

A study of the Relationship between Vegetation Health and Land Surface Temperature Using Landsat Data in Dhaka District of Bangladesh

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Abstract

Temperature is increasing day by day all over the world due to climate change and many anthropogenic causes like urbanization. Bangladesh is also one of the victim countries of climate change, where urbanization is occurring at an alarming rate, which has an adverse impact on the urban population in terms of increase in Land Surface Temperature over time. Moreover, this is happening in the center of Bangladesh, especially in and around Dhaka city. In this study, it is observed that when urbanization is limited to a certain area (2001), high temperature is observed only over a smaller region that ranges from 12.15°C to 40.45°C. Whereas, the expansion of urbanized zone increases the area of high temperature zone and maximum temperature is observed 43.81 °C, that is 3°C higher than the last two decades. The average temperature for each land class shows an increase of 1 to 2°C. The weighted average temperature is 25.72°C and 27.33°C respectively in the years 2001 and 2020. This is the direct indication of an urban heat island that is occurring due to the growth of the urban area. These changes in land surface temperature is very essential for urban planners.

Keywords: Climate Change, Urbanization, Heat Island, Anthropogenic causes.

1. Introduction

Urbanization is a new phenomenon in human history. Previously people live in small community in rural areas and involved in primary economic activities. However, due to economic insecurity, political instability and different climate change or disaster related issue make rural people shift to urban areas. More than half of the world's total population are now living in urban areas, increasingly in highly dense cities. Rural areas are also transforming to urban through the process of urbanization. As modern cities are growing rapidly, it create a huge environmental pressure and deteriorating city dweller's living quality. Urbanization does not mean only the ground transformation, but it is caused for transformation of air quality, energetic resources and human population as well as create environmental impact. All of these happen due to reduction of green areas since those few spaces with vegetation are replaced by buildings, streets and many other build structures that reduce their ecological value [1, 2]. In addition to that, climate change is occurring that also has a negative impact by increasing urban temperature.

The urbanization rate of Bangladesh is 3.17% with the rank of 37 [3]. Maximum migration is now occurring in Dhaka and its nearby areas. To support this large population pressure, number of build infrastructure are being constructed by clearing trees and forestry and filling up water bodies. This actions are disturbing ecological and environmental balance. Insufficient green and blue infrastructure and expansion of impervious surface change the hydrothermal properties of urban area. It ultimately raise the land surface temperature and cause of urban heat island. In urban areas, land surface temperature (LST) is higher than that of its surrounding rural areas due to important human impacts on the local surface climate, which is known as the Urban Heat Island (UHI) [4].

In this research, human impact is shown using normalize difference vegetation index (NDVI) mapping, where changes in vegetation and build structure is clearly displayed. The Spatial and temporal changes resulted increase in LST due to changes occurred in land use/ land cover and influence on the local weather of that area. Previous studies suggest that there exists a strong negative correlation between NDVI and LST. Previous studies also suggest that there exists a strong negative correlation between NDVI and LST [5, 6]. Multi-temporal and multi-resolution remote sensing

images can provide basic data for analyzing urban spatial information and thermal environment effectively. Satellite images of two different time period is used to prepare LST and NDVI map for finding out the variation.

Main purpose of this study is to show the effect of urban land use and NDVI changes which are closely related to temperature change that is shown using LST. This research shows how urban area is expanded and as a result, temperature of the land surface increase that with time. The result of this study will help urban planner to understand the impact of urbanization on urban temperature. It will ultimately help to plan eco-friendly urban area considering the urbanization impact.

2. Study Area

Dhaka district, part of Dhaka division is situated at the central part of Bangladesh. Total area of this district is 1463.60 square kilometers. It lies between 23.58 to 24.06°N latitude and 90.01 to 90.37°E longitudes. Administrative boundary of Dhaka district was delineated in 1772. Gazipur and Tongi district bound it from the North, Munshiganj and Faridpur district from the south, Narayanganj from the east and Manikganj from the west. The total number of population of this district is 1,20,43,997. Dhaka District consists with Dhaka, Keraniganj, Nababganj, Dohar, Savar and Dhamrai upazila. Dhaka is the densest among all the upazilla. It is the capital of Bangladesh where rapid urbanization is occurring. Due to rapid urbanization, the amount of open spaces and greenery of this city are reducing and build infrastructure are increasing. Due to this microclimatic situation the city is also getting affected.

The rivers flowing through and around this district are Buriganga, Turag, Padma, Kaliganga, Dhaleshwari, Ichamati, Sitalakhsha, Bangshi, Balli, Elamjani, Alam, Ramkhrishnadi, Elisamari, Tulshikhali [7]. Physio-graphically of Dhaka district is situated on the southernmost part of gently rolling Madhupur tract of old alluvium is bounded by the Brahmaputra-Jamuna floodplain in the northwest and southwest, Meghna flood plain in the southeast [8]. In Madhupur Tract, most of the trees are Sal (around 70%), drainage system of this area is dendritic. This study area experience hot, humid and tropical climate [7].

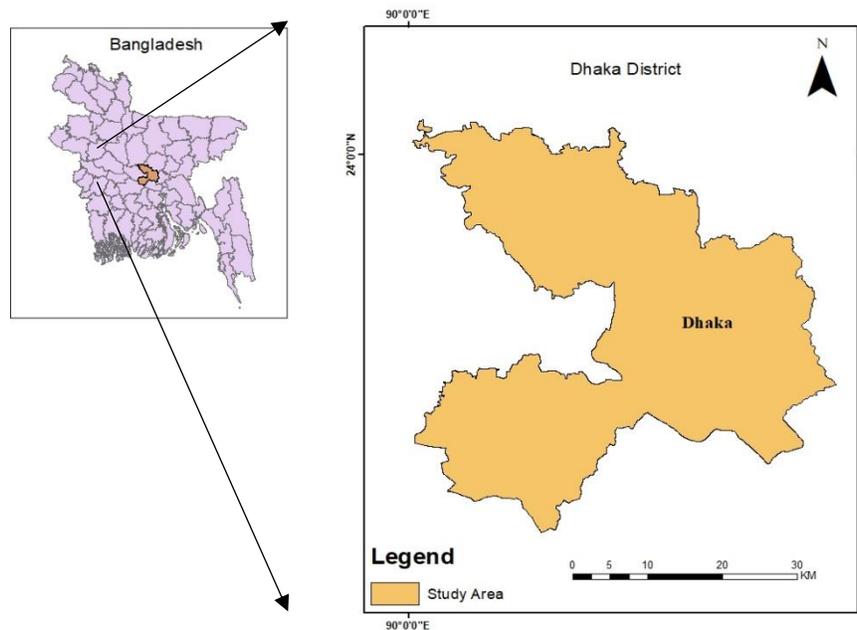


Fig. 1: Location of the study area

3. Methodology

Satellite based thermal infrared (TIR) data is directly linked to the LST through the radiative transfer equation and that attracted much attention and its history dates back from 1970s. Remote sensing technology provides a unique way for evaluating LST on global scale. Remote sensing application is also required to observe the spatiotemporal land cover changes using Red and NIR band data of satellite images that used to prepare NDVI map. LANDSAT-7 Enhanced Thematic Mapper (ETM+) and LANDSAT-8 TIRS having resolution of 100m in thermal region. LST is sensitive to vegetation and soil moisture; therefore, it can be used to observe land use/land cover changes, such as urbanization, desertification etc. So, in this study the images of LANDSAT-5 (for 2001) and LANDSAT-8 (for 2020)

are used. ArcGIS software is used for preparing of LST and NDVI map. In order to fulfill the objectives and to meet the questions of this research the following methods are performed:

3.1. Image selection

To assess the changes in vegetation health and Land surface temperature with time, two image of Landsat 5 TM (2001) and Landsat 8 OLI+TIR (2020) of 30 m resolution are used. Images are acquired from USGS [9].

3.2: Image Pre-processing

Image preprocessing methods for Landsat TM/ETM+ imagery includes- Geometric correction, Noise correction, Atmospheric Correction, Topography Normalization and Radiometric Correction [10]. Based on the quality of the obtained image geometric Correction and radiometric correction are conducted.

3.3: Calculation of NDVI and Map Generation

Most commonly used vegetation Index is Normalized Difference Vegetation Index (NDVI) that is based on the difference between the maximum absorption of radiation in Red band because of chlorophyll pigments and the maximum reflectance in NIR spectral region as a result of leaf cellular structure [11]. While Red is the 3rd band for Landsat 4, 5 and 7, it is the 4th band for Landsat 8. The infrared is band number 4 for Landsat 4, 5 and 7, whereas it is band 5 for Landsat 8 [12]. At this situation NDVI is calculated using band 5 for Landsat 8 and band 4 for Landsat 5; Red is calculated using band 4 for Landsat 8 and band 4 for Landsat 5.

$$NDVI = \frac{NIR-Red}{NIR+Red} \dots \dots \dots (1)$$

NDVI value thresholds from -1 to +1. High NDVI value corresponds to healthy vegetation and low NDVI value indicates stressed vegetation. NDVI maps are generated using ArcGIS software and maps are validated using Google Earth.

3.4: Calculation of Land Surface Temperature and Map Generation

Thermal bands are used for the determination of the land surface temperature (LST). This is the sixth band for Landsat 4, 5 and 7 and bands 10–11 for Landsat 8. Satellite TIR sensors measure top of the atmosphere (TOA) radiances, from which brightness temperatures are derived using Plank’s law.

The Steps of LST Calculation are:

Step1: Conversion of Digital Number (DN) to Top of Atmosphere (TOA) Radiance:

Different equations are used for this step for Landsat 5 and Landsat 8.

For Landsat 5:

$$L_{\lambda} = \left(\frac{L_{max\lambda} - L_{min\lambda}}{Qcal_{max} - Qcal_{min}} \right) \times (Qcal - Qcal_{min}) + L_{min\lambda} \dots \dots \dots (2)$$

For Landsat 8:

$$L_{\lambda} = M_L Qcal + A_L \dots \dots \dots (3)$$

Where, L_{λ} indicates Spectral Radiance at the sensor's aperture

Qcal indicates the quantized calibrated pixel value in DN

$L_{min\lambda}$ indicates the spectral radiance, scaled to $Qcal_{min}$ (1.238 for Landsat 5 and 0 for Landsat 7)

$L_{max\lambda}$ indicates spectral radiance, scaled to $Qcal_{max}$ (15.303 for Landsat 5 and 17.040 for Landsat 7)

$Qcal_{min}$ indicates the minimum quantized calibrated pixel value (corresponding to $L_{min\lambda}$) in DN =0

$Qcal_{max}$ indicates the maximum quantized calibrated pixel value (corresponding to $L_{max\lambda}$) in DN = 255

M_L indicates Band-specific multiplicative rescaling factor from the metadata

A_L indicates Band-specific additive rescaling factor from the metadata

Qcal indicates Quantized and calibrated standard product pixel values (DN)

Step 2: conversion of TOA Radiance to TOA Brightness Temperature (At satellite brightness)

$$T = \frac{K2}{Ln \frac{K1}{L_{\lambda}} + 1} - 272.16 \dots \dots \dots (4)$$

$L\lambda$ indicates TOA spectral radiance

K_1 indicates Band-specific thermal conversion constant from the metadata

K_2 indicates Band-specific thermal conversion constant from the metadata

Step 3: Calculation of LST from At Satellite Brightness Temperature

$$LST = \frac{BT}{\left[1 + \lambda \times \left(\frac{BT}{\rho}\right) \times \ln(e)\right]} \dots \dots \dots (5)$$

Where,

BT indicates At Satellite Temperature

λ indicates Wavelength of emitted radiance

$\rho = 14380$

e indicates Land surface emissivity

3.5: Area Calculation of Land Cover and Comparison

To calculate area of any land cover; pixel size and pixel numbers are required. Landsat 5 and 8 has been used for both images of 2001 and 2020 and they both have 30mX30m resolution. Pixel numbers are calculated by classifying the NDVI images. Product of these values provide each land cover area in square kilometers. Area of each land cover for two different times are calculated and then compared to understand the changes happened in the interested time.

3.6 Calculation of Weighted Average of Land Surface Temperature

To calculate temperature over Dhaka district in 2001 and 2020 precisely, the maximum and minimum temperatures of each of the individual land classes are been calculated and then average temperature of each of the classes are calculated as-

$$t = \frac{t_{min}+t_{max}}{2} \dots \dots \dots (6)$$

Where, t_{min} and t_{max} are the minimum and maximum temperature of each class in both LST maps and t is the average temperature.

To compare those temperatures, the area-weighted average of LST have been calculated. For this purpose, the following equation is used:

$$\bar{x} = \frac{(a_1t_2+a_2t_2+a_3t_3+a_4t_4+a_5t_5)}{(a_1+a_2+a_3+a_4+a_5)} \dots \dots \dots (7)$$

Where, a_1, a_2, a_3, a_4 and a_5 denotes the area of water body, buildup area, barren land, crop and grassland and dense vegetated area of Dhaka district respectively. Similarly, t_1, t_2, t_3, t_4 and t_5 are temperatures in degree Celsius for each corresponding land class.

4. Result and Discussion

The spatial pattern of NDVI for Dhaka district in 2001 and 2020 are shown in Figures 2(a) and 2(b) respectively. These two NDVI maps of Dhaka district include Dhaka city, which is the densest city of Bangladesh. The color bar represents the different feature of the Dhaka district, which are water, build area, barren land, crop/grass land and dense vegetation.

In 2001, most of the build area is shown at the mid-southeastern part of the map. The build area is also shown in the bank of the Padma River, which is situated in the southwestern part of the map. On the other hand, the dense vegetation area is shown in the northeastern and southeastern part of the map.

In 2020, the build area is found to increase and spread into the major portion of the district area in 2020. The build area is spread into the right side of the map and replace with the dense vegetation of 2001The barren land area has increased in 2020 compared to 2001.

The NDVI images are validated by comparing them with real-time google earth images by exporting the raster NDVI to KML (Keyhole Markup Language) format, where we can clearly observe that the buildup area in Dhaka city and its fringe area has increased noticeably for which the amount of barren land and crop or grassland reduced. However, amount of dense vegetation has increased in these 20 years.

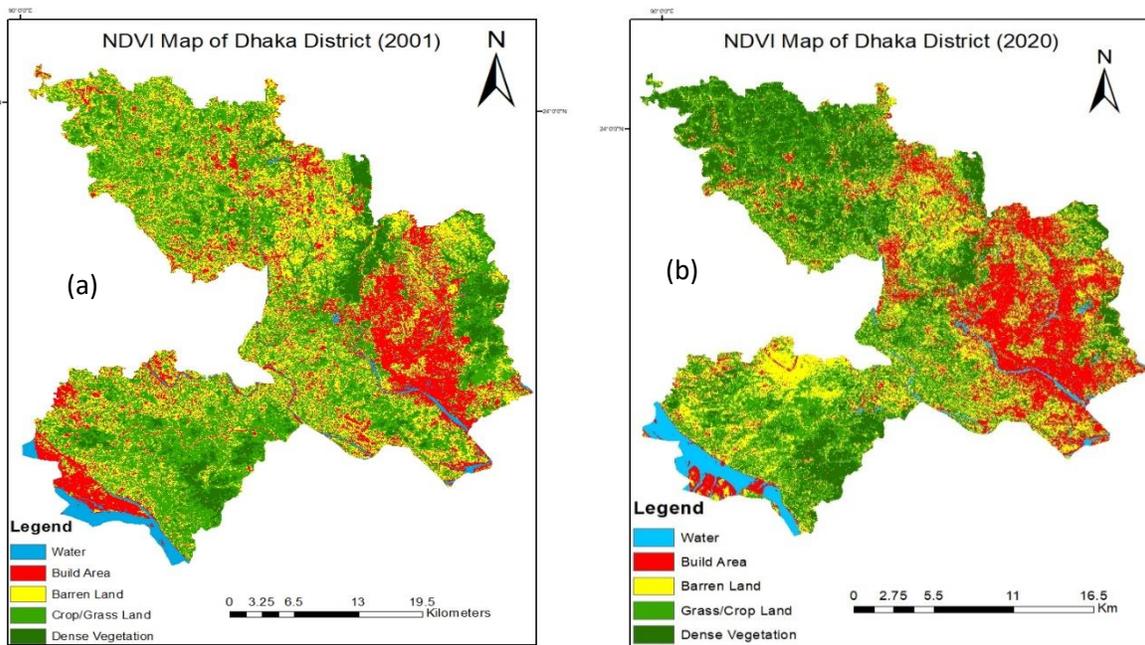


Fig. 2: NDVI map of Dhaka District for (a) 2001 and (b) 2020

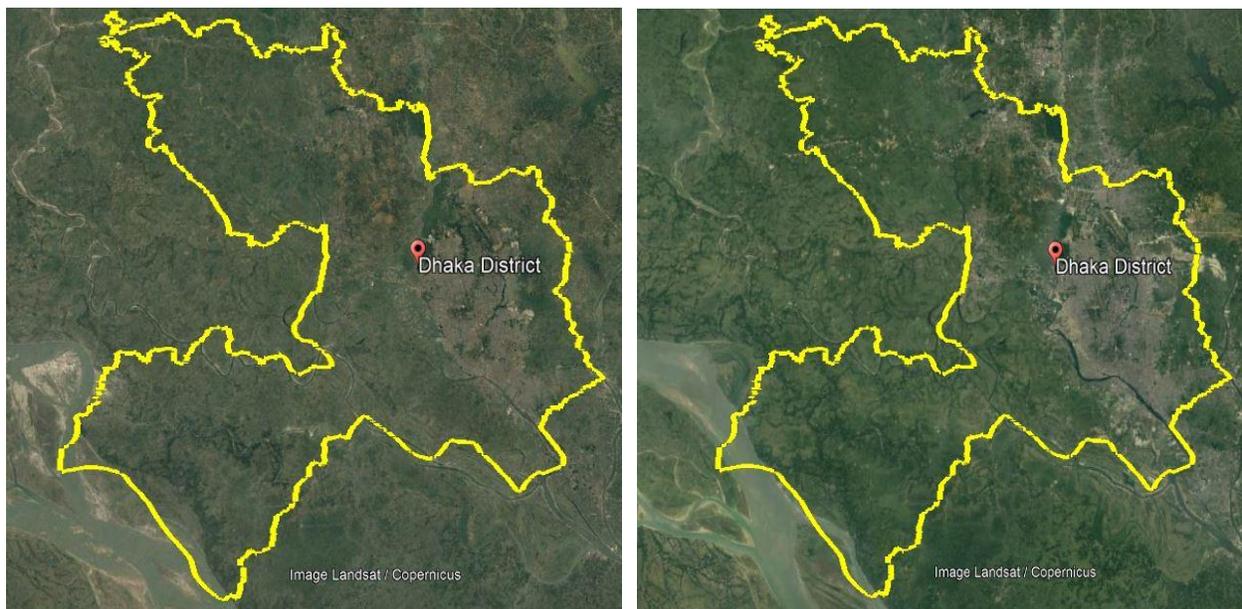


Fig. 3: Google Earth imagery of Dhaka district and nearby region of (a) 2001 and (b) 2020

The spatial pattern of Land Surface Temperature (LST) for Dhaka district in 2001 and 2020 are shown in figure 4. The color bar represents temperature gradient of the Dhaka district ranging from nearly 12.16°C to more than 40.46°C in the LST map of 2001 and at a range of nearly 4.63 °C to more than 43.8°C in the LST map of 2020. The maximum temperature is indicated using dark red and yellow color, while moderate and relatively lower temperatures are represented using green and blue color.

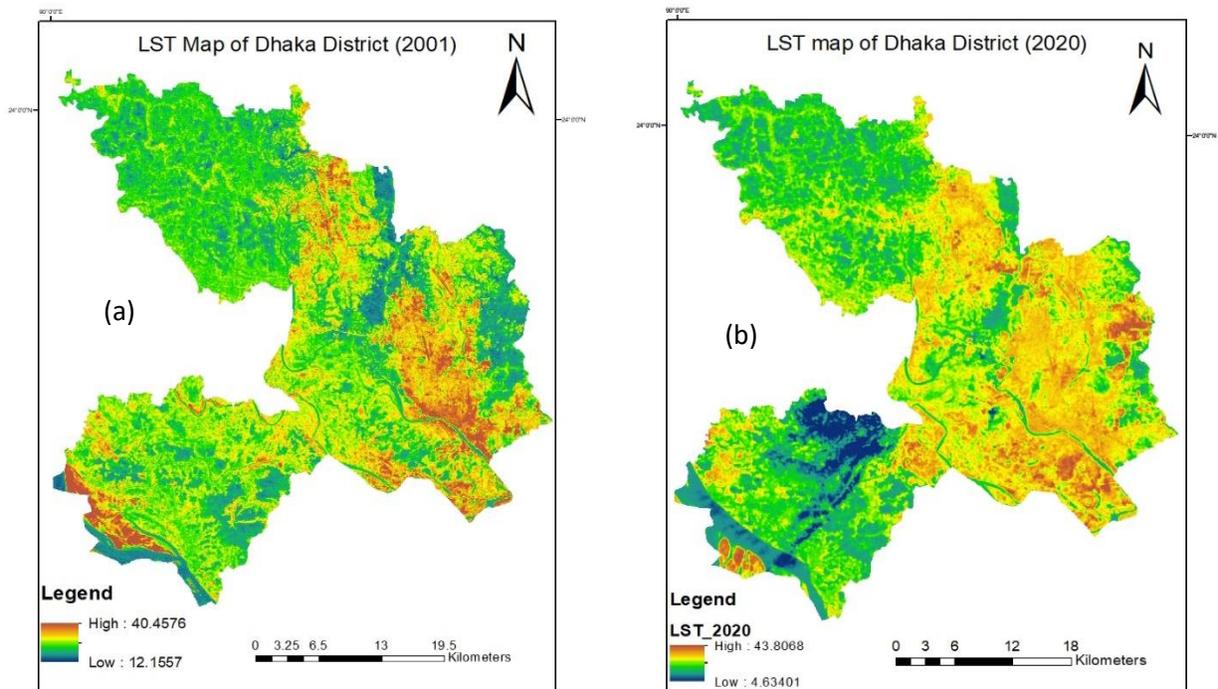


Fig. 4: Land surface temperature map of Dhaka district for (a) 2001 and (b) 2020

In the map of 2001, the highest temperature is observed over the east-central and southwestern parts with the temperature reaching more than 40°C. The lowest temperature (more than 12.16°C) denoted by blue color is observed in north central and the northeastern corner of the map (both side of Dhaka city). Minimum temperature is also observed in the lower southeastern part of the map.

LST map of 2020 indicates that, the maximum temperature has increased and at the same time, the area with maximum temperature has expanded (Fig 4 (b)) compared to the map of 2001 (Fig 4 (a)) and the highest temperature reaching more than 43.8°C. The lowest temperature is observed in the southeastern part of the district map that is more than 4.6°C denoted by blue color. Barren land has displayed the minimum temperature. Whereas moderate to high temperature is observed in the completely eastern side of the map that actually represent Dhaka city and its fringe area.

In both maps, highest temperature is seen over the city's build up area. In these 20 years, maximum temperature increment is significant and it is 3.35°C. This increase as well as expansion of maximum temperature coverage area proves the reduction of NDVI value are fueling more with climate change impact to increase LST. Rapid urbanization is observed in Dhaka city, so the UHI is also growing and affecting it.

Tables 1 and 2 shows areas of different land cover. Areas are calculated by multiplying cell size with the number of pixel for each land class.

Table 1: Area calculation of different Land Cover of Dhaka District (in 2001)

Land Class	Cell Size (Resolution in m)	No of Pixel (n)	Class Area (sq. km) a= (Cell size x n)/ 1000000	Class Area (%)
Water	30x30	45470	40.923	2.79
Build up Area	30x30	309475	278.5275	18.96
Barren Land	30x30	478680	430.812	29.33
Crop and Grassland	30x30	675960	608.364	41.42
Dense Vegetation	30x30	122254	110.0286	7.49

Table 2: Area calculation of different Land Cover of Dhaka District (in 2020)

Land Class	Cell Size (Resolution in m)	No of Pixel (n)	Class Area (sq. km) a= (Cell size x n)/ 1000000	Class Area (%)
Water	30x30	68702	61.83	4.21
Build up Area	30x30	356753	321.08	21.86
Barren Land	30x30	419794	377.81	25.73
Crop and Grassland	30x30	469917	422.92	28.80
Dense Vegetation	30x30	316656	284.99	19.40

Comparison of these two tables (table 1 and 2) shows that with time, build up area has increased (1.9%) and barren land and crop and grassland areas have decreased respectively by 3.6% and 12.6%. Which means crop and barren land areas are replaced by buildup areas. However, the amount of dense vegetation area is increased by 11% in the northwestern part of the map in 20 years.

Tables 3 and 4 display the average temperature of each class and a single weighted average temperature for two different years (2001 and 2020).

Table 3: Calculation of Weighted Average Temperature in 2001

Class	Area (a)	Minimum temperature (t_{min})	Maximum temperature (t_{max})	Mean Temperature (t °C)	Weighted average mean temperature (°C)
Water	40.923	19.2	24.35	21.775	25.72
Build up Area	278.5275	28.8	38.66	33.73	
Barren Land	430.812	30.75	12.15	21.375	
Crop and Grassland	608.364	26.86	25.36	26.11	
Dense Vegetation	110.0286	22.84	20.78	21.81	

Table 4: Calculation of Weighted Average Temperature in 2020

Class	Area (a)	t_{min}	t_{max}	t (°C)	Weighted average temperature (°C)
Water	40.923	29.52	21.21	25.365	27.33
Build up Area	278.5275	42.40	32.40	37.4	
Barren Land	430.812	36.60	5.81	21.205	
Crop and Grassland	608.364	31.55	21.30	26.425	
Dense Vegetation	110.0286	26.88	24.92	25.9	

Table 4 shows that average temperature of each class in 2020, which is higher than the temperature of 2001, is a direct indication of climate change. The weighted average of temperature also increased by 1.61°C from 2001 to 2020. Conclusion can then be made that NDVI and LST are positively correlated, which means changes in NDVI make changes in LST.

5. Conclusion

Buildup area expansion and LST patterns have been assessed in this study. This is the first study for the assessment of spatial and temporal variability of Dhaka district. LST increase with urban expansion to increases in urban settlement density. The maximum temperature of Dhaka district has increased by 0.17°C/year. The results show a significant rise in urban temperature in the city with significant change of NDVI due to ongoing urbanization. This situation may become unbearable if global warming-induced temperature rise, which is already noticed in the country like other parts of the globe. The climate of Dhaka district is humid due to its location in monsoon-dominated region. Higher temperature combined with high humidity may cause a large increase in public health risk in this highly populated urban area. Specially, the Dhaka city needs urgent attention to reduce the UHI effect to avoid catastrophic effects in the forthcoming years. Higher-resolution longer period temperature data, such as Landsat LST can be used

for understanding the consequence of different urban landcover alteration on the UHI of Dhaka district. The impact of global warming-induced climate change can be separated for a better evaluation of urbanization on UHI.

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