3	30.22	36.45
138	139	93	176	3	29.42	35.62
139	140	29	175	5	29.15	35.34
140	141	25	176	5	29.42	35.62
141	142	38	172	5	28.34	34.50
142	143	145	172	4	28.34	34.50
143	144	41	181	5	30.75	37.01
144	145	29	183	5	31.28	37.56
145	146	63	171	5	28.07	34.22
146	147	28	180	5	30.49	36.73
147	148	21	184	5	31.55	37.83
148	149	9	181	3	30.75	37.01
149	150	19	144	3	20.54	26.38
150	151	18	177	5	29.69	35.90
151	152	4	142	4	19.96	25.78
152	153	10	185	5	31.81	38.11
153	154	5	184	3	31.55	37.83
154	155	35	174	5	28.88	35.06
155	156	2	143	4	20.25	26.08
156	157	18	180	3	30.49	36.73
157	158	142	173	4	28.61	34.78
158	159	2	138	4	18.80	24.57
159	160	1	140	4	19.38	25.17
160	161	98	145	3	20.83	26.68
161	162	22	178	5	29.95	36.18
162	163	6	183	3	31.28	37.56
163	164	83	175	4	29.15	35.34
164	165	66	177	4	29.69	35.90
165	166	82	176	4	29.42	35.62
166	167	110	174	4	28.88	35.06
167	168	132	140	1	19.38	25.17
168	169	3	137	2	18.51	22.02
169	170	16	139	1	19.09	24.87
170	171	6	138	5	18.80	24.57
171	172	5	159	1	24.78	30.79
172	173	5	164	2	26.16	29.87
173	174	31	179	5	30.22	36.45
174	175	25	182	5	31.02	37.28
175	176	4	186	5	32.07	38.38
176	177	10	187	5	32.33	38.65

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
177	178	2	190	5	33.12	39.47
178	179	1	188	5	32.59	38.93
179	180	1	189	5	32.86	39.20
180	181	3	143	3	20.25	26.08
181	182	2	161	1	25.34	31.37
182	183	91	179	4	30.22	36.45
183	184	67	178	4	29.95	36.18
184	185	66	180	4	30.49	36.73
185	186	20	181	4	30.75	37.01
186	187	6	182	4	31.02	37.28
187	188	5	163	2	25.89	29.58
188	189	5	165	2	26.44	30.15
189	190	2	183	4	31.28	37.56
190	191	1	166	2	26.71	30.43
191	192	1	187	4	32.33	38.65
192	193	2	185	4	31.81	38.11
193	194	1	160	1	25.06	31.08

Table B3: Derived data of LST according to classified LCA in 2010

ROWID	VALUE	COUNT (No. of Cell)	B6_2010 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
0	1	13529	4	133	20.83	27.75
1	2	67854	2	133	20.83	25.46
2	3	75814	2	132	20.40	25.01
3	4	8428	4	132	20.40	27.30
4	5	3890	1	133	20.83	27.75
5	6	29634	5	134	21.26	28.21
6	7	17434	2	135	21.68	26.35
7	8	14701	4	136	22.10	29.11
8	9	14674	4	135	21.68	28.66
9	10	36132	2	134	21.26	25.91
10	11	13274	1	131	19.97	26.84
11	12	24960	1	130	19.54	26.38
12	13	32237	1	129	19.11	25.92
13	14	22819	1	128	18.67	25.46
14	15	4340	4	131	19.97	26.84
15	16	68292	2	131	19.97	24.56
16	17	50215	2	130	19.54	24.11
17	18	15179	4	134	21.26	28.21
18	19	11675	4	137	22.53	29.56

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
19	20	5301	4	139	23.37	30.46
20	21	3907	4	140	23.78	30.90
21	22	2801	4	141	24.20	31.35
22	23	8606	2	136	22.10	26.80
23	24	22757	5	133	20.83	27.75
24	25	30874	5	135	21.68	28.66
25	26	28587	5	136	22.10	29.11
26	27	19846	5	137	22.53	29.56
27	28	2106	3	136	22.10	29.11
28	29	1090	3	134	21.26	28.21
29	30	299	3	132	20.40	27.30
30	31	8216	5	131	19.97	26.84
31	32	7115	1	132	20.40	27.30
32	33	7860	4	138	22.95	30.01
33	34	1569	3	135	21.68	28.66
34	35	624	3	133	20.83	27.75
35	36	13599	5	132	20.40	27.30
36	37	5852	5	130	19.54	26.38
37	38	689	5	128	18.67	25.46
38	39	2543	5	129	19.11	25.92
39	40	19844	2	129	19.11	23.65
40	41	2373	3	137	22.53	29.56
41	42	7501	1	127	18.24	24.99
42	43	1814	4	130	19.54	26.38
43	44	11956	5	138	22.95	30.01
44	45	87	4	128	18.67	25.46
45	46	4432	2	128	18.67	23.20
46	47	559	2	127	18.24	22.74
47	48	456	4	129	19.11	25.92
48	49	1185	2	138	22.95	27.68
49	50	2346	3	138	22.95	30.01
50	51	887	1	135	21.68	28.66
51	52	1903	1	134	21.26	28.21
52	53	117	5	127	18.24	24.99
53	54	2572	1	126	17.80	24.53
54	55	110	3	131	19.97	26.84
55	56	372	1	136	22.10	29.11
56	57	3319	2	137	22.53	27.24
57	58	7444	5	139	23.37	30.46
58	59	2594	3	140	23.78	30.90
59	60	2530	3	139	23.37	30.46
60	61	400	2	139	23.37	28.12
61	62	157	1	137	22.53	29.56

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
62	63	33	3	130	19.54	26.38
63	64	1964	4	142	24.62	31.79
64	65	1418	4	143	25.03	32.23
65	66	4835	5	140	23.78	30.90
66	67	1294	4	144	25.44	32.67
67	68	2429	3	141	24.20	31.35
68	69	2280	3	142	24.62	31.79
69	70	1051	4	145	25.85	33.11
70	71	888	4	146	26.26	33.54
71	72	858	4	147	26.67	33.98
72	73	633	4	148	27.08	34.41
73	74	2199	5	141	24.20	31.35
74	75	804	3	147	26.67	33.98
75	76	1003	5	142	24.62	31.79
76	77	567	5	143	25.03	32.23
77	78	4	3	129	19.11	25.92
78	79	3	3	128	18.67	25.46
79	80	2141	3	143	25.03	32.23
80	81	211	5	144	25.44	32.67
81	82	970	3	146	26.26	33.54
82	83	1062	3	145	25.85	33.11
83	84	1587	3	144	25.44	32.67
84	85	928	1	125	17.36	24.06
85	86	67	5	145	25.85	33.11
86	87	9	5	126	17.80	24.53
87	88	537	3	148	27.08	34.41
88	89	42	5	146	26.26	33.54
89	90	248	3	149	27.48	34.84
90	91	81	3	150	27.89	35.28
91	92	279	4	149	27.48	34.84
92	93	130	2	140	23.78	28.56
93	94	82	1	138	22.95	30.01
94	95	11	5	147	26.67	33.98
95	96	18	2	142	24.62	29.43
96	97	38	2	141	24.20	29.00
97	98	18	1	140	23.78	30.90
98	99	30	1	139	23.37	30.46
99	100	12	4	127	18.24	24.99
100	101	33	2	126	17.80	22.28
101	102	53	1	124	16.92	23.59
102	103	12	2	143	25.03	29.87
103	104	2	2	125	17.36	21.82
104	105	99	4	150	27.89	35.28

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil

ROWID	VALUE	COUNT (No. of Cell)	B6_2000 (DN Value)	Classified LCA[1]	At-Satellite Temperature(T_B)	Land Surface Temperature(LST)
105	106	6	2	144	25.44	30.30
106	107	10	1	141	24.20	31.35
107	108	5	2	146	26.26	31.16
108	109	2	2	145	25.85	30.73
109	110	2	1	142	24.62	31.79
110	111	1	1	143	25.03	32.23
111	112	1	1	145	25.85	33.11
112	113	19	4	151	28.29	35.71
113	114	5	4	152	28.69	36.13
114	115	4	3	151	28.29	35.71

Table B4: Land cover areas change over the period of 1989 to 2010 in DMA (derived from 30 m spatial resolution)

Land cover area Types (Unit: no. of cell)		**2000**					
		Water	**Vegetation**	**Built-up**	**Earth fill or sand**	**Bare soil**	**Total**
1989	Water	13315	42478	5520	5365	18278	84956
	Vegetation	2929	23452	33728	10192	47316	117617
	Built-up	2293	5114	48097	2015	8867	66386
	Earth fill or sand	879	3297	7019	12866	10070	34131
	Bare soil	2324	4063	12297	5728	12486	36898
	Total	21740	78404	106661	36166	97017	339988
Land cover area Types (Unit: no. of cell)		**2010**					
		Water	**Vegetation**	**Built-up**	**Earth fill or sand**	**Bare soil**	**Total**
2000	**Water**	12248	4268	2643	774	1806	21739
	Vegetation	14749	34343	9277	10341	9693	78403
	Built-up	990	6465	95728	606	2873	106662
	Earth fill or sand	485	8279	13085	1879	12439	36167
	Bare soil	10845	44847	24466	3262	13597	97017
	Total	39317	98202	145199	16862	40408	339988
Land cover area Types (Unit: no. of cell)		**2010**					
		Water	**Vegetation**	**Built-up**	**Earth fill or sand**	**Bare soil**	**Total**
1989	**Water**	23168	25478	16279	9640	10389	84954
	Vegetation	6501	45863	47999	3315	13940	117618
	Built-up	4749	8138	49883	1179	2437	66386
	Earth fill or sand	944	8605	14286	1849	8448	34132
	Bare soil	3954	10119	16750	881	5194	36898
	Total	39316	98203	145197	16864	40408	339988

[1] 1= Water, 2= Vegetation, 3= Built-up, 4= Earth fill or sand & 5= Bare soil