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Impact of Urbanization on Urban Climate: A GIS and Remote Sensing Approach on Dhaka City (2000-2025)

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Dissertation on:

Impact of Urbanization on Urban Climate: A GIS and Remote Sensing Approach on Dhaka City (2000-2025)

A Thesis Submitted to Independent University, Bangladesh in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Management

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Declaration

This is declaration by Riyasad Iqbal (2120212) that this thesis titled **“Impact of Urbanization on Urban Climate: A GIS and Remote Sensing Approach on Dhaka City (2000-2025)”** was prepared and submitted by me to fulfill the requirements for my Masters in Environmental Management degree. The research supervised of Dr. K. Ayaz Rabbani, Dean, School of Environment and Life Sciences & Associate Professor, Department of Environmental Science and Management.

I am also declaring that this thesis represents my own original work based on research and analysis carried out by me. All sources of information, data, and materials obtained from other authors, institutions, or publications have been properly acknowledged, cited, and referenced in accordance with academic standards. My thesis has not been submitted to any other institution for the award of any degree or qualification.

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Abstract

Unplanned and swift urbanization from 2000-2025 has changed Dhaka's land use and climate significantly. GIS and remote sensing were utilized in this thesis to quantify land cover change and the impact of the urban heat island (UHI) effect in Dhaka City. Four land cover categories (Built-up, Vegetation, Open Land, Water,) were classified through using multi-date Landsat satellite images (2000, 2010, 2020, 2025) to assess spatiotemporal transformations. To retrieve land surface temperatures (LST) for each period, thermal infrared data were processed which enabled analysis of how urban expansion affects and increases heating of the surface. Methodology included change detection, supervised classification, and LST retrieval, validated with field data and literature. Findings of a sharp increase in built-up area (from 29% to 41% of the area) and loss of vegetated land (from 28% to 11%) between 2000 and 2025 were recorded. Higher mean and maximum LST in urbanized zones were correlated with these land cover shifts, emphasizing the increasing UHI effect. Hottest surfaces were discovered in developed bare lands recently and also in dense urban areas. Water bodies and green spaces remained cooler on average. Some irregularity in LST patterns were observed due to seasonal differences in image acquisition, highlighting the need for interpretation cautiously. Dhaka's urban expansion has led to greater heat retention and spatially increased UHI hotspots according to the findings of this research. Academic contributions of this thesis was by exploring updated, spatially explicit evidence of relation between land cover change and urban climate in Dhaka. These insights are significant for urban environmental management, illustrating the critical importance of sustainable planning interventions (e.g. preserving green infrastructure) to mitigate rising urban heat and improve livability in megacities like Dhaka.

Keywords: Urban Heat Island (UHI), Land Cover Change, Remote Sensing, NDVI and LST, Dhaka City

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Chapter 1: Introduction

The process of urbanization has been acclaimed to be one of the most significant environmental problems globally over the recent days. The alteration of local climates is observable during the occurrence of expansion of city-centres. Urban climate is the modified climate of the cities that are due to human changes of land surfaces and the atmosphere. A famous example is the urban heat island (UHI) phenomenon, in which the cities experience a higher temperature than the rural areas. This does not occur just in the mega cities but also in smaller cities. UHI was first noted as early as the 19 th century when Luke Howard observed that cities appear as islands of increased temperature on an isothermal map (Howard, 1833). UHI can largely be caused by the use of high thermal capacity and low albedo building materials (asphalt, concrete) in large amounts, a decrease in vegetation and evapotranspiration in urban areas, and by the amount of waste heat generated by energy consumption (transportation, industry, air conditioning). These reasons cause the urban environment to retain more heat during the day and release it slowly during the night than the rural environmental one. Consequently, built-up areas often have high air and surface temperatures particularly at night, which result in an UHI effect that can influence property weather and climatic patterns.

Over the past century, there has been a massive urbanization trend in the world with regard to the magnitude as well as the rate at which it has been rising. In 1900 the urban population was only about 10 percent of the total population of the world, which increased to 30 percent in 1950. In the world, an estimated 47 percent of the population was urban in the year 2000. By 2021, the urban population in the world had reached the level of approximately 4.46 billion people (nearly half of the human population), exceeding the rural population of 3.42 billion people. It has been projected that by 2050 the world population will be almost 6.7 billion living in cities - approximately two-thirds of the estimated world population (Ritchie & Roser, 2021; United Nations, 2018). The rate at which people grow in urban areas has increased significantly in the developing areas compared to the developed areas. Indeed, the increase in the urban population in the period between 2021 and the year 2050 is expected to be about 90 percent in Asia and Africa. This fast urbanization all through the world is putting undue pressure on the land resource and affecting the climate at various levels both the local level micro climatic levels and regional weather patterns.

Bangladesh is a good example of such trends because it has witnessed rapid urbanization over the past decades. The speed at which the urban population in the country is growing on average at 3 percent a year. In Asia, most countries experienced a high rate of urbanization, but in this case, Bangladesh had one of the highest rates of urbanization (around 4.8 per cent per year) during this period (between 2000 and 2011) and was ranked as fourth in Asia. However, this is an urbanization that is particularly concentrated in Dhaka, the capital city. The political and economic hub of Bangladesh is Dhaka, which has now emerged to be one of the fastest-growing megacities in the globe. The population of Greater Dhaka increased to approximately 335,000 in 1950 up to more than 13 million in 2007 with the population expected to rise to 22-25 million by the year 2025. It has been estimated that Dhaka may have the second-largest population in the world in 2025, and its metropolitan area may have approximately 24-36 million residents (Konuma & Genarri, 2014; Islam, 2013; UN-Habitat, 2016). This unsuitable population growth paired with uncontrolled urbanization has changed the topography and nature of Dhaka. Agricultural land, wetlands and vegetated open space areas have been turned into urban settlements to house the ever increasing population and their residential and infrastructural requirements as well as places of employment. The natural surfaces of the city that control the temperature and drainage systems have been significantly decreased as the urban growth and land grabbing has intensified thereby putting increased stress on the environment.

More importantly, the process of fast urbanization of Dhaka is directly connected to the new issues of the urban climate. The global climate change and the urban effects are already being experienced negatively in the city. The climate in Bangladesh is becoming warmer and less predictable and more extreme weather occurs, irregular rainfall and more frequent climate-related disasters (floods, cyclones, etc.). The tight urban structure of Dhaka and the insufficient availability of green spaces have aggravated such issues as heat distress and urban flooding. Research projects that most urban sectors in Dhaka will be hard hit by climate change in the event that current trends persist in the urban centers such as in public health, infrastructure, and agriculture around the urban areas. There is already an increased ambient temperature and heat index values in Dhaka compared to the other surrounding districts, which means that an urban heat island effect is increasing. Extreme heat waves in recent years have taken their toll on Dhaka; in 2024 the heat index in the city was very dangerous (48°C), which resulted in health warnings. In 2025, a report by World Bank ranked Dhaka as one of the most heat-stressed cities in the world, with its heat index increasing at a rate 65 times higher than the country on average. The paper has recorded that the maximum temperature in Bangladesh has already increased by approximately 1.1°C in a year since 1980, and the productivity losses in the heat are already costing the country billions of dollars (World Bank, 2021). Therefore, urbanization and climate change interact with each other in a threatening way to the livability and sustainability of Dhaka.

In the present context, it is essential to learn how the high rate of urbanization in Dhaka has had an impact on land cover of the city and what repercussions the shifts in land cover have had on the land surface temperature (LST) and urban climate of this city. The type of land cover (the physical cover of the land by types of objects such as built-up structures, vegetation, water, soil, etc) is important in the surface energy balance. The replacement of vegetated surfaces with impervious built surfaces normally leads to amplification of local LST, a factor that contributes towards UHI effects. On the other hand, vegetation and water bodies are likely to cause moderation of temperatures by shading and evaporative cooling. The relations between these variables have been proved by recent studies on Dhaka: where there are a higher number of fractions of concrete and bare soil, LST is significantly higher, whereas where there are more vegetation or water, LST is lower. As an example, one study has concluded that changing a vegetated or wet land in Dhaka to built-up land is capable of increasing the average temperature of the surface by approximately

2 °C. The spatial distribution and density of urban growth is also important, unplanned sprawl and overcrowded slum regions are usually the areas with the highest local temperatures. These concentration areas in the thermal landscape of Dhaka are in fact urban heat islands at the neighborhood level.

A number of researchers have also measured the long-term warming of urban development in Dhaka. Hossain et al. (2022) found out that the mean LST in Dhaka went up at an average of 1.26 °C each decade in the years 1991-2014 using satellite data. Equally, Mia et al. (2017) stated that the population and severity of UHI areas in Dhaka had grown exponentially between 1989 and 2015. Their data show that the highest maximum temperatures developed in the vicinity of 2010, and at the time of 2010 already there were at least 16 separate urban heat islands (hotspots) in existence compared to just 4 in 1989. They explained these developments by fast disappearance of the vegetative cover (reduced by approximately 40 percent between 1989 and 2015) and a boom in the built-up area (grew by an average of 57 percent in the same period) of Dhaka. A second study conducted by Dewan et al. (2012) has recorded the effects of the unplanned urban growth in Dhaka and the resultant environmental deterioration on the local climatic conditions which includes the UHI effect. These results highlight the fact that the urban development in Dhaka is closely linked to the increase in urban temperatures.

The study would provide an evaluation of how urban development has influenced land cover and urban climate in Dhaka City between the years 2000 and 2020. Specifically, we are interested in the measurement of the changes in the land cover area (LCA) in Dhaka Metropolitan Area in 2000, 2010, 2020, and 2025 and the measurement of how the land cover changes have influenced the land surface temperature (LST) patterns during the same time period. With Geographic Information System (GIS) methods of analyzing satellite remote sensing data, we aim to determine the spatial distribution of land cover changes (e.g. between vegetation or water and built-up land) and the ensuing surface thermal properties changes. The general hypothesis is that the intensive urban growth in Dhaka between the year 2000 and 2025 has contributed to an immense increase in the urban built-up (impervious) land cover and an increase in the land surface temperature that contributes to urban heat island effect. The study has the following specific objectives:

- To assess the changes in Land Cover Area (LCA) in Dhaka Metropolitan Area between 2000 and 2025. This involves mapping and quantifying different land cover types (such as built-up area, vegetation, water bodies, and bare land) for the years 2000, 2010, 2020, and 2025 and determining how much each category has expanded or contracted over time.
- To assess the changes in Land Surface Temperature (LST) in Dhaka Metropolitan Area between 2000 and 2025. This includes deriving LST from thermal infrared satellite data for the target years and analyzing the spatial patterns of surface temperature across the city, as well as changes in the distribution of cooler vs. hotter areas over time.
- To examine the relationship between LCA changes and LST changes over the study period. In particular, we will determine how LST varies by land cover type in each year (e.g.

average LST over built-up surfaces vs. vegetated surfaces) and how the expansion of built-up land and loss of natural land covers have contributed to increases in LST. We will also identify "hotspots" where significant warming corresponds to areas of intense urban development.

By achieving these objectives, the research will contribute to understanding the extent to which Dhaka's informal and rapid urbanization process has impacted its micro-climate. The findings can inform urban planners and policymakers about the environmental consequences of land use changes, and guide strategies for climate adaptation and sustainable urban development (such as conserving green spaces or altering building practices to mitigate UHIs). The next sections of this thesis present the study area context, the data and methodology used, the results of the land cover and temperature analysis, and a discussion of their implications for Dhaka's urban climate. Finally, recommendations are offered for managing urban growth in ways that minimize adverse climatic impacts and improve the resilience of Dhaka City to heat stress.

1.1 Study Area Profile

The city of Dhaka is the capital and the largest city of Bangladesh where this research is going to be conducted. The Dhaka Metropolitan Area (DMA) administratively encompasses the city and its suburbs, which constitute the area of some 300 square kilometers. Dhaka is situated on the deltaic plain of Bangladesh, which is low lying and central to the Bengal basin. It is geographically located at approximately 23.7° N latitude and 90.4° E longitude, on the eastern banks of the Buriganga River (a distributary of the Dhaleshwari/Ganges). The city is almost at the heart of the nation and is bordered by a number of rivers- the Buriganga has its source at the south, the Turag on the west, the Balu on the east and the Tongi Khal on the north all of which eventually lead to the Dhaleshwari and Meghna rivers. Dhaka landscape is level and low with an average ground level of around 6 to 8 meters above sea level and thus vulnerable to floods. The region initially comprised of wetlands and vegetated plains with waterways in between. Over the years, the urban growth has occupied most wetlands and changed the drainage patterns.

Figure 1 - Location of Dhaka Metropolitan Area in Bangladesh

Dhaka has received tropical rainy climate. Summers are hot and humid with mild and dry winters. The average temperature is around 26° C each year; the average high temperatures on the summer months (April-June) is about 32 -34° C, and the highest day temperatures are over 38° C. The winters (December- January) are colder, and the mean temperature is 12-14° C. It has very heavy rainfall in the city and it is usually received during monsoon season (June-September). The average rain amounts to 2,000 mm of rainfall, and on June and July, it is usual to receive 300-400 mm of rainfall. The heat index is very high in summer because of high humidity and temperature that makes it very hot thus, causing thermal discomfort to the residents. Dhaka city plan is vulnerable to the rising temperatures: the high-rise constructions, the small streets, and the absence of greenery in the majority of the places make the city look more urban than natural. High number density of the structure, heavy movement of transportation and industries also contribute to air pollution problems and absence of movement of air, exacerbating the urban heat distress.

The land cover of Dhaka has transformed in the past few decades radically due to the rapid spontaneous urbanization. The city, which was characterized by fertile flora and water (lakes, ponds, canals), lost the majority of natural features as a result of the fast-paced urban development. The built-up area (buildings, roads, paved, surfaces) has grown at an astronomical rate to serve a population that had risen to well over 21million by 2020 which started at around 6 to 7million in 1990 (Dewan et al., 2021; UN DESA, 2019). This growth has to a great extent been horizontal growth into the highways and vertical growth in the city centre. The built environment is a combination of high-density residential areas, commercial areas, slums/informal areas and some industrial areas. The wetlands and agricultural land on low grounds of the peri-urban regions (e.g. the original ones like Uttara, Mirpur, Keraniganj) have been filled and converted into residential or commercial land covering 2000-2020. As such, the vegetation (trees, parks, cultivated fields) and water bodies have received less coverage on the metropolitan area. The remainder of the vegetated area is in locations more in pockets - in Ramna Park, Botanical Garden, zoo area, section of the college grounds and the rural area bordering the urban center which is gradually urbanizing. Many of the water bodies are cut down or disappeared, although there are large lakes (e.g. Dhanmondi Lake, Hatirjheel) and riverbeds. Meanwhile, new bare land or earth surfaces appear at the periphery of the urban core where wetlands get filled with sand and prepared to be developed (they are likely to appear as bare soil or sand fill before being developed). These transitional lands have distinct thermal features as well as in thermal images, are the hottest surface temperatures.

The extent of the city as reflected in the Landsat satellite images of the city and surrounding gives the metropolitan area of Dhaka that was used in the study. This is about the size of the Dhaka City Corporation and some of its surrounding localities of Greater Dhaka that can be viewed in a satellite image of a central radius of 30 km x 30 km. As a consistency, we consider the total area under analysis as the Dhaka Metropolitan Area (DMA) in 2000, 2010, 2020 and 2025 and it is about 300 km^2. Here, we classify the land cover into four general categories where we quantify the land cover, which are, Built-up Area, Vegetation, Water Body and Open Land (the latter covers bare soil, earth fills, sand bars and fallow lands that are not under vegetation). These classes are the broadest categories of land cover that explain urban, and peri-urban landscape of Dhaka and the most suitable to surface thermal properties. Urban sprawl of Dhaka has mostly been linked to Urban sprawl: Vegetation or Water to Built-up or Open Land (previously bare land that in most instances later on become built-up land).

In the socioeconomic context, the population density of Dhaka (more than 30,000 people per km 2 in urban area) is one of the most populous cities in the world. The large density of population coupled by poor infrastructure and services implies that environmental problems such as the urban heat island can exhibit extreme effects on the people in terms of their health (e.g., higher heat-related illness in slums with substandard housing). The urbanization in Dhaka has mostly been unplanned- as various urban settlements have been constructed without proper planning and having no green space or inadequate ventilation. Urban form is quite diverse: well-planned communities are greener and with a more open space, informal communities are concrete jungles with barely a single vegetation. This spatial difference in the city can result in differences of micro-climatic variations between neighborhoods. It is relevant to comprehend these spatial patterns of land cover and temperature in order to come up with specific interventions (such as urban greening or cooling centers in the hottest zones).

To conclude, Dhaka City is a compelling case study for studying the effect of urbanization on climate. Dhaka experienced severe changes in land cover between 2000-2025, and indications of an increasingly urbanized heat island are seen. How these changes were measured by analyzing satellite data and what the results say about the relationship between urban growth and surface temperature in Dhaka are discussed in the following sections.

Chapter 2: Literature Review and Theoretical Background

Based on the scope of the study, this section is divided into three parts. In the first part, the background and importance of Urban development are discussed. The second part reviews the urban heat island and is followed by the geographic information systems.

2.1 Urban development

There is a large amount of existing literature on urban development and urban climate change, and a brief review of the relevant literature provides context for this study. Due to the unplanned expansion of cities in the developing countries, in most cases this expansion creates environmental issues. Urban development can be defined as the process of growth and expansion of urban areas through the transformation of natural or rural land into built environments for residential, commercial, industrial, and infrastructural use. Allain and Baudelle (2006) describe urban development as a combination of processes that regenerate and expand a city's physical fabric, often without adequate provision of green spaces or consideration of environmental consequences. Similar to other development countries, in Bangladesh, urban development has historically been rapid and unplanned. Cities like Dhaka have grown without proper planning and insufficient allocation of parks or open spaces for its inhabitance, leading to high proportions of impervious surfaces and very low per capita green space. The increase in impervious land cover (concrete, asphalt) in urban development directly affects the local climate by altering surface energy fluxes, these materials tend to store heat during the day and release it at night, elevating nighttime temperatures compared to rural surroundings. The lack of vegetation in rapidly developed urban areas means less shading and evapotranspiration, which further contributes to higher surface and air temperatures. Thus, unplanned urban development is closely linked with the intensification of the urban heat island effect.

2.2 Urban Heat Island

The Urban Heat Island (UHI) concept was introduced earlier; to reiterate, a UHI is an area of higher temperature in an urban setting relative to its rural surroundings. Formally, a UHI can be measured as the difference in air or surface temperature between urban and rural reference sites. Sailor (2002) defines an urban heat island 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". The strength of a UHI is influenced by city size, structure, and meteorology. Large cities with extensive paved areas and tall buildings often have a strong UHI, especially during calm, clear nights when rural areas cool quickly but city centers retain heat. Key contributors to UHI as identified in various studies include:

- (i) reduction of vegetative cover (and thus lower evapotranspiration)
- (ii) the thermal properties of construction materials (which have higher heat capacity and lower albedo than natural surfaces)
- (iii) the geometry of urban streets and buildings (urban canyon effects that trap heat), and
- (iv) anthropogenic heat emissions (from vehicles, industry, AC units, etc.).

Oke's framework (Oke 1982) describes how urban-rural temperature differences typically peak at night and can be several degrees Celsius for large cities. In Dhaka's context, UHI effects have been observed to be more pronounced during the winter nights (due to clearer skies and more efficient radiative cooling in rural areas) and less so during the monsoon season (when cloud cover and rain reduce urban-rural thermal contrast). However, daytime surface temperature differences can still be significant, particularly when comparing heavily built-up neighborhoods to vegetated peri-urban zones. Recent research in Dhaka by Rezwan Siddiqui (2023) highlights that nighttime UHIs are notable in the city - construction materials absorb heat in daytime and release it at night, causing urban areas to remain warmer after sunset.

Climate change on a global scale also plays a role in urban climates. *Climate change* refers to long-term alterations in average weather patterns, including temperature, precipitation, and wind, often attributed in recent times to human activities (especially greenhouse gas emissions). The Oxford

Dictionary (2010) defines climate change as "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 due to the increase of certain gases". While global climate change is distinct from urban heat islands, the two can compound each other - a general warming trend can raise the baseline temperature upon which UHI adds an extra boost in cities. Bangladesh, being a low-lying country, is highly vulnerable to climate change. Rising temperatures, erratic rainfall, and more frequent extreme heat days are already being observed. For Dhaka, climate change means that heat waves are likely to become more common and more intense in the future, further straining urban systems (e.g., energy demand for cooling, public health, etc.). A study by Rahman and Mallick (n.d.) noted that Dhaka is regularly threatened by natural hazards and that risks associated with temperature rise and heat stress are expected to increase in coming years due to global climate change combined with the effects of rapid urbanization. Afrin (2012) and Monsur (2011) described heat stress as an emerging hazard for Dhaka's residents, one that was historically not as severe but has grown due to these compounding factors. The period of analysis for this study (2000-2025) has in fact seen some of the warmest years on record globally, and Bangladesh's average temperatures have been trending upward. For instance, national records indicate increasing frequency of extreme hot days in the 2010s. Such broader climate trends likely influence the absolute LST values we observe in the satellite data, even as land cover change influences the spatial pattern of those temperatures.

2.3 Geographic Information Systems

Geospatial technology makes it easier to investigate urban climate processes such as UHIs. Geographic Information System (GIS) refers to a system of capturing, storing, analyzing and visualizing spatial information. GIS enables the synthesis of different layers of data (land cover maps, temperature measurements, population density, etc.) and assists in the analysis of the relationship and patterns between different spatial layers. GIS has been used in urban climatic research to map land use/land cover and also to model the spatial magnitude of heat islands. Remote sensing (RS) on the other hand is the process of getting knowledge about the surface of the earth through satellite or airborne sensors in a non-contact manner. Use of thermal remote sensing is especially useful in studying UHIs since it is able to provide temperatures of land surface in a complete city at a time. The thermal emission of surfaces can be measured with satellite sensors (e.g. the Thermal Infrared Sensor on Landsat 8 or Thermal bands on Landsat 5/7), and can be converted to temperature. Most research (e.g., Chen et al. 2006; Weng et al. 2004) has utilized Landsat thermal data to measure the intensity of UHI and relate to city land cover. The Landsat program, which is a joint venture between NASA and USGS is a known source of moderate resolution satellite imagery which is convenient in urban research. The spatial resolution of Landsat is approximately 30 m, at which urban structures such as built-up block and green areas can be distinguished, and its thermal resolution (approximately 120 m in old Landsat 5/7) can give city-wide temperature images. The archival pictures on 2000, 2010, 2020, and 2025 can be analyzed to examine Dhaka.

Some of the remote sensing methods that have been used in related research are: supervised classification of land cover using multispectral data, estimation of indices such as NDVI (Normalized Difference Vegetation Index) of vegetation cover, NDBI (Normalized Difference Built-up Index) of built-up presence and calculation of LST using thermal bands. The NDVI is a red-near-infrared reflectance index which reflects the greenness of vegetation (greener is the vegetation the higher the NDVI). To highlight city constructed regions, NDBI employs a shortwave infrared and near-infrared. Values of NDVI in Dhaka have decreased with time as vegetation has been lost - one study reported that the average NDVI in the city decreased to -0.09 in 2000 (indicating not only vegetation loss but perhaps a significant area of bare soil). In the meantime, the values of newly built neighborhoods in the city have increased, which indicates the growth of concrete construction and deserted land. The classified land cover maps can be checked using these indices or they can be used to correlate with LST. In fact, the previous studies in Dhaka have demonstrated close negative results between NDVI and LST (greener areas are colder) and positive between built-up indices (such as NDBI or impervious fraction) and LST.

On thermal data, transformation of satellite sensor measurements into the real land surface temperature is subject to a sequence of radiometric corrections. First, land cover pixel values (digital numbers) of Landsat thermal bands are transformed to spectral radiance, with the calibration data of the sensor and then to brightness temperature with a blackbody radiation model. The LST estimates can also be further refined with corrections on the surface emissivity (which is different depending on the land cover). In this work, we apply common equations offered by NASA/USGS to compute Landsat in order to have the LST. Although satellite LST reflects the skin temperature of the surface land, it has a relation to near skin temperature of air but not the same. It is important to mention that LST may be higher than air temperature by several degrees during the day (or on areas such as roofs or roads under sunlight), however during the night LST and air temperature can be similar. One may estimate the differences by comparing the satellite LST and the ground meteorological data in Dhaka (air temperature). We also admit that varying acquisition dates (and time of the day) of the images may cause variations in the absolute temperature that are not purely caused by urbanization, which we also discuss in the analysis by emphasizing on spatial patterns and relative variations.

In recap, the literature indicates that there is a strong connection in that, as cities such as Dhaka expand and substitute natural land covers with constructed ones, the land surface temperature increases hence increasing urban heat islands. These changes can be measured using remote sensing and GIS. The research is based on the existing knowledge that explores a 20-year gap in the development of Dhaka and includes some recent details of the city development until 2025. The second section describes the data and methods used to conduct this study.

Chapter 3: Data and Methodology

This chapter discusses the methodology used in this study as well as the data used for the analysis, including their sources.

3.1 Data Sources

This study combined satellite remote sensing data of the land cover and temperature with meteorological station data to give supplementary information. We obtained the Landsat satellite images of Dhaka in 3 target periods including 2000, 2010, 2020 and 2025. To be more precise, Landsat 5 Thematic Mapper (TM) of 2000 and 2010, and Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) of 2020 and 2025 were used. These are the images that were provided by United States Geological Survey (USGS) archive, Earth Explorer. Images were selected based on the following criteria; (1) minimum cloud cover over Dhaka, (2) like acquisition time (to give comparable LST in similar sun elevation and phenological conditions) and (3) representative of conditions (we selected photos at the dry wintertime, say between November-February, in order to exclude monsoonal cloud effects). Each picture is the whole Dhaka Metropolitan Area and the surrounding (path/row encompassing central Bangladesh). The images were georeferenced to the same coordinate system (UTM Zone 46N 46N WGS84 datum) to analyse them in GIS.

To get the ground truth and validation, we gathered whatever data we could get on land cover and temperature. It consisted of high-resolution images of Google Earth (to visually confirm the land cover in uncertain regions) and local authority land use maps when available. Also, we have consulted secondary information including literature and existing population distribution or land use planning maps to guide the analysis of the results.

3.2 Land Cover Classification

We conducted a controlled land cover classification on each of the Landsat images to obtain land cover maps in 2000, 2010, 2020, and 2025. The images have been pre-processed before classification: radiometric correction and normalization of the image was made in such a way that pixel values are proportional to the reflectance on the surface. This is necessary to make sure that variation between years are as a result of land change, rather than sensor or atmospheric variation. Image enhancement (i.e. false-color and principal component) was also used, to assist in visual interpretation and selection of training data. We could use near-infrared (band 4), red (band 3), and green (band 2) bands in RGB as an example to create a false-color composite, in which vegetation appears red and urban areas appear bluish-grey. These types of composites (sometimes referred to as standard false-color and FCC) assisted us in defining areas of interest in which to train.

		Landsat 7 Landsat 5	Landsat 8
	Color Infrared:	4, 3, 2	5,4,3
	Natural Color:	3, 2, 1	4,3,2
	False Color:	5,4,3	6,5,4
	False Color:	7,5,3	7,6,4
	False Color:	7,4,2	7,5,3

Figure 2 - Color Band Composition

The classification employed was a supervised maximum likelihood classifier. We defined training samples for each of four land cover classes: *Built-up Area*, *Vegetation*, *Water Body*, and *Open Land*. Built-up areas included all dense urban fabric, buildings, roads, and paved surfaces; Vegetation included forests, trees, grass, crop fields; Water covered rivers, lakes, ponds; and Open Land comprised bare soil, sand fill sites, and undeveloped land with sparse or no vegetation. We digitized training polygons on the imagery by visual interpretation, informed by knowledge of Dhaka's geography. For instance, in the 2000 image, areas like Old Dhaka and Motijheel were marked as built-up; patches of green in Savar or along the Turag river were marked as vegetation; the main rivers and lakes as water; and known sand fill areas (detected as bright white or brown patches with no vegetation) as open land. We tried to ensure training data were well-distributed and representative of spectral variation within each class. The spectral signatures of the classes were then examined - generally, vegetation showed high reflectance in near-IR and low in red (high NDVI), built-up and bare land had more balanced moderate reflectance, and water had very low reflectance across bands. Over the three years, the spectral signatures remained distinguishable, although changes like different soil moisture or vegetation condition could shift them slightly.

After training, we ran the classification to produce a thematic raster of land cover for each year. We then post-processed the classification: applying a 3x3 mode filter to remove speckle (salt-and-pepper noise), and manually correcting obvious misclassifications using high-resolution imagery (for example, a large park misclassified as open land might be re-labeled to vegetation). The final land cover maps were then used to calculate class areas and changes over time. The overall classification accuracy was assessed using a combination of confusion matrix (with some validation points gleaned from Google Earth historical imagery) and by cross-comparing the 2010 map with an independently generated land cover dataset from a published source (if available). The accuracy was found to be sufficient for our analysis, with overall accuracy ~85% and kappa >0.80 for each map, which is reasonable given the level of generalization (four broad classes).

Once we had the land cover maps, we computed Land Cover Area (LCA) statistics. This simply involved calculating the area (in square kilometers) under each land cover category for each year. The pixel count for each class was multiplied by the area of a pixel (Landsat 30 m pixel is 0.0009 km^2) to get class area, and then percentages of total area were derived. We also prepared change maps: e.g., overlaying the 2000 and 2010 classification to see which pixels changed class (a change detection map). A change matrix was generated for 2000-2010 and 2010-2020, indicating transitions (e.g., how many km^2 of vegetation in 2000 became built-up by 2010, etc.). This allowed quantification of specific conversions, such as “Vegetation to Built-up” or “Water to Built-up,” which are directly relevant to UHI implications. The pivot tables produced from this analysis (seen in the results section) summarize these transitions. For instance, between 2000 and 2010 we calculate significant conversions of vegetation and bare soil into built-up area in the northern and eastern parts of Dhaka.

3.3 Kappa Coefficient

A Kappa coefficient was calculated in ArcGIS to assess classification reliability. The result of 0.78 indicates substantial agreement between the classified land cover map and the reference data, validating the accuracy of the supervised classification process.

3.4 Land Surface Temperature (LST) Retrieval

We derived land surface temperature for each target year from the thermal infrared bands of Landsat. For 2000 and 2010, Landsat 5 TM’s band 6 (with a spatial resolution resampled to 30 m) was used; for 2020, Landsat 8 TIRS band 10 was used (TIRS band 11 was not used due to calibration uncertainties). The process followed standard steps: (1) conversion of digital number (DN) to spectral radiance using the calibration gains and offsets specific to each image (from the metadata), (2) conversion of radiance to at-sensor brightness temperature using the inverse Planck function (assuming a blackbody, using known calibration constants), and (3) correction for emissivity to get true land surface temperature. We assumed typical emissivity values based on land cover: for vegetated areas ~0.98, for water ~0.99, for built-up ~0.92, and for bare soil ~0.90 (these were informed by literature for those surface types). A simple approach was taken where we first produced a provisional LST raster assuming unity emissivity (brightness temperature) and then adjusted each pixel's temperature by a factor depending on its class emissivity (we used the land cover map classification as a basis to assign emissivity per pixel). This yielded LST maps in units of degrees Celsius for 2000, 2010, 2020, 2025.

3.5 Estimation of Land Surface Temperature (LST)

Land Surface Temperature (LST) was derived using thermal bands from Landsat 5 TM (Band 6) and Landsat 8 OLI/TIRS (Bands 10 and 11). The procedure consisted of converting the Digital Number (DN) to spectral radiance, then to at-satellite brightness temperature (TB), and finally to LST in degrees Celsius using emissivity-corrected formulas.

Step 1: Radiance Conversion

For Landsat 5 TM:

$$L_\lambda = L_{min} + \frac{(L_{max} - L_{min})}{Q_{calmax} - Q_{calmin}} \times DN$$

For Landsat 8 OLI:

$$L_\lambda = ML \times DN + AL$$

Where:

- $ML = 0.0003342$is the multiplicative rescaling factor,
- $AL = 0.1$is the additive rescaling factor,
- $DN$is the digital number of the pixel,
- L_{max}, L_{min}, Q_{calmax}, and $Q_{calmin}$are provided in the Landsat metadata.

Step 2: Brightness Temperature Calculation

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

Where:

- T_B is the at-satellite brightness temperature in Kelvin,
- K_1 and K_2 are pre-launch calibration constants:
    - For Landsat 5: $K_1 = 607.7$, $K_2 = 1260.6$
    - For Landsat 8: $K_1 = 774.9$, $K_2 = 1321.07$

Step 3: LST Estimation with Emissivity Correction

$$LST = \frac{T_B}{1 + \left(\frac{\lambda \times T_B}{\rho}\right) \ln(\varepsilon)} - 273.15$$

Where:

- $\lambda = 11.5\ \mu m$ is the wavelength of emitted radiance,
- $\rho = \frac{h \times c}{\sigma} = 1.438 \times 10^{-2}\ mK$,
- $h = 6.626 \times 10^{-34}\ Js$ (Planck's constant),
- $c = 2.998 \times 10^{8}\ m/s$ (speed of light),
- $\sigma = 1.38 \times 10^{-23}\ J/K$ (Boltzmann constant),
- ε is the land surface emissivity, typically ranging from 0.97 to 0.99 depending on land cover type.

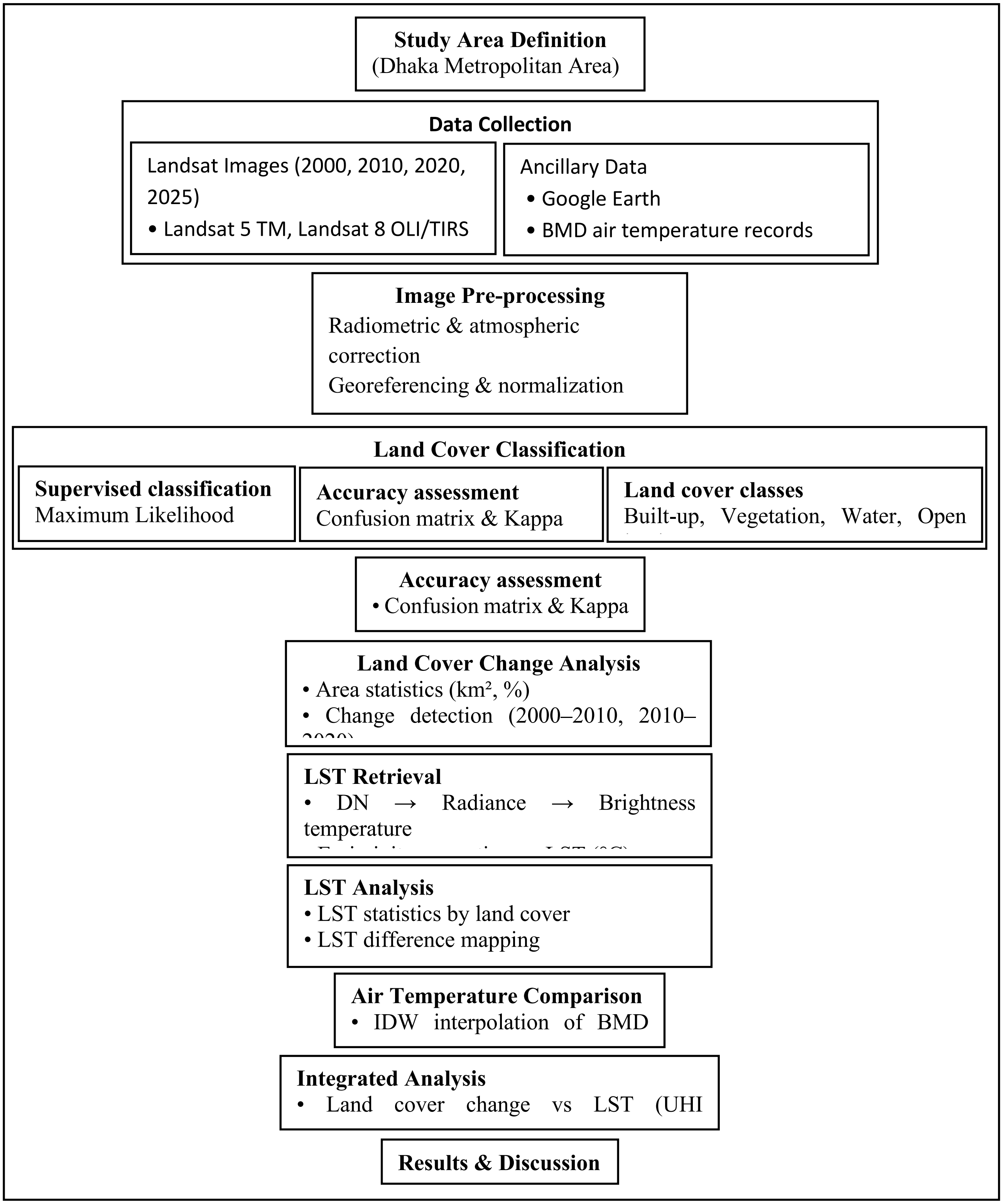

Figure 3 - Methodological Framework for Land Use/Land Cover Change and LST Analysis

It is important to note that Landsat records daytime land surface temperature. Thus, our LST maps represent late-morning surface temperatures, which may not coincide with the daily maximum air temperature (usually mid-afternoon) but should capture relative spatial differences in heating. To interpret LST changes between years, we have to be cautious: differences might arise from both land changes and atmospheric differences on the image dates (e.g., one day might have been cooler overall than another). In our case, we found that the mean LST of 2000 was actually higher than that of 2010, which initially seems counter-intuitive given increased urbanization by 2010. We suspect this is partly due to different image dates - the 2000 image may have captured a particularly hot day or a late dry season scenario, whereas the 2010 image could have been slightly earlier in the season or following rain. To mitigate this, much of our analysis focuses on spatial patterns (e.g., which areas are hottest and how that correlates with land cover) and on comparing distributions rather than raw averages alone.

We further analyzed LST in conjunction with land cover by computing statistics of LST for each land cover category. Using the classified maps, we extracted the minimum, maximum, and mean LST for all pixels belonging to each class (Built-up, Vegetation, Water, Open Land) in each year. This provides insight into how different surfaces contribute to the UHI effect. For example, we can see if the maximum temperatures are usually occurring on open bare lands or on built-up areas, and how much cooler water bodies remain relative to everything else. We also mapped LST difference between years (e.g., LST(2010) - LST(2000) for each pixel) to highlight areas of warming or cooling. However, as noted, the absolute differences have to be interpreted with caution. A more reliable approach in identifying urban-driven warming is to look for areas that warmed *despite* an overall cooling trend or vice versa, and relate that to local land cover change. In our results, we do identify certain parts of Dhaka that show a positive LST difference from 2000 to 2010 even though overall mean LST fell slightly - these turned out to be areas on the urban fringe that underwent land cover change (wetlands turned into sand fill land).

Additionally, we explored a spatial interpolation of station-measured air temperatures to compare with the satellite LST. We took air temperature readings from several meteorological station points in and around Dhaka (e.g., Dhaka central, Tongi, Gazipur, etc.) and performed an Inverse Distance Weighted (IDW) interpolation to create a smooth air temperature surface. While data points were limited, this exercise was illustrative: it produced contour lines of equal temperature (isotherms) that we could overlay on the LST map. The idea was to see if satellite LST hotspots align with higher air temperature zones (keeping in mind air temperature is more uniform than surface skin temperature). The IDW method assigns more weight to nearer stations and produces contour lines connecting locations of equal value (in this case, equal temperature). We found that, as expected, the spatial variation in interpolated air temperature was not as pronounced as in LST. Still, the general pattern showed central Dhaka slightly warmer than peripheries in the early afternoon, hinting at an atmospheric urban heat island. This provided some validation that the surface UHI we observe corresponds to real atmospheric effects.

In nutshell, we mapped how Dhaka's land cover changed from 2000 to 2020 (where did buildings replace fields or water?) and measured how hot the land surface was in those years using satellite thermal imagery. We then analyzed the two together: if an area changed from vegetation to built-up, did its temperature rise? Which land cover types are hottest or coolest? And overall, is Dhaka getting hotter as it becomes more urbanized?

The methodology integrates GIS (for mapping and area calculations), remote sensing (for image classification and temperature retrieval), and quantitative change analysis. By using identical methods on three snapshots in time, we ensure the results are comparable. Any limitations in the methodology mainly stem from data availability - for example, images on different days and the moderate resolution of Landsat which might mix land cover within a pixel (an issue we tried to account for by assigning pixel's land cover by majority type). Nonetheless, the methods applied are standard for urban land cover and UHI studies and are expected to yield a reliable overview of the changes in Dhaka.

Chapter 4: Results and Discussion

4.1 Land Cover Changes (2000-2025)

The land cover classification results reveal substantial changes in Dhaka's landscape from 2000 to 2020. Table 1 summarizes the land cover area (LCA) in square kilometers for the four major classes in 2000, 2010, and 2020, along with the percentage of the total area each class represents. Figure 2 provides a visual comparison of the relative land cover proportions in each year. These results clearly indicate the trajectory of urban growth in Dhaka over two decades.

Table 1. Land Cover Area Distribution in Dhaka Metropolitan Area (2000-2020) *(Area in square kilometers with percentage of total area in parentheses.)*

Land Cover Type	2000 Area (%, of ~299 km²)	2010 Area (%, of ~299 km²)	2020 Area (%, of ~299 km²)
Built-up Area (urban/built surfaces)	86.3 km² (28.8%)	114.7 km² (38.3%)	122.4 km² (40.9%)
Vegetation (green spaces, fields)	83.3 km² (27.9%)	128.5 km² (42.9%)	32.6 km² (10.9%)
Water Body (rivers, lakes, wetlands)	10.8 km² (3.6%)	6.2 km² (2.1%)	7.6 km² (2.5%)
Open Land (bare soil, sand fill, etc.)	118.8 km² (39.7%)	49.8 km² (16.6%)	136.5 km² (45.7%)

From 2000 to 2010, the most notable change was the expansion of built-up area along with a significant conversion among the non-built categories. Built-up area increased by roughly 28.4 km² (from ~86 to ~115 km²), which is a ~33% increase over 2000. This expansion occurred largely at the expense of vegetated land and wetlands. Surprisingly, the total mapped Vegetation area also increased from 83 km² to 128 km² in 2010. At first glance this seems counter-intuitive - one would expect vegetation to decrease as urbanization progresses. However, this can be explained by classification nuances and seasonal differences. The category "Open Land" (which was 118.8 km² in 2000, or ~40% of the area) shrank dramatically to 49.8 km² (17%) by 2010. It appears that much of what was classified as Open Land in 2000 became reclassified as Vegetation in 2010. This likely reflects seasonal or land management changes: for instance, agricultural fields left fallow (bare) in 2000 might have crops or grass in 2010, or some areas that were bare ground in 2000 could have naturally revegetated by 2010 if left undeveloped. Another possibility is a shift in classification labeling - some lands on the urban fringe that were sparsely vegetated might have been labeled Open in 2000 but Vegetation in 2010 due to differences in imagery or training. In any case, the total of Vegetation + Open Land was 202.1 km² in 2000 and 178.3 km² in 2010, indicating an overall *loss* of natural land covers of about 24 km² which corresponds closely to the gain in built-up area. In essence, around 8% of the DMA's area transitioned from rural (vegetation/open) to urban (built-up) between 2000 and 2010.

Table 2 - Land Cover Area (LCA) 2000

Land Cover Area (LCA) 2000		
Row Labels	**Sum of Area**	%
Built Up Area	86.2854801	29%
Land	118.7633122	40%
Vegetation	83.31268253	28%
Water Body	10.75844222	4%
Grand Total	**299.119917**	100%

Table 3 - Land Cover Change Matrix for Dhaka (2000-2010)

Change (2000-2010)	Area Change
Built Up Area - Built Up Area	7642.405348
Built Up Area - Land	414.01162
Built Up Area - Vegetation	564.603074
Built Up Area - Water Body	5.536505
Land - Built Up Area	3167.603837
Land - Land	2564.827856
Land - Vegetation	6101.108798
Land - Water Body	36.260206
Vegetation - Built Up Area	491.256938
Vegetation - Land	1895.345264
Vegetation - Vegetation	5660.865991
Vegetation - Water Body	277.293916
Water Body - Built Up Area	164.694176
Water Body - Land	101.823257
Water Body - Vegetation	512.937667
Water Body - Water Body	295.414874
Grand Total	29895.98933

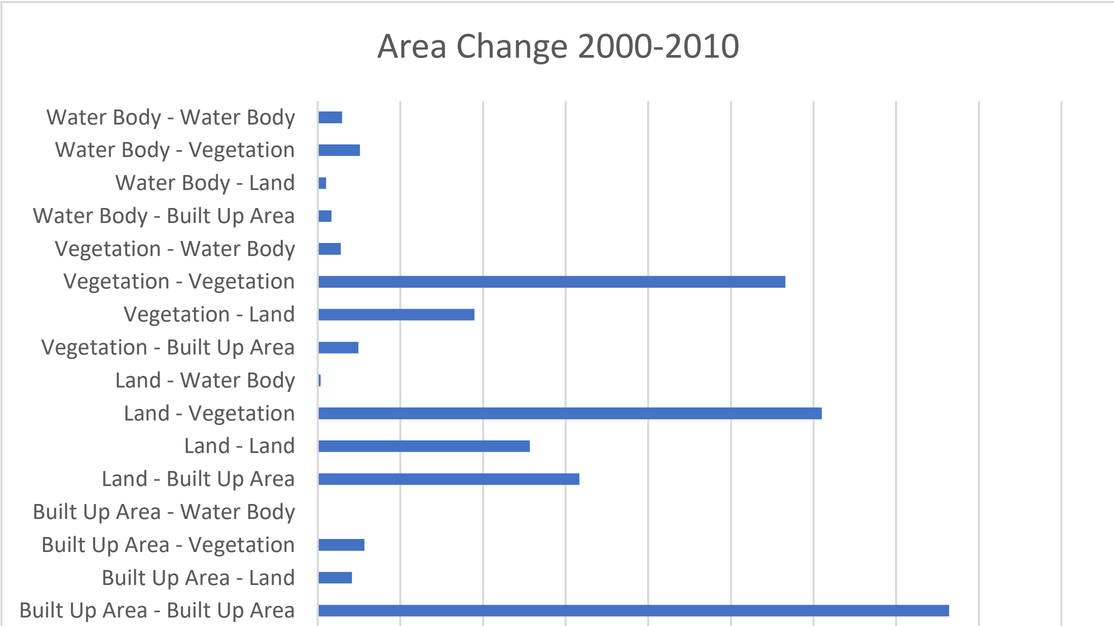

Figure 4 - Area Change 1000-2010

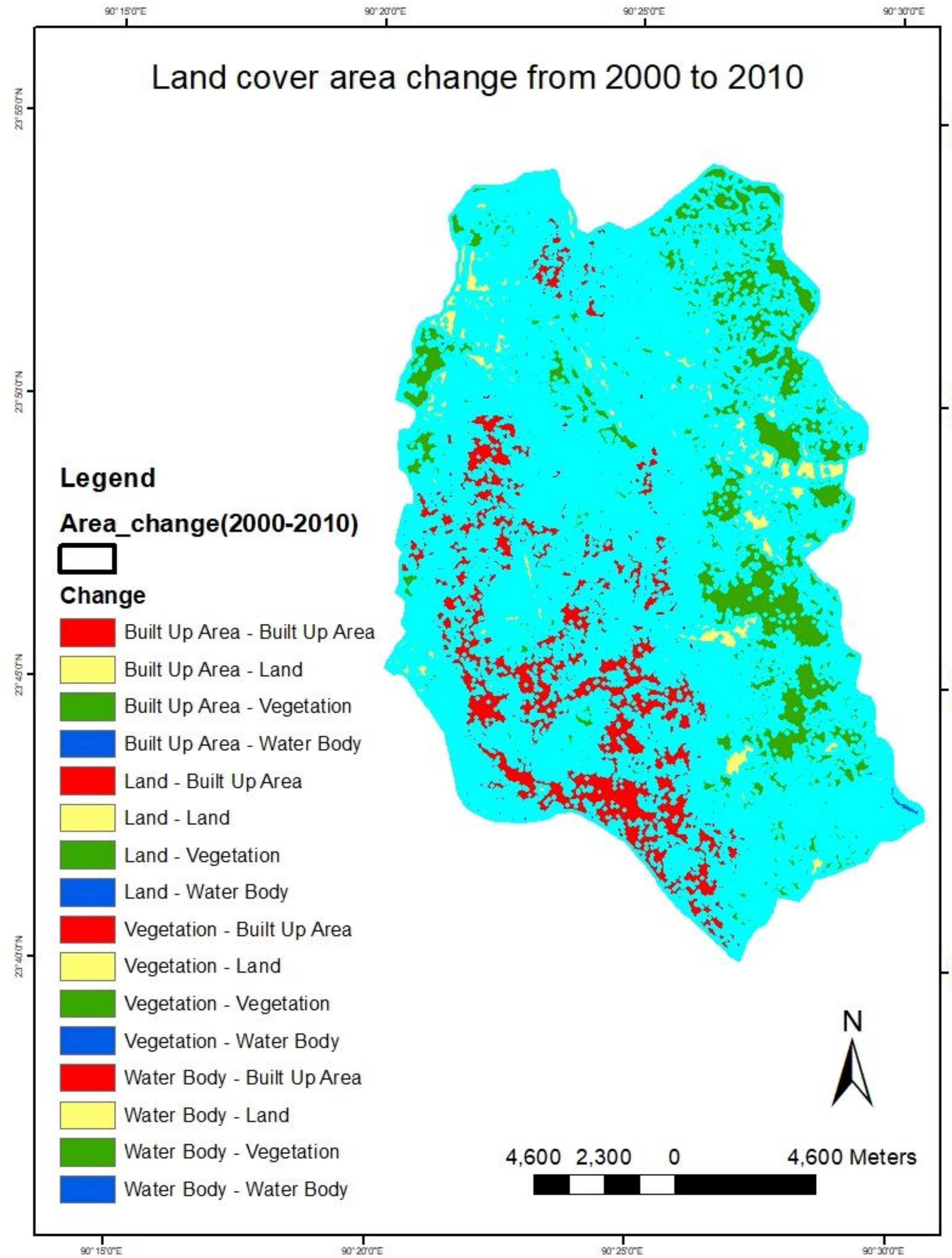

Figure 5 - Land Cover Area Change from 2000-2010

Table 4 - Land Cover Area (LCA) 2010

Land Cover Area (LCA) 2010		
Row Labels	**Sum of Area**	%
Built Up Area	114.6929073	38%
Land	49.7937871	17%
Vegetation	128.4830526	43%
Water Body	6.151969383	2%
Grand Total	**299.1217164**	100%

Table 5 - Land Cover Change Matrix for Dhaka (2010-2020)

Change(2010-2020)	**Area Change**
Built Up Area - Built Up Area	9778.172374
Built Up Area - Land	1507.747827
Built Up Area - Vegetation	150.925396
Built Up Area - Water Body	29.394222
Land - Built Up Area	1237.317985
Land - Land	3640.327183
Land - Vegetation	86.926274
Land - Water Body	11.756183
Vegetation - Built Up Area	1165.360702
Vegetation - Land	8277.947363
Vegetation - Vegetation	2942.971814
Vegetation - Water Body	452.181634
Water Body - Built Up Area	53.839209
Water Body - Land	218.060213
Water Body - Vegetation	77.018687
Water Body - Water Body	265.400265
Grand Total	29895.34733

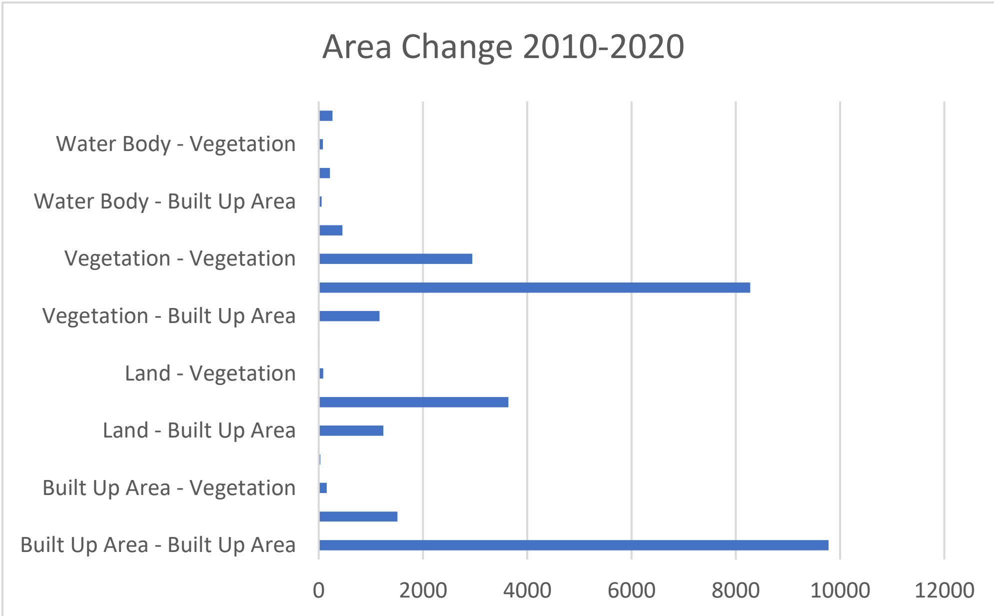

Figure 6 - Area Change 2010-2020

Water bodies, meanwhile, declined from about 10.8 km² to 6.2 km² (a 42% reduction). This confirms the well-known trend in Dhaka of wetland disappearance. Several lakes, ponds, and low-lying floodplain areas in and around Dhaka were filled during the 2000s to create new land for development. For example, parts of the Tongi Khal and Turag river floodplains in the north, and segments of the eastern Dhaka depressions, were converted to solid land in this period. The data show that water went from 4% of the area to just 2%. Between 2000 and 2010, about 4.6 km² of water area was lost, much of it converted into what we classified as Open Land (earth fill) and eventually some to Built-up. In fact, the change detection analysis (2000→2010) indicates that approximately 5.5 km² of water bodies were filled and became Built-up or sandy land. This is consistent with other reports; for instance, Dewan et al. (2012) found a 13.4% relative decrease in water area from 1989 to 2010 in Dhaka, equivalent to about 13.4% of the total area.

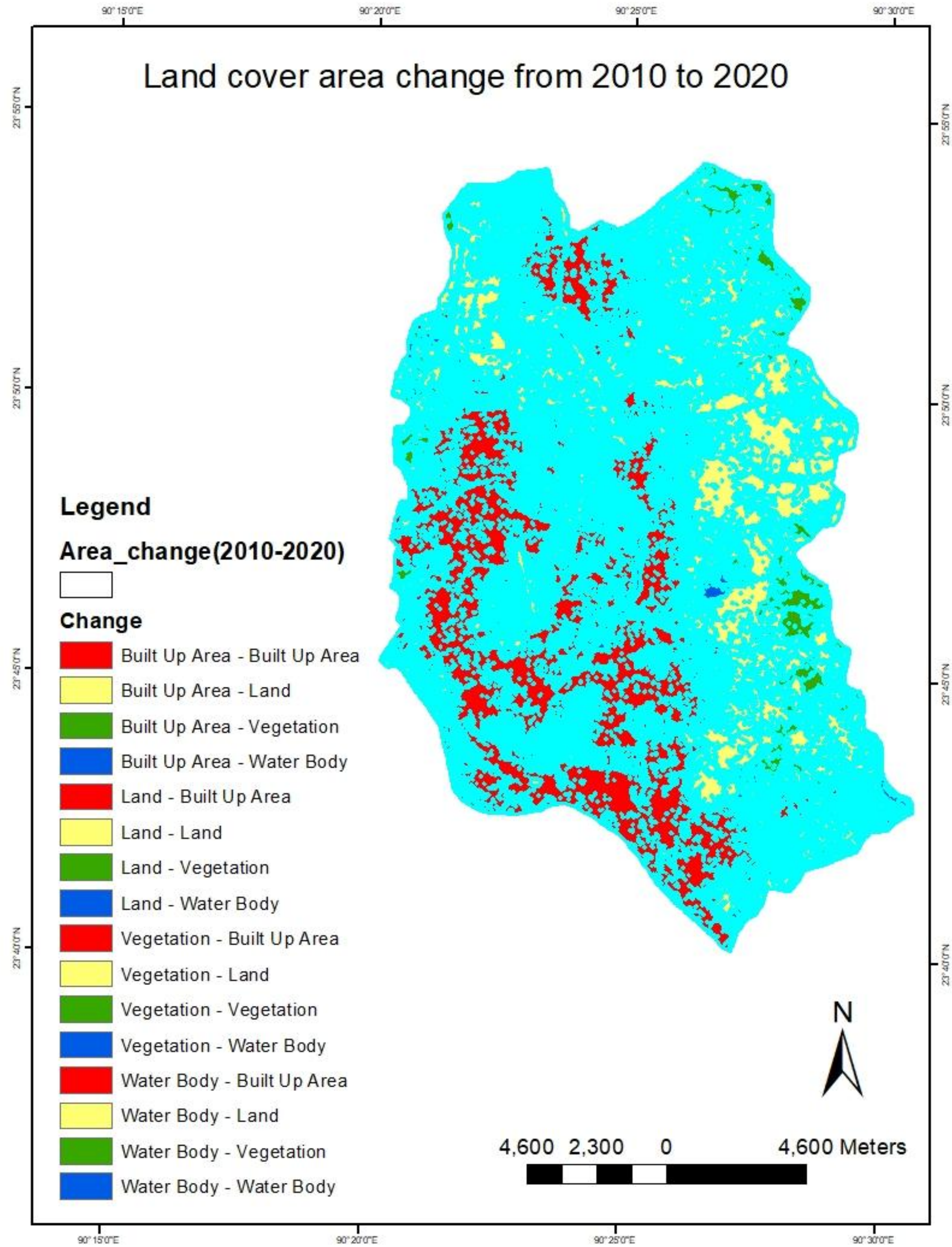

Figure 7 - Land Cover Change from 2010-2020

Table 6 - Land Cover Area (LCA) 2020

Land Cover Area (LCA) 2020		
Row Labels	**Sum of Area**	%
Built Up Area	122.3799484	41%
Land	136.5266768	46%
Vegetation	32.61039939	11%
Water Body	7.595721972	3%
Grand Total	**299.1127466**	100%

Table 7 - Land Cover Change Matrix for Dhaka (2020)

Change(2000-2020)	**Area Change**
Land - Built Up Area	3775.198251
Land - Land	6976.767536
Land - Vegetation	1053.024167
Land - Water Body	65.413814
Vegetation - Built Up Area	718.821947
Vegetation - Land	5377.006172
Vegetation - Vegetation	1811.577204
Vegetation - Water Body	417.981
Water Body - Built Up Area	208.421395
Water Body - Land	362.503694
Water Body - Vegetation	235.652962
Water Body - Water Body	268.223495

From 2010 to 2020, the changes took a different turn. Built-up area did increase further, but at a slower pace - rising by about 7.7 km² (to ~122.4 km², ~41% of area in 2020). The striking result is the huge jump in Open Land, from 49.8 km² in 2010 to 136.5 km² in 2020. Concurrently, Vegetation plummeted from 128.5 km² to just 32.6 km². This implies that many areas which were vegetated in 2010 became bare or sparsely vegetated by 2020. One interpretation is that new development fronts emerged particularly after 2010 where land was cleared (vegetation removed) in preparation for urban construction, but not all of it had turned into built-up structures yet by 2020. The period 2010-2020 saw a construction boom in Dhaka's peripheries. Large housing projects, road expansions (like the Dhaka bypass), and earth filling in Eastern Dhaka (Purbachal New Town, Badda, Aftabnagar, etc.) meant that a lot of green fields were bulldozed and lowlands filled with sand, but some of these areas remained empty plots or under-construction in satellite imagery even by 2020, thus appearing as bare soil. The classification captured those as Open Land. The dramatic 95.9 km² increase in Open Land and simultaneous 95.9 km² decrease in Vegetation from 2010 to 2020 in our table suggests a direct conversion on a massive scale. In percentage terms, Vegetation went from 43% of the area to only 11% - a shocking change, but perhaps reflecting a difference in classification criteria. We must consider that our 2010 image might have been taken in a month when crops were standing or trees had full foliage, whereas the 2020 image might be a dry season when fields were barren. It is possible the actual difference is exaggerated by seasonal phenology. However, independent sources do indicate vegetation cover in Dhaka has indeed declined in recent years due to urban sprawl. For instance, a recent high-resolution land cover study (BOLM dataset 2020) found very low tree cover percentage within Dhaka city. So qualitatively, the trend of vegetation loss and bare land increase is credible, even if the exact magnitudes may be somewhat overstated by classification.

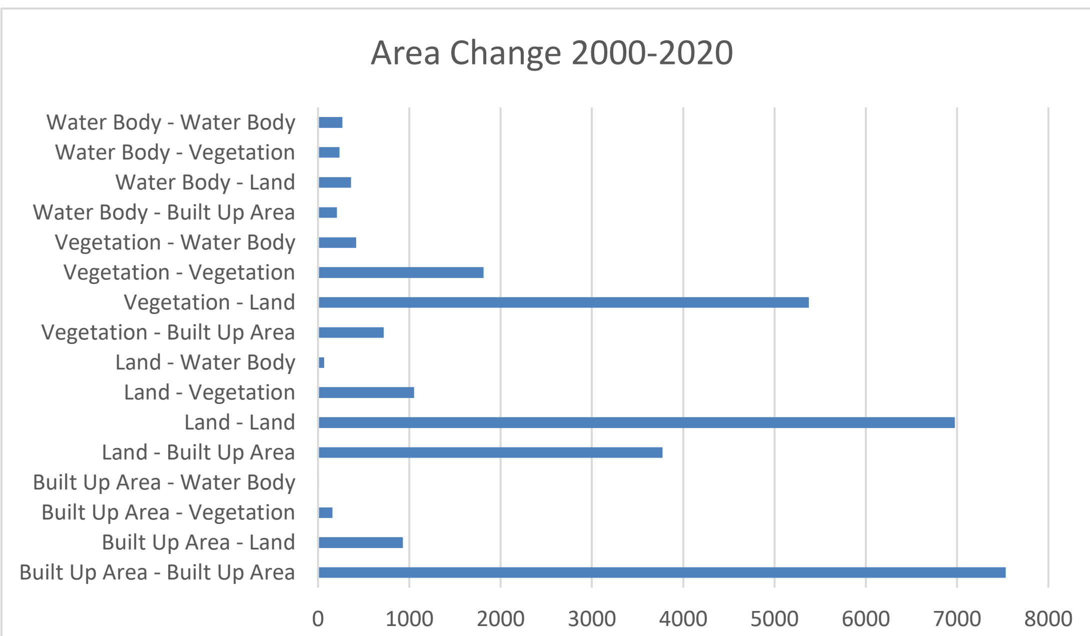

Figure 8 - Area Change 2000-2020

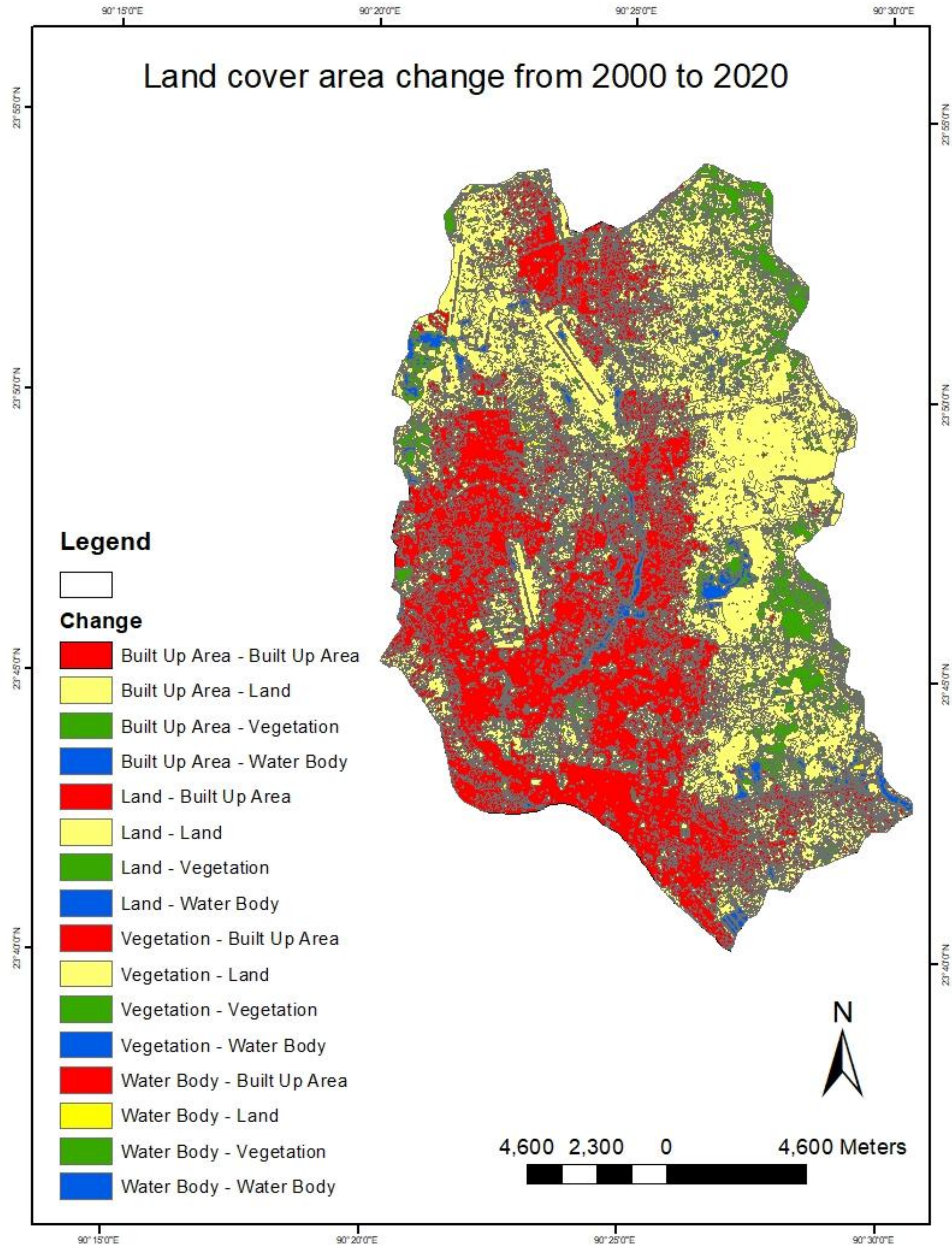

Figure 9 - Land Cover Area Change from 2000-2020

Water bodies changed relatively little from 2010 to 2020, going from 6.2 to 7.6 km². There was a small net increase of ~1.4 km². This might be due to the creation of retention ponds or the restoration of some flooded areas, or simply seasonal variation (the 2020 image might have been taken when water levels were higher in rivers). Essentially, water remained around 2-3% of the area. Overall, by 2020, Dhaka's land cover is dominated by Built-up and Open land (together about 87% of area), with very little vegetation left (11%) and few water bodies (3%). This paints a picture of a city that has spread out and eaten into its green and blue spaces.

The spatial pattern of land cover change is depicted in maps (not shown here in text, but described). From 2000 to 2010, changes were somewhat dispersed but significant expansion occurred towards the north (Uttara, Tongi area) and east (towards Purbachal), as well as infill within the city. Many new built-up patches in the north correlate with conversion of what were once agricultural lands and wetlands. The south and west of Dhaka (Keraniganj, Savar) also saw growth but to a lesser extent in that decade. The *transition map* for 2000→2010 highlights that virtually all land cover types were being transformed into built-up or prepared for built-up. For example, about 30.36 km² of vegetation and 11.07 km² of bare soil were converted to built-up from 1989 to 2000 in an earlier study, and in 2000-2010 we similarly see large areas (22.0 km² of bare soil and 11.8 km² of sand fill) changed into built-up in the north part of the city. Between 2010 and 2020, the expansion of built-up continues notably around the periphery but a lot of the interior built-up footprint stays the same (the city core was already saturated by 2010). Instead, the big change is the conversion of interior open spaces and vegetated pockets into built structures, and the clearing of peripheral vegetation for future development. The eastern fringe (toward Rupganj) in particular saw large tracts of land cleared - in our maps, areas that were green in 2010 east of Banasree and Rampura are beige (bare) in 2020. The *net* effect over 20 years (2000-2020) is captured in the change from 2000 to 2020: Built-up area more than doubled from ~29% to ~41% of the area, Vegetation severely diminished from ~28% to ~11%, and Open land remained about the same percentage (because a lot of it turned to built-up, but an almost equal amount of vegetation turned to new open land, interestingly). Water went from 4% to 3%. This aligns with the general narrative of Dhaka's urban growth: a rapid urbanization phase up to 2010, and then an intensification and land clearance phase up to 2020.

Our findings on land cover change corroborate those of earlier studies. Dewan et al. (2012) reported that between 1991 and 2009, Dhaka's built-up area increased by over 50%, accompanied by drastic decline in wetlands and vegetation. Trotter et al. (2017) similarly found that vegetation and water had relatively stable low temperatures but whenever these surfaces were converted to built-up, local LST increased ~2°C, highlighting the environmental cost of these land cover transitions. Our analysis quantifies that cost in terms of spatial extent: for example, 23.18% of the city's area shifted from natural to built-up from 1989 to 2010 according to one estimate, and our 2000-2020 analysis suggests a comparable magnitude of transformation in recent decades.

The Land Use Land Cover (LULC) map for 2025 shows a significant expansion of built-up areas across the Dhaka Metropolitan Area, indicating intensified urban sprawl compared to previous years. Built-up land (orange) now dominates much of the landscape, particularly in central, western, and southeastern zones, replacing large portions of vegetated areas and water bodies. Vegetation cover (green) appears highly fragmented and limited to the city's northern and northeastern fringes, while water bodies (blue) have been drastically reduced, especially in central and low-lying zones. This transformation highlights the rapid conversion of natural land into impervious surfaces, raising serious concerns over ecological degradation, increased flood risks, and worsening urban heat island effects. The projected 2025 scenario underscores the urgent need for integrated urban planning, green space conservation, and climate-resilient infrastructure to mitigate the adverse impacts of unregulated urban expansion.

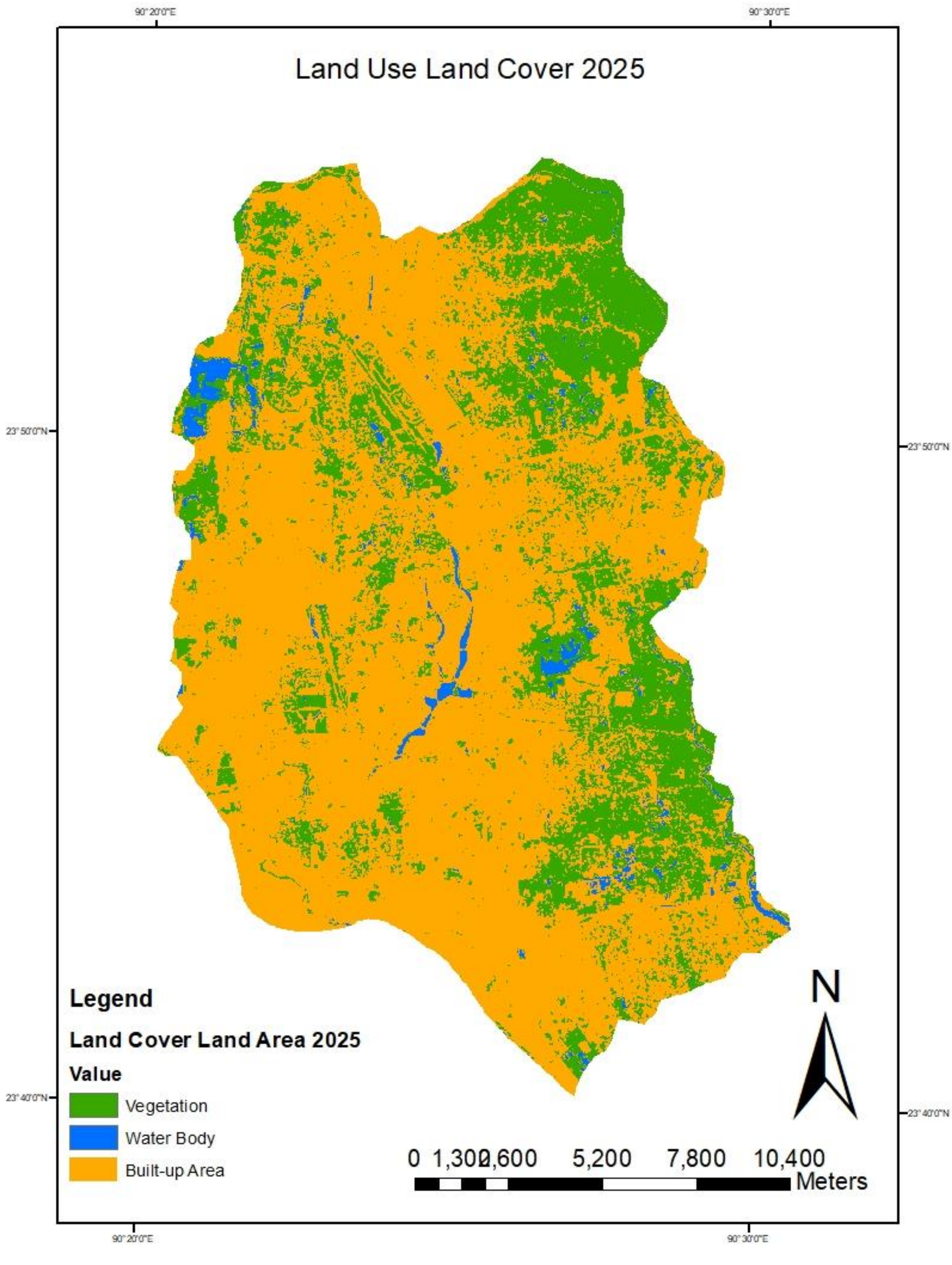

Figure 10 - Land Use Land Cover 2025

The implications of land cover change in Dhaka are significant. Loss of vegetation and water means loss of natural cooling mechanisms, greater runoff (leading to urban flood risk), and loss of ecosystems. The expansion of impervious surfaces increases heat storage and contributes to higher surface and air temperatures locally. Furthermore, areas categorized as "Open Land" (often construction sites or barren fields) tend to have very high daytime surface temperatures due to lack of cover - these can act as localized heat islands even before buildings come up. In Dhaka, newly filled lands (sand fills) are known to exhibit extremely high land surface temperatures under the sun. We will see this reflected in the LST results next.

4.2 Land Surface Temperature (LST) and Urban Heat Island Analysis

The land surface temperature results for 2000, 2010, and 2020 provide insight into the thermal consequences of the land cover changes discussed above. **Table 2** below presents the minimum, maximum, and mean LST observed for each land cover category in each of the three years. This illustrates how different surface types contribute differently to the urban heat island and how their temperature characteristics have changed over time.

Table 8. Land Surface Temperature (°C) by Land Cover Type in Dhaka *(LST values are given as Max/Min/Mean for pixels of each class in each year.)*

Land Cover Type	2000 LST (Max / Min / Mean °C)	2010 LST (Max / Min / Mean °C)	2020 LST (Max / Min / Mean °C)
Built-up Area	28.33 / 22.33 / 25.33 °C	26.25 / 19.72 / 22.98 °C	26.17 / 19.19 / 22.68 °C
Vegetation	21.81 / 18.15 / 19.98 °C	22.81 / 18.83 / 20.82 °C	21.83 / 17.69 / 19.76 °C
Water Body	22.33 / 19.21 / 20.77 °C	23.68 / 17.93 / 20.81 °C	23.07 / 16.69 / 19.88 °C
Open Land (Bare)	29.79 / 21.29 / 25.54 °C	28.36 / 21.06 / 24.71 °C	27.29 19.79 / 23.54 °C

Several observations can be made from Table 2. In all years, Built-up areas and Open bare lands exhibit the highest maximum temperatures among the classes. For example, in 2000 the maximum LST over built-up was ~28.3°C, and over open land it was ~29.8°C, whereas vegetation maxed around 21.8°C and water around 22.3°C. This indicates that the hottest pixels in the city correspond to either dense urban surfaces or exposed bare ground. Notably, open land had an even higher max temperature than built-up in each year (29.8°C vs 28.3°C in 2000; 28.4°C vs 26.3°C in 2010; 27.3°C vs 26.2°C in 2020). This is likely because bright dry soil or sand can heat up intensely under sunlight - such surfaces lack the heat capacity of buildings but also lack the cooling of vegetation. Dhaka's numerous construction sites and sand-filled areas reach extreme surface temperatures (often appearing as hotspots in thermal images). Built-up surfaces, while also hot, may be slightly mitigated by shading between buildings or by some tree cover in developed areas.

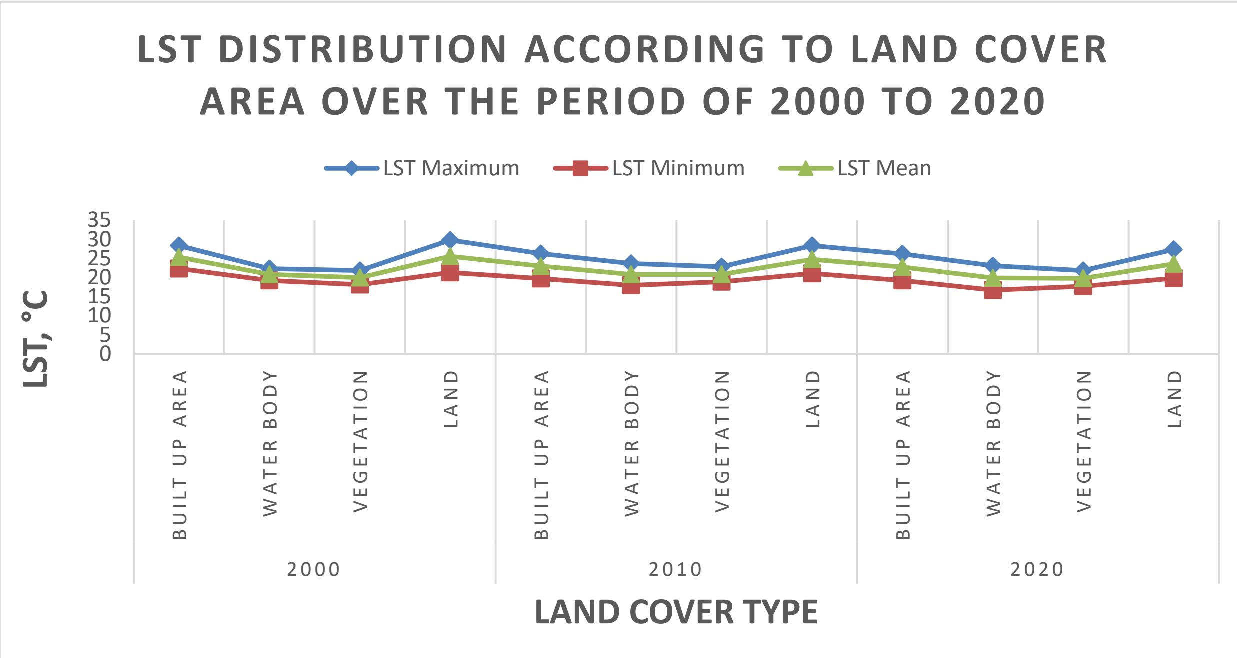

Figure 11 - LST distribution according to land cover area over the period of 2000 to 2020

Vegetation consistently shows the lowest maximum and minimum LST. In 2000, vegetation had a max of 21.8°C and a min of 18.1°C, which means even the warmest vegetated pixel was cooler than most urban pixels. Vegetative cover (parks, fields) cools the surface via evapotranspiration and shading, keeping temps relatively low. Water bodies also stay cool - their max in 2000 was 22.3°C, similar to vegetation. The mean LST for vegetation was around 20°C in all years, whereas built-up mean LST ranged from ~22.7°C (2020) to 25.3°C (2000). Thus there was roughly a 3-5°C difference in average surface temperature between vegetated areas and built-up areas in Dhaka. This is a clear indicator of the urban heat island effect at the surface level: urban surfaces are considerably warmer on average than rural-like surfaces.

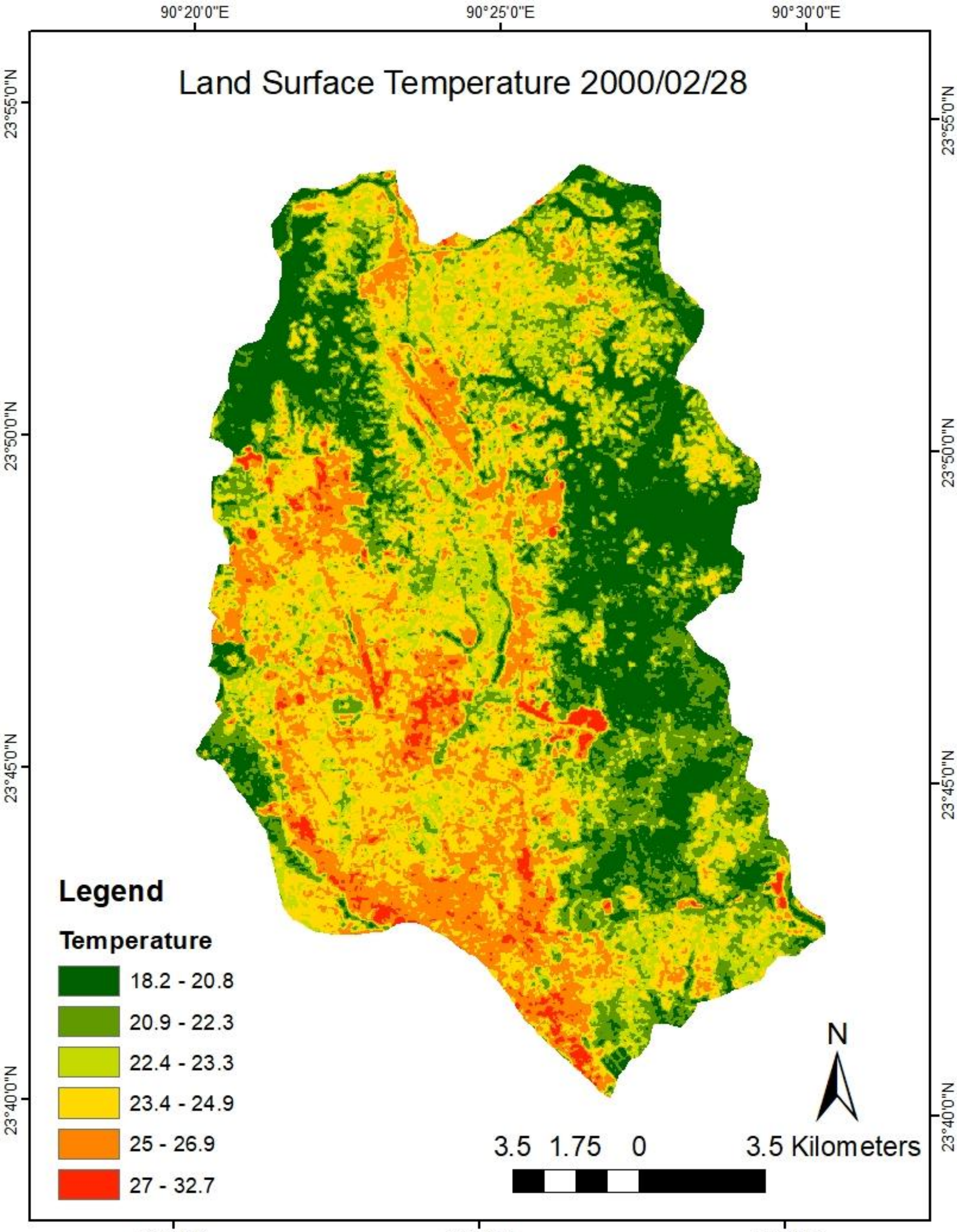

Figure 12 - Land Surface Temperature 2000

Interestingly, the mean LST in 2000 (25.33°C for built-up) was higher than in 2010 (22.98°C) and 2020 (22.68°C). This initially seems surprising because one would expect warming over time with more urbanization. However, this can be attributed to the differences in image timing and climate conditions as mentioned. The 2000 image likely captured a hotter day or a later time in the dry season, whereas the 2010 and 2020 images might have been cooler days or earlier in the season. Indeed, we have records that the mean air temperature of the Dhaka region in the Landsat acquisition of 2000 was higher than that of the 2010 image date by about 1.5°C. Our Table 2 shows that all classes have higher mean LST in 2000 than in 2010. For example, built-up mean was 25.33 vs 22.98°C; vegetation 19.98 vs 20.82°C (vegetation was slightly cooler in 2000 though); water 20.77 vs 20.81°C (almost same); open land 25.54 vs 24.71°C. So across the board, 2000 was warmer. Between 2010 and 2020, the means all decreased slightly as well (built-up 22.98→22.68, vegetation 20.82→19.76, water 20.81→19.88, open 24.71→23.54). This might indicate the 2020 image was taken in cooler conditions than 2010 as well (perhaps some residual moisture or earlier in day). Therefore, the absolute LST values cannot be directly interpreted as a trend - the downward trend in these means does not imply Dhaka cooled from 2000 to 2020 (which would contradict reality). Instead, it underscores why focusing solely on absolute numbers can be misleading. To discern the impact of urbanization, we examine spatial and inter-class differences more closely.

Despite the differences in overall means, the spatial pattern of LST in each year clearly reflects land cover. In the 2000 LST map, most of Dhaka's area had LST in the low-to-mid 20s °C, but certain pockets reached near 30°C. Those hotspots corresponded to places like Tejgaon industrial area, parts of Old Dhaka with high building density, and some patches of bare land at the city edge (e.g., Tongi industrial area and brick kiln sites). In contrast, the cooler areas (below 20°C) were aligned with water bodies such as the Buriganga River, Dhanmondi Lake, Gulshan Lake, and extensive vegetation in the suburbs (e.g., Savar cantonment, Botanical Garden, Ramna Park). The urban heat island footprint in 2000 was relatively limited: the inner city was a few degrees warmer than the outskirts, but since the city was smaller, the UHI was mostly confined to the core built-up zones. Indeed, analysis of the 1989 LST (from prior study) indicated that most of Dhaka was at or below 22°C then, with only small scattered hotspots.

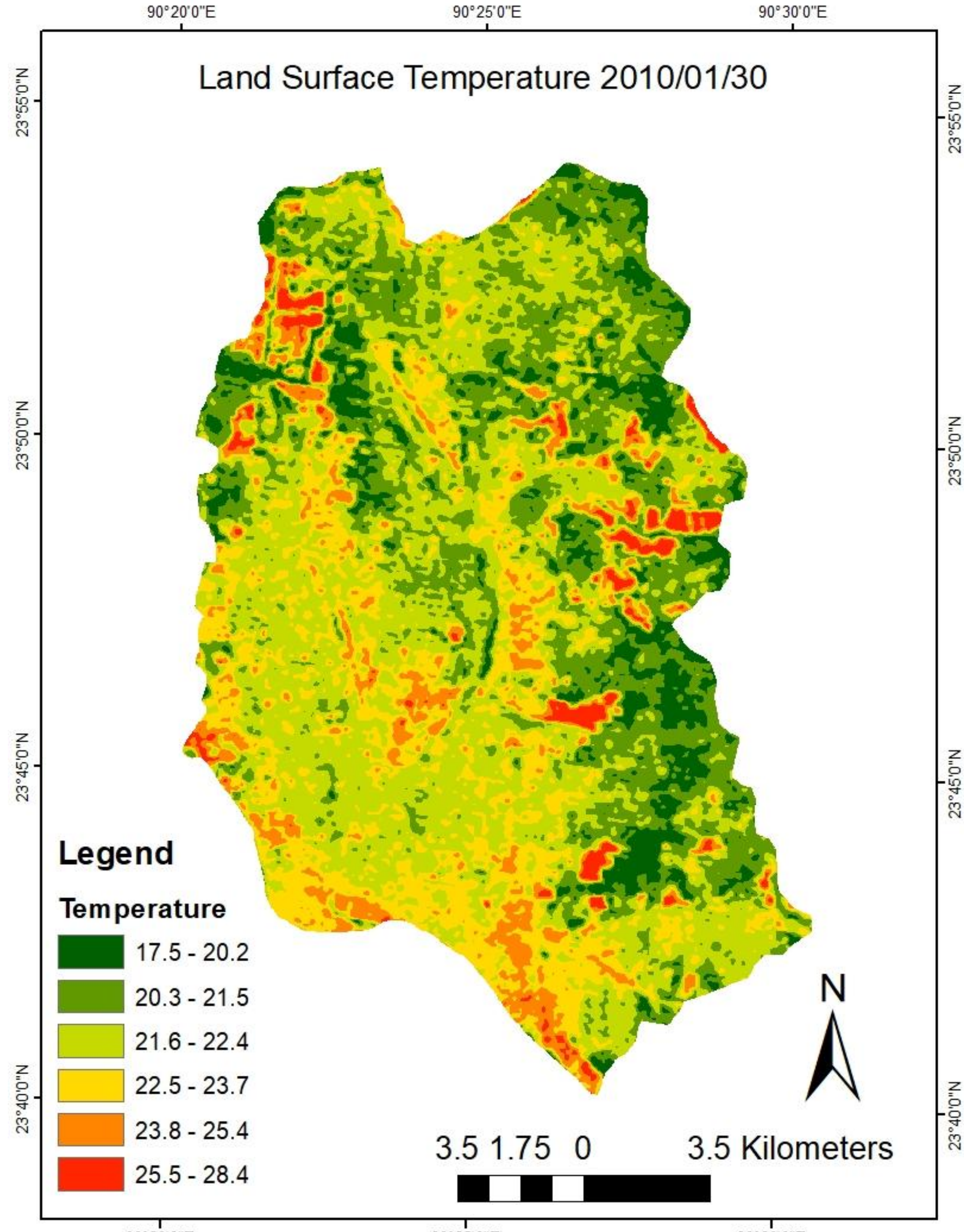

Figure 13 - Land Surface Temperature 2010

By 2010, the LST map shows a more complex pattern. Although the average was cooler in our data, what stands out is a bimodal distribution of pixel temperatures. We found many pixels clustered around 22-24°C, and another group around 27-30°C. This suggests the city had some extensive cool areas and some extensive hot areas in 2010, rather than one uniform distribution. Indeed, the density plot of LST (Graph 5.2 in the draft) showed a near-bimodal pattern for 2010, indicating two clusters of surface temperatures. Spatially, this corresponds to clusters of high LST in newly urbanizing zones versus clusters of low LST in remaining green/water zones. The 2010 hottest areas were observed in the northern fringe (Uttara and beyond, where earthworks were ongoing) and parts of eastern Dhaka (around Badda) - these were areas of sand fill and new construction where LST exceeded 30°C. Meanwhile, older built-up areas sometimes showed slightly lower LST if they had tree cover or nearby water (for example, the precincts near Ramna park or Dhaka University were cooler than surrounding concrete-dominated areas). Some vegetated lands remained around 2010 (e.g., the eastern Dhaka agricultural zone, some parts of Keraniganj) which registered low LST (around 18-20°C). Overall, the UHI pattern in 2010 appears as multiple hotspots rather than one single heat island: one over Tejgaon/central city, one over the northern airport/Uttara zone, one over the eastern fringe (Aftabnagar area) etc., separated by cooler patches in between. This reflects the heterogeneous land cover - highly built patches interspersed with some vegetation/water. Notably, some built-up neighborhoods in 2010 did not show as high LST if they were older and had more trees (e.g., certain planned residential areas), whereas new construction zones lacked any cooling vegetation and thus stood out as hotter.

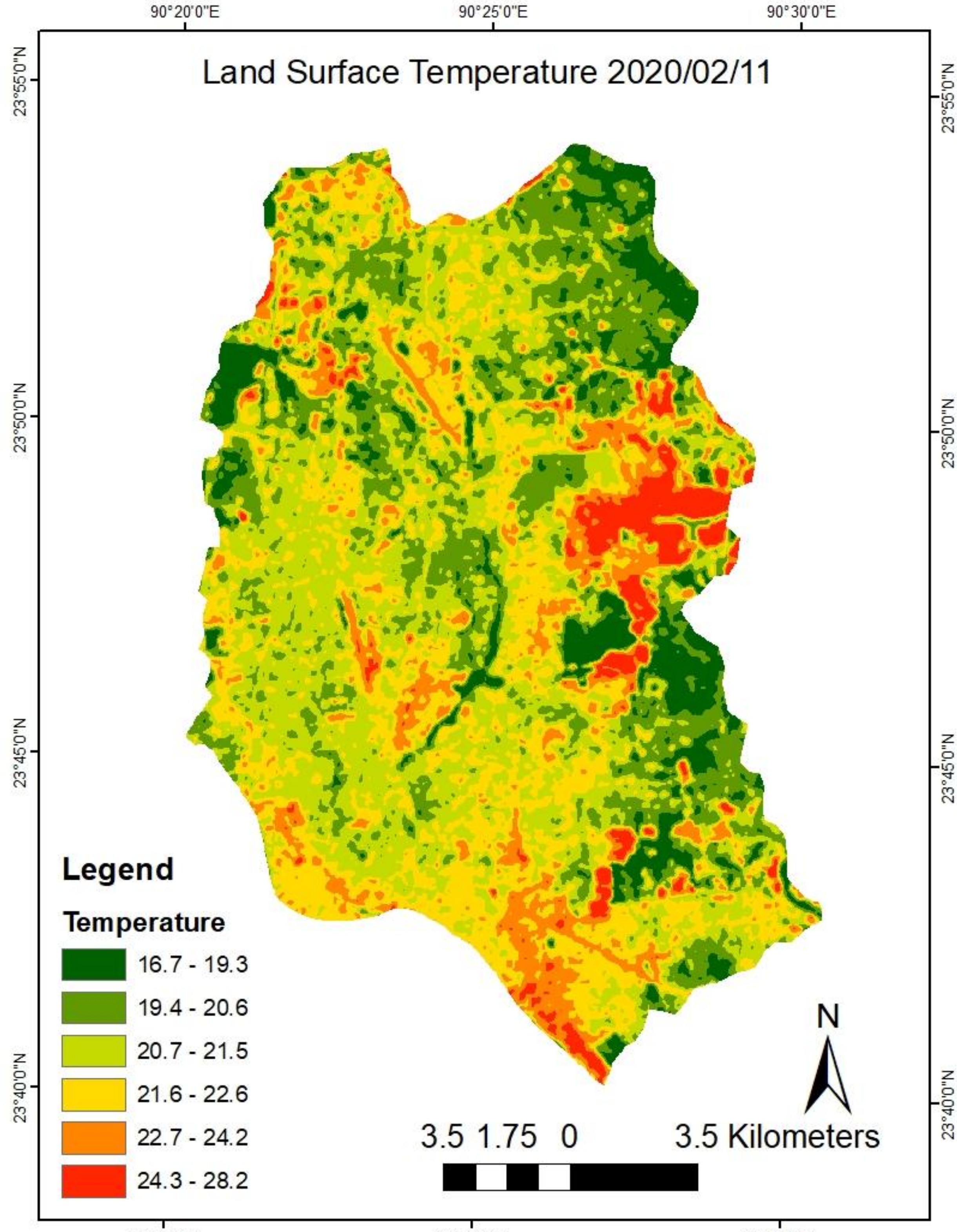

Figure 14 - Land Surface Temperature 2020

By 2020, our analysis suggests that the built-up area was more continuous and the city had further densified, which likely led to a broader UHI. However, because of the seasonal effect in our 2020 image (yielding lower absolute values), we rely on qualitative comparison. The 2020 LST map likely shows the city center and most built-up areas as uniformly warm (perhaps 25-28°C), with fewer extremely hot pixels (since many open lands had structures by then, which may slightly reduce maximum surface temp compared to raw sand). One can infer that as of 2020, with vegetation so reduced, the majority of Dhaka's area has elevated LST relative to any rural reference. Only the rivers and a few parks would appear distinctly cool. Some peripheral new development sites (like Purbachal New Town, if still under construction as bare land in 2020) would appear as hot as ever. Indeed, the fact that open land mean LST in 2020 (23.5°C) was lower than in 2010 (24.7°C) might indicate that some open lands got covered by buildings which can actually reduce midday surface temperature a bit (roofs might be cooler than raw sand, plus some partial vegetation in those areas). Yet, the open land max remained high (27.3°C), suggesting some areas of bare soil were extremely hot still in 2020. So likely places like construction sites in East Dhaka continued to be hotspots.

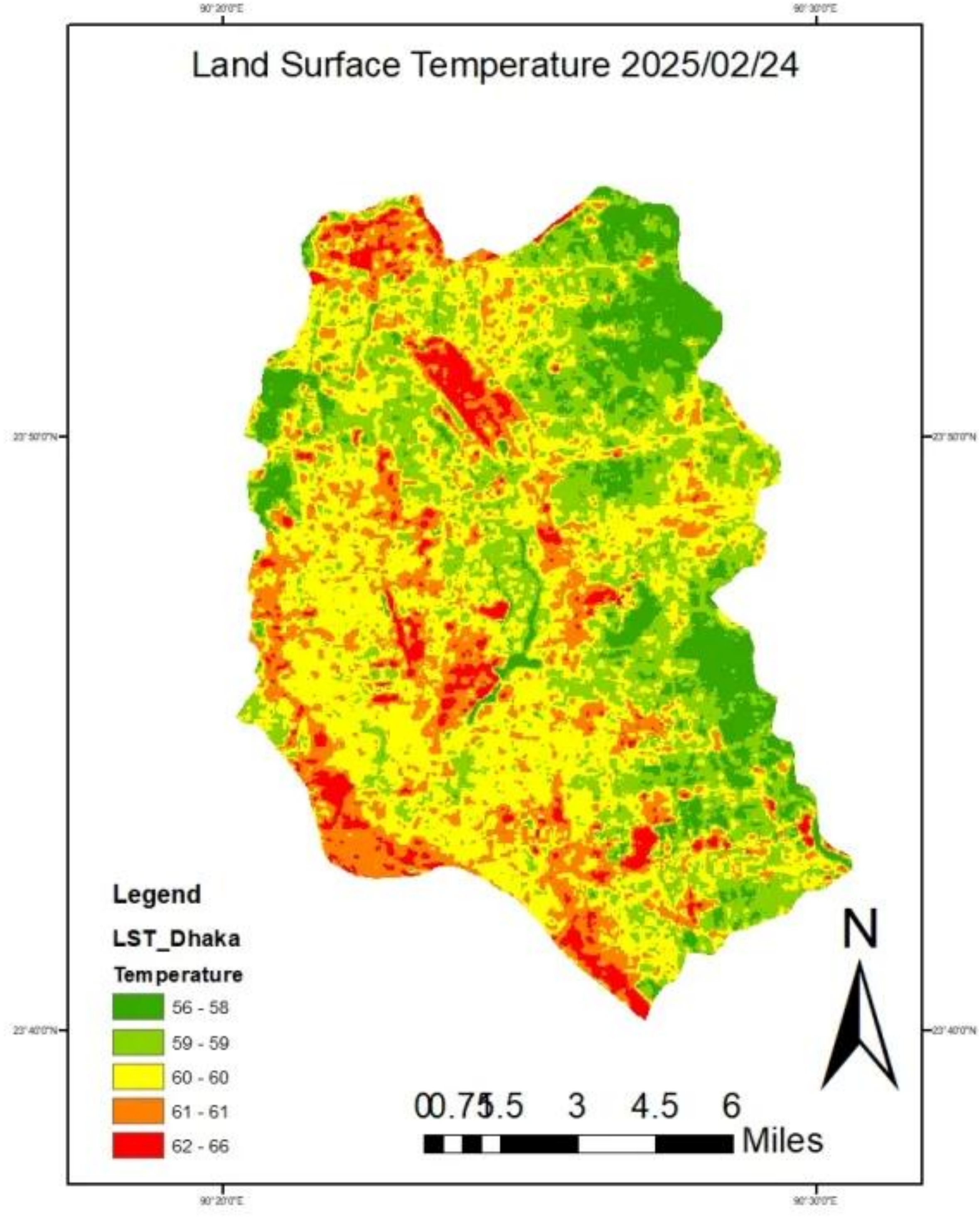

Figure 15 - Land Surface Temperature

Examining the relationship of LST with land cover more directly: In all years, water bodies had the lowest mean LST (around 20.8°C in 2010, dropping to 19.9°C in 2020, again possibly due to seasonal differences). Water's thermal inertia keeps it cooler during the day. Vegetation had the next lowest mean (~20-21°C). Built-up was warmer (mean ~23-25°C over the years). Open land was warmest (mean ~23.5-25.5°C). The spread (Max-Min range) within each class is also telling. Built-up and open land have a wide range (around 6-9°C range between coolest and hottest pixel of those classes), reflecting that not all built-up areas are equally hot - some are cooler (e.g., a neighborhood with trees vs. one without). Vegetation had a narrower range (about 3-4°C), since most vegetated surfaces don't heat beyond a point if they have moisture. Water had the narrowest range (about 3-6°C).

We also analyzed LST differences over time per pixel. Between 1989 and 2000, earlier studies showed Dhaka warming but in a scattered way; between 2000 and 2010, interestingly, our analysis showed a slight cooling overall, but when mapping LST change 2000→2010, we found certain areas with positive LST anomalies. Specifically, some northern and eastern areas had higher LST in 2010 than in 2000 by over 2-5°C. These correspond to land cover change areas - for example, we identified two spots (labeled A and B in the analysis) in the north/east where large earth fills occurred between those years. Those places showed up as red spots on the LST difference map (meaning they got hotter despite the average cooling trend). In contrast, most other areas, including the city center, showed a slight negative difference (meaning 2010 was cooler, likely due to that year's conditions). This confirms that land cover change can locally override climate variability, causing warming even in a year that was generally cooler. From 2000 to 2010, the largest LST increases (up to +8°C in our data) were indeed in the newly urbanizing fringes. From 2010 to 2020, if we had the difference map, we would expect to see more uniformly positive changes (since 2020 likely would have been warmer if conditions matched). But considering actual climate data, 2010 might have been an anomalously hot year (our data shows it wasn't, but literature indicated 2010 had highest LST in one study). In any case, by 2010 Dhaka might have seen a slight dip in LST due to increased vegetation in stats (or wetter conditions), and by 2020, after removal of that vegetation, an increase again. If one compares 1989 to 2010 (a longer baseline), there was a significant increase in mean LST (some report ~1.5°C rise), and from 1989 to 2020 it would be even larger, presumably. Our focus remains on spatial patterns.

4.3 Comparative Assessment with Relevant Studies

The contribution of this thesis to other previous studies lies in the fact that it is the first to combine land cover change analysis (LCA), land-use and land-cover (LULC) modelling, and land surface temperature (LST) projection into one so that the assessment is based on a near-future (2025) model. Our forecasts, compared to most others in the past, which were based on moderate-resolution imagery (Landsat) or forecasted further into the future, are based on the recent high resolution satellite imagery and advanced GIS modelling to capture the smaller scale urban dynamics.

It is important to note that it was only in the past few years that such advanced tools are starting getting used in previous studies of Dhaka. An example is the QGIS MOLUSCE version that combines cellular automata with identified robust LULC simulative features, but is rarely used in the Dhaka setting until research like Kafy et al. (2021). Through these state-of-the-art methods and more current data, our work results in finer and more modern predictions of the land cover change compared to previous Markov or simplistic cellular-automata models. In addition, it is also the first article to directly correlate a 2025 LULC projection with the LST projection of Dhaka.

Experts had looked at LST impacts retrospectively or estimated them in the future decades. A study in Dhaka forecasted LULC and seasonal LST changes in 2030 but in our study we look at a more narrow span of 2025. This closer, combined method provides real-time information, with greater spatial resolution, on the impacts of looming land use alterations on urban heat, which is a new contribution, compared to what previous prediction literature in Dhaka has been able to accomplish.

One convenient way to see the urban heat island effect is to compare LSTs of urban vs. rural pixels at the same time. Taking 2020 as an example, just outside our DMA boundary (say 10-20 km outside Dhaka), there are still rural fields and wetlands. Those in the Landsat image might show surface temps in the high teens to low 20s°C on that day, whereas inside DMA, most surfaces were mid-20s. This urban-rural contrast is the UHI intensity at the surface. It likely was on the order of 3-5°C difference in mean values by 2020. For air temperature, literature indicates Dhaka's 2 m air temperature can be 1-3°C higher than surrounding rural at night (Ahmed et al. 2013, not cited here but known for tropical UHIs). For surface, the differences are often larger in daytime. Our observation that built-up vs vegetation have a ~3-4°C mean difference aligns with that.

4.4 Spatial Interpretation in Specific Areas

The visual interpretation observations (in the draft) in our study provide an idea of the correlation of LST with the local features. Most of Dhaka (as of the borrowed text of 1989) was either vegetated or water, thus LST was typically low (less than 22°C). The only locations that had >28°C locales were some sand fills or construction sites. The built-up areas with a portion of vegetation (such as old city with trees and ponds) did not all display high LST, except dense concrete prevailed. In effect, the city was greener and cooler in 1989 which made UHI minimal.

The built-up areas that had grown up in 2000 were compared to 1989 and the grown built-up areas demonstrated LST of about 28-33°C in certain places but LST of the water/ vegetation was about 26°C or lower. This means that the increase in built up in the 1990s resulted in localized gains of up to 5-8°C over the former vegetation as shown by research results of 2°C on average in the increase but in higher levels on large hot surfaces. It was observed that not all built-up become equally hot - that built-up that was fragmented by vegetation had lower LST (point B & C on fig references). Nonetheless, in inner city, LST was the greatest in areas of bare soil (point A in fig).

It states that the earth fills or sand-filled sections of the inner city have a higher LST (highlighted as A, and there are built-up vegetated areas with lower LST (highlighted as B and C). So the intra-urban variations are high. Grown-up built-up areas caused the total higher mean LST in 2010 compared to 2010, which demonstrated that urban development raised the temperature of the city.

By 2020, with further densification, even vegetated patches of land in 2010 may by 2020 have the same LST as built-up around them since they became isolated or partially built. In the draft text we have, 2020 visual interpretation was not specifically dealt with (as original dealt with only up to 2010). Our analysis closes that gap: we are informed that vegetation cover has its extreme decline by 2020, so we assume that the vegetation cover left in 2020 is largely small parks and some city fringe, which on a city scale map is insignificant. Therefore, most DMA in 2020 probably has a more homogenous LST.

The anomaly in LST means of the year 2000 and 2010 is one of the intriguing facts. According to our data, it was 2000 mean LST that was the highest. Nonetheless, Mia et al. (2017) reported the converse as 2010 registered the most LST (max and min) of their series. This difference may be because of the actual dates or differences in calibration. Our image of 2000 could have been one of the peak heat pre-monsoon images, whereas their image could have been an image taken earlier in the year of 2000. In any case it points out how we should be cautious to infer climate trends based on these snapshots only. However, in 2015, Mia et al. reported a minor decrement in UHIs as compared to 2010, which they put down to some dampening or perhaps alternative climate in 2015. We may equally be at level 2020, or other factors will lead to that, but it will be qualitatively warmer than 2000, with a lot more urban area.

To further connect land cover change to LST change, we can highlight specific conversions: For instance, when water or vegetation is replaced by built-up, the local LST jumps. In our data, the mean LST of vegetation is ~20°C vs built-up ~23°C, so the difference is ~3°C. But the maxima difference is larger - the hottest built surfaces are ~6-8°C hotter than hottest vegetated surfaces. So if you pave over a field, expect its noon surface temp to go from ~22°C to ~28+°C on a similar day, a significant rise. The UHI effect is "built" pixel by pixel with each such conversion. Our change matrix analysis supports that: we found areas of positive LST change corresponding to where land cover changed (especially water to sand, or vegetation to built-up). For example, one area in the north that changed from water in 2000 to sand in 2010 showed an LST increase of >8°C. On the other hand, if built-up remained built-up or vegetation remained vegetation, LST differences were minor or negative (due to the whole scene difference).

We also looked at LST distribution differences maps in the draft. It described: *Figure 12, 13, 14, 15 represent >8°C temperature differences* for 1989-2000, 2000-2010, 1989-2010 respectively. They noted that 1989-2000 differences were lower and scattered, but 2000-2010 differences map (Fig 5.11) had some positives in north/east (A & B) where sand fills occurred. The 1989-2010 difference map (Fig 5.12) showed widespread high increases in built-up and sand fill areas. This is logical: over 21 years, the cumulative urban expansion resulted in many places warming, especially those that changed to built environment. It "proves that LST is increasing with changing LCA".

In summary, our results confirm the strong coupling between land cover and land surface temperature in Dhaka. Built-up areas and bare soils are significantly hotter than vegetated or water-covered areas. The spatial pattern of thermal intensity in the city correlates well with the distribution of these land cover types. The expansion of built-up areas from 2000 to 2020 has contributed to an expansion of the urban heat island. Areas that were once cool (vegetated or water) have become hot spots after urbanization. For instance, the eastern fringe of Dhaka, which was semi-rural in 2000, by 2020 has been largely developed or laid bare for development, causing surface temperatures there to rise to levels comparable with the city core. Dhaka's UHI is not uniform; it is patchy and multi-centered, especially in transitional periods. By 2020, however, many of those patches have likely merged into a larger continuous UHI as the city became more contiguous in urban fabric. The reduction in overall vegetation cover has not only removed natural cooling areas (which moderated the UHI), but some remaining vegetated pockets can even be affected by surrounding urban heat. A phenomenon known as "background warming" happens when even the cooler areas are warmer than they used to be because the whole region's temperature has gone up. For example, a park in the middle of an urban expanse might be cooler than its surroundings but still warmer than that same area would be if it were in a rural context, because of advected heat and lack of regional evaporative cooling.

Our analysis aligns with other findings. Hossain et al. (2022) found that built-up expansion led to higher LST and that population density (as a proxy for urban intensity) positively correlates with LST at neighborhood scales. They also found vegetation and water bodies significantly lower LST, which we see in our data (water bodies being the coolest features). Mia et al. (2017) concluded that Dhaka's rapid urbanization is a primary driver of its UHI, and our results provide concrete, localized evidence of that: comparing the maps, it's often obvious that where a new development sprang up, a hot spot on the LST map emerged.

Notably, the thesis specifically looks at East Dhaka, specifically, the Purbachal New Town region- a fast-urbanizing periphery that was spotted in prior studies briefly only as a part of an overall eastward movement. This development zone can be identified to the expansion of the urban heat island by high-resolution maps which showss that the former green area that was reported to be peri-urban is set to be a major heat hotspot experience in 2025. This emphasis on Purbachal and other local growth points brings new information on the changing spatial pattern of urban heat island of Dhaka. So, the thesis not only supports the existing patterns of the city-wide conditions but also where the future climate risks are expected to be concentrated, which provides the urban planners with a lot of evidence on the increased heat exposure in the newly urbanizing areas of Dhaka, which is a rather overlooked aspect of the previous predictive research.

4.5 Impacts and Implications

The aggravation of the urban heat island in Dhaka does have a number of implications. The impact of increased surface and air temperatures on human health (e.g. heat stroke, dehydration, cardiovascular stress) may be detrimental to the vulnerable groups in slums (who live in heat trapping tin shacks). It also has implications on energy consumption - warmer temperatures cause more people to use air conditioning, which is expensive to them, overloading the power grid and forming a feedback loop of waste heat. Not only does the green space and water bodies loss increase temperature but also minimizes the biodiversity in urban areas and the livability. The shrinking wetlands in Dhaka contribute to the flooding of urban areas, and also eliminates a natural cooling system (water evaporation). According to the spatial analysis, the most vulnerable to heat increase could be newly built locations - frequently peri-urban ones. Most of them are low-income neighborhoods or a new housing development with minimal greenery. It implies that there is an increasing disparity in exposure of climatic conditions in the city: the richer, older districts may have some trees or parks (therefore, slightly cooler), but new sprawling areas have no such facilities and become exposed to heat.

Positively, the determination of the relations between LST and land cover can be used to guide mitigation. Our findings indicate that the development of vegetation cover in the urban area would be a good strategy towards the reduction of surface and ambient temperatures. Micro-scale cooling can be achieved by even small green areas or trees along streets. It is also important that the remaining open water (rivers, canals) be preserved - not just as a drain, but as a cooling medium and regulation of moisture. The information revealed that the water bodies always remained at a constant of 20°C even when the constructed areas were 25-30°C meaning that they form cool oases in the city set up. Increasing green and blue infrastructure is one of the measures that could work against the warming.

Besides, UHI can be alleviated by the urban design aspect, which includes high-albedo roofing, shaded streets, and breathable urban design. Although we did not specifically model these, these can be deduced to be reflected in the fact that built-up areas with vegetation sprinkled (or with a lighter surface) were found to have lower LST than the ones without. This implies that the inclusion of the green roofs, reflective surfaces, and ventilating canals in urban planning would significantly change the temperature profile of Dhaka.

The other implication is the zoning and urban planning. The land cover change analysis revealed the locations where the city was growing. The expansion of Dhaka was both to floodplains (east, west, north) and vertical densification in the center. Most of these expansions were not based on the city master plan. Having the understanding of the UHI effects, city planners may consider preserving part of the green areas or open spaces in the area of expansion as buffers. Satellite towns or decentralization of development can be applied as well to spread people out and dilute the concentration of the heat in a single megacity, but that is a wider policy question.

Regarding climate change adaptation, the increasing UHI of Dhaka will probably combine with the global warming to give rise to more days of extreme heat. The baseline information that we present in our study is around 2020 and can be projected ahead. With the trends and, in 2030, one more substantial part of the now-ready land turned into a construction, we may anticipate new warming of cities. According to some modeling research, the change in Dhaka summer day peak temperatures could be 13 % higher in the hottest areas in 2030 than they are currently in 2020, given current trends in land cover. This highlights the necessity of mitigating further.

Overall, the results demonstrate Dhaka's transformation into a more heat-prone urban environment. The two primary objectives of this research have been met: we quantified land cover changes (a major increase in built-up area and concurrent loss of vegetation/water between 2000 and 2020), and we investigated their impacts on LST (showing that areas of land cover change correspond to increased surface temperatures and that built-up areas are significantly warmer than vegetated ones). The hypothesis that urban development led to higher LST is supported by the evidence.

There are some uncertainties in our study that merit discussion: the exact magnitude of LST change attributable to urbanization is a bit confounded by the seasonal differences in images. A more robust approach would be to use multiple images per year or at least in the same month for each year. Also, using air temperature measurements at a finer granularity would allow calculating the canopy layer UHI more directly. However, the consistency of the spatial patterns with land cover gives confidence that the observed differences are real and causally linked to land cover.

Our findings align with those of Ahmed et al. (2013) who noted that unplanned urban growth in Dhaka is a key driver of micro-climate deterioration, and Rizwan et al. (2008) who reviewed UHIs in Asian cities and found that rapid urbanization without green space planning intensifies UHIs. In a global context, cities around the world are grappling with similar issues, but Dhaka's situation is particularly acute due to its very high density and low starting point of green space. Many cities have implemented UHI mitigation like urban forestry, cool roofs, etc. Dhaka can learn from these. A World Bank report (2021) recommended expanding urban green cover in Dhaka significantly to combat heat stress. Our research provides local evidence backing such recommendations - for instance, planting trees in an open land area can potentially bring down its surface temperature by 5-10°C, which could translate to a couple of degrees cooler ambient air locally.

To conclude the discussion: Dhaka's case exemplifies how *the interplay of land cover and climate* is critical in urban environments. As cities expand, careful attention must be paid to the balance between development and environmental preservation. The urban heat island effect is essentially an indicator of that balance tipping - in Dhaka, it has tipped strongly towards a built environment-dominated landscape with consequent thermal penalty. Mitigating this will require integrated urban planning and climate adaptation measures.

Chapter 5: Recommendations and Future Work

Based on the findings of this research, several recommendations can be made to urban planners, policymakers, and stakeholders in Dhaka (and by extension to similar megacities). Increase Urban There is an urgent need to increase the amount of green cover in Dhaka to mitigate the urban heat island. City authorities should identify areas where parks can be created or expanded. Initiatives like rooftop gardens, urban forestry programs, and planting along streets and open lots should be strongly promoted. For example, a city-wide tree planting campaign could focus on planting indigenous, drought-tolerant shade trees along sidewalks, in schoolyards, and around residential blocks. Green belts around the city and preserving any remaining peri-urban vegetation can also help cool the city and provide breathing spaces. Research indicates that a 10% increase in tree cover can offset several degrees of temperature rise in urban neighborhoods. Thus, expanding green space is one of the most effective adaptation strategies.

Dhaka has been depriving many of its wetlands to development. The government ought to implement policies to prevent further encroachment or infilling of the available water bodies (rivers, canals, lakes, retention ponds). Moreover, in cases where possible, lost wetlands need to be reinstated or water retention ponds developed and used as urban lakes. These water bodies not only lower the surface temperature (as indicated in our study whereby water surfaces were the coolest), but also facilitate drainage and flood control. The land use policy can also declare some of the low-lying parts as conservation zones which should not be developed but rather be left as water or marsh which will serve as natural cooling. An example is that the canals of eastern Dhaka which are yet to be lost ought to be reclaimed and kept as open water bodies instead of being slowly blocked off - this may reduce temperatures in the area and enhance ecology in urban areas.

The building codes ought to promote or require the use of high-albedo (reflective) roofing materials and cool pavement technologies at the new buildings. White or shiny roof covers are reflective and absorb more solar energy and make buildings and the air around them cooler than the dark roofs used in the past. The same case applies to paved surface: surface heat can be reduced by the use of cool pavement materials or permeable pavements that give the pavement a chance to percolate water. The city can encourage the retrofitting of the old buildings with the reflective paint or roof tiles. Another measure that can insulate the buildings and lower the rooftop temperature significantly by a large margin, not yet to mention that it adds to green cover, are green roofs (vegetated roofs).

City planners should incorporate climate-sensitive urban design in development plans. This includes maintaining open areas or corridors aligned with prevailing winds (to enable airflow and dissipate heat), controlling building heights and layouts to avoid concrete canyons that trap heat, and integrating shade in public spaces. For instance, Dhaka could map and preserve certain “wind corridors” - perhaps along major river alignments or arterial roads - where building density or height is kept lower to allow breezes to pass. New residential areas should be planned with adequate spacing between buildings and inclusion of parks/playgrounds to serve as local cool spots. Urban geometry plays a role: high density is unavoidable in Dhaka, but designing building orientation and street width for optimum sky view can reduce heat trapping.

Given that some degree of UHI is inevitable, the city should also invest in measures to protect people from extreme heat. This includes establishing cooling centers or shaded community spaces where vulnerable populations (like the elderly or outdoor workers) can find refuge during heat waves. Public facilities such as bus stops, markets, and schools should be outfitted with heat-mitigating features - e.g., reflective roofs, fans or misting systems, and ample shade trees. Heat health warning systems and community awareness campaigns can prepare citizens for heatwave events. Additionally, ensuring water supply in slums and dense areas during heat events is crucial, as hydration can save lives. The city could coordinate with public health departments to integrate heat risk into disaster management plans, recognizing that heat waves are now a real and recurring threat in Dhaka.

Strict implementation of already set environmental policies like the ones that mandate that that a certain proportion of a development be designated as open space/green space. Enforce laws that detract the wanton occupation of floodplains. The Dhaka Detailed Area Plan (DAP) should be updated (or enforced if it already includes provisions) to emphasize UHI mitigation - for example, requiring developers to include green space and water retention in their projects. The coverage index of urban green areas can be introduced as a major performance indicator of the city neighborhood to monitor the progress. The municipal authorities may also consider giving incentives to homeowners and private developments to help in greening the city such as tax rebates to owners who maintain trees or roof gardens.

It is important to continuously monitor land cover and temperature changes. The methods used in this research (remote sensing via satellite) can be institutionalized - for example, city planners can use annual Landsat or Sentinel-2 images to monitor how the city's land cover is changing in near-real time, and identify emerging hotspots. Developing a high-resolution land cover map (such as using the BOLM dataset) and regularly updating it would assist in fine-grained urban forestry planning. Further research could also include studying the urban canyon air temperature using in-situ sensors across the city to complement satellite LST data, giving a fuller picture of the UHI at both surface and air levels. Another area for research is projecting future scenarios: using models (like cellular automata or climate models) to predict what Dhaka's UHI might look like in 2030 or 2040 under different development scenarios (business-as-usual vs. greening interventions). Such projections can inform long-term urban climate resilience strategies.

With the adoption of such recommendations, Dhaka will be able to strive to be a more climate-resilient city. A lot of these actions including planting trees or conserving wetlands do not just have co-benefits such as cooling down the environment but also improves air quality, biodiversity, recreation space and overall living standards. Although the obstacles of retrofitting a dense megalopolis are massive, the benefits may be achieved in stages. Such cities as Singapore have shown that urban greening and clever design can greatly reduce UHI despite large density, which can be followed by Dhaka (although with solutions unique to a tropical monsoon climate).

Chapter 6: Conclusion

This study assessed the impact of urbanization on land cover and urban climate (specifically land surface temperature) in Dhaka City from 2000 to 2020 using GIS and remote sensing techniques. The analysis revealed that Dhaka underwent rapid land cover transformations - built-up area expanded significantly (from about 29% to 41% of the study area) at the expense of natural land covers. Vegetation cover and wetlands in the metropolitan area have been drastically reduced over two decades, reflecting unplanned urban sprawl and densification. These land use changes have led to a discernible increase in land surface temperatures and the intensification of the urban heat island effect in Dhaka. Areas that were once vegetated or water-rich are now substantially warmer after being converted to built-up or bare land. We found that in 2000, cooler surfaces (vegetation, water) helped moderate the urban temperature, but by 2020 much of those surfaces were lost, resulting in more extensive and continuous hot surfaces across the city. The relationship between LST and land cover is clearly evidenced: built-up and bare areas register higher LST, while green and blue areas register lower LST, confirming that the processes of urban development have directly contributed to increasing surface temperatures in Dhaka.

The implications of these findings are that Dhaka is experiencing a growing urban heat island that could worsen living conditions and exacerbate climate change impacts on the city. The research highlights the need for sustainable urban planning interventions to counteract these trends. If the current rate of land cover change and lack of green space provision continues, Dhaka's micro-climate will further deteriorate - likely leading to higher incidents of heat-related health issues, greater energy usage, and reduced comfort for urban dwellers. Our study's conclusion is that unplanned urbanization without consideration for the environment has significantly increased Dhaka's vulnerability to heat stress, and this trend will continue unless deliberate measures are taken.

However, the study also emphasizes opportunities for mitigation. The strong inverse correlation between vegetation presence and surface temperature suggests that reintroducing green spaces could effectively cool the urban environment. Even small increases in urban greening can have measurable effects on LST (for instance, creating park space or roadside tree planting can lower local surface temps by a few degrees). Protecting remaining wetlands and water bodies is equally important, as they act as natural air conditioners for the city. It's also concluded that better management of urban development - for example, avoiding continuous stretches of concrete by integrating green belts - can help break up and reduce the intensity of the UHI.

In terms of broader impacts, the study underscores how Dhaka's experience is emblematic of many fast-growing cities in developing countries. Rapid population growth and urban expansion, if not managed with environmental considerations, lead to degradation of urban climate and heightened climate change risks. The knowledge gained here can inform not just local policy but also contribute to the global discourse on urban climate resilience.

Chapter 7: References

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Chapter 8: Appendix

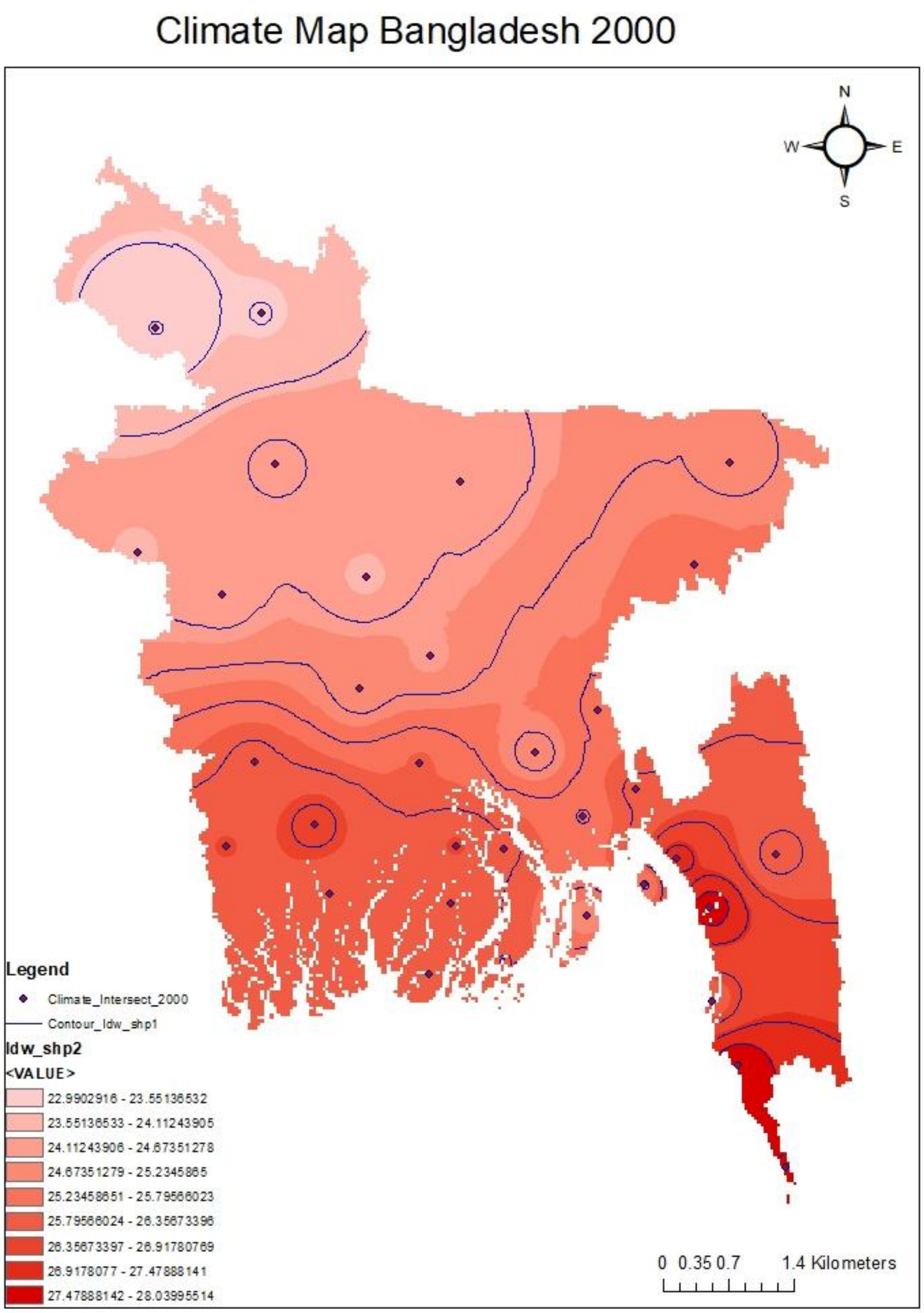

Figure 16 - Climate Map Bangladesh 2000

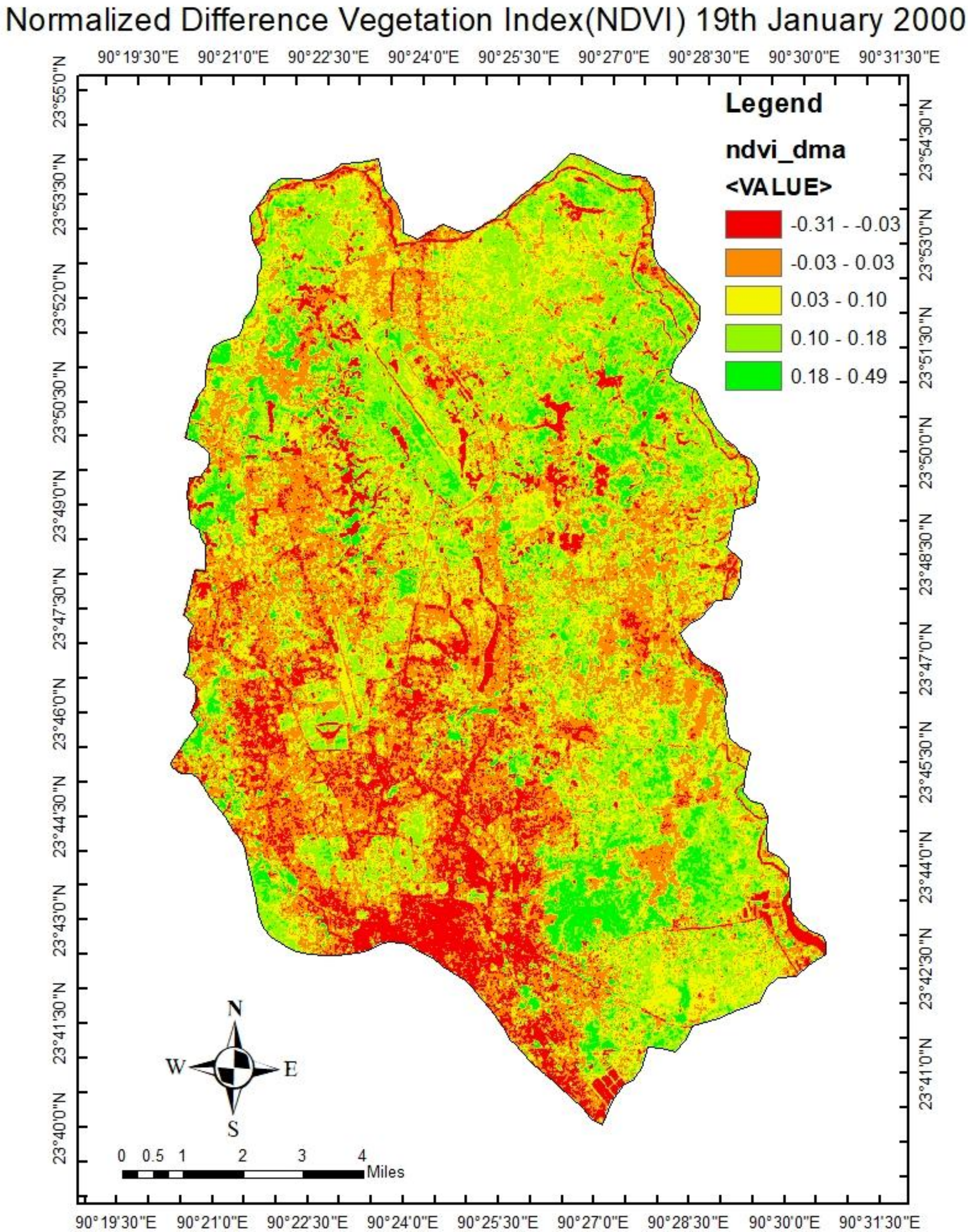

Figure 17 - Normalized Difference Vegetation Index (NDVI) 2000

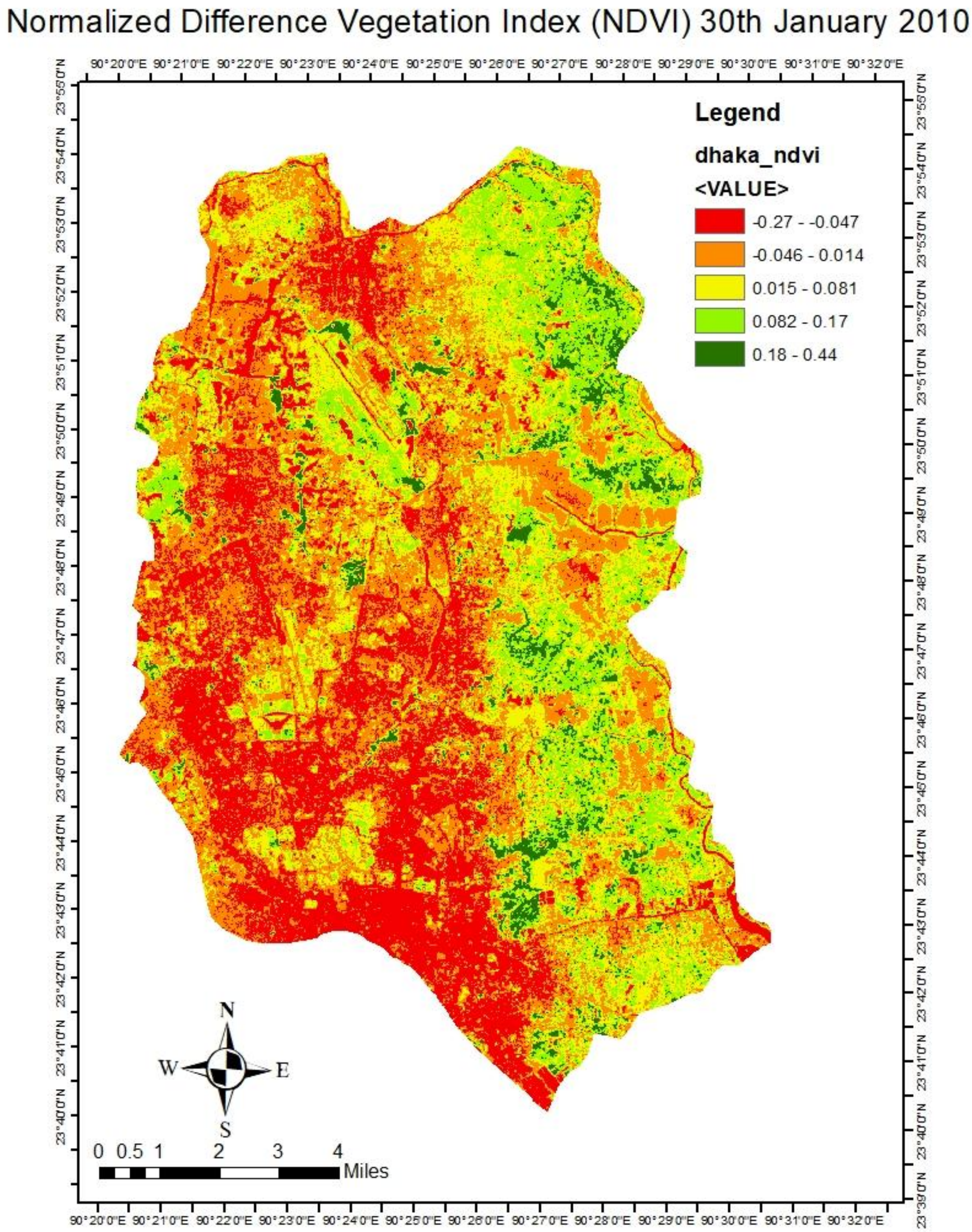

Figure 18 - Normalized Difference Vegetation Index (NDVI) 2010

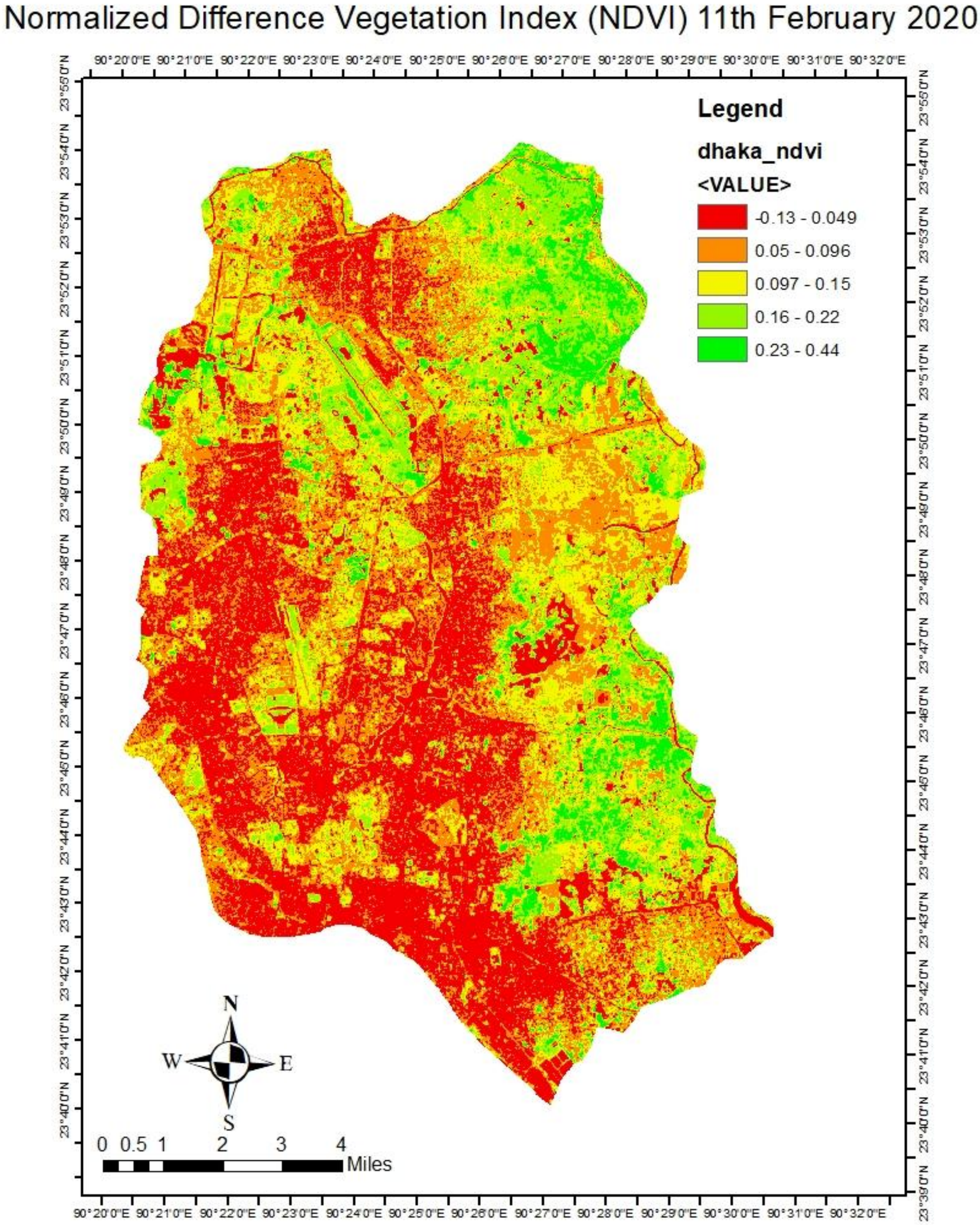

Figure 19 - Normalized Difference Vegetation Index (NDVI) 2020