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Correlation and Monitoring of Land Surface Temperature, Urban Heat Island with Land Use-Land Cover of Dhaka City Using Satellite Imageries

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Abstract: *Dhaka city has been expanding rapidly by urbanization process to meet up the needs for increasing population in Bangladesh. The study has been conducted to monitor and correlate the changes of land use-land cover (LULC), land surface temperature (LST) and urban heat island (UHI) of Dhaka city from 1989 to 2015 using four sets of Landsat TM, ETM+ and OLI/TIRS images. The LULC result showed that the water body and vegetation was declined respectively about 40.06% and 39.81% due to the increased urbanization of about 56.66% in the Dhaka city from 1989 to 2015. The bared land was decreased about 20% from 1989 to 2000 due to urbanization of cultivated or vegetated coverage area, but it increased again about 18% from 2000 to 2015 because of landfilling of low land or water bodies for urbanization. On the other hand, LST result showed that the ranges of LST obtained about 48.18°C to 54°C and 15°C to 25°C from 1989 to 2015 respectively in terms of maximum and minimum value. The LST found highest in 2010 and lowest in 1989 both in terms of their maximum and minimum. The number of urban heat islands area observed four in 1989, eleven in 2000 sixteen in 2010 and nine in 2015 from this study. That means, the higher land surface temperature producing zones or urban heat islands have been expanded throughout the city during this period. The study showed that the rapidly increased urban growth caused the huge loss of vegetation, bared and water bodies in and around the Dhaka city.*

Keywords: *Satellite image, land use-land cover, land surface temperature, urban heat island, Dhaka city*

1. Introduction

Urbanization is an important indicator of World's development, especially in developing countries like Bangladesh. Dhaka, the capital city of Bangladesh, is now one of the rapidly growing city in Bangladesh due to rural to urban migration of people [1]. This rapid urbanization is responsible for destroying urban forest, water bodies and vegetation in the Dhaka city of Bangladesh. Urbanization is actually creating varieties of structures and impervious surfaces concerning a set of environmental factors such as the net primary production, the biodiversity, and the weather and climate at local, regional and global scale [2]. In other way, unplanned urbanization poses a threat to the overall ecosystem, environment, and various other associated elements in developing countries like Bangladesh. So, the continuous expansion of urban transforms the open spaces to high rise buildings, and pavements from agricultural land and forest [3]. Local climate of Dhaka city changes due to the increasing human activities such as discarded heat, diverse buildings and structures, and impervious surfaces. It is impossible to regain the destroyed urban forest and vegetation in this city but it could play an important role to its urban ecosystem and environment.

For an overpopulated city like Dhaka, it is very crucial to identify the trend of changing LST with the urbanization growth. But unfortunately few studies have been conducted in this aspect. According to BBS, rural areas of Bangladesh has been converted to urban areas and about 809 km2 of agricultural lands are lost each year to build cities, roads and infrastructures. The average rate of expansion of Dhaka city is 4.24% per year and by 2020, likely to become the largest megacity of the world according to the World Bank report [30]. The migration of rural areas to urban areas is responsible for such growth [1]. The environmental issues have been studied by geospatial techniques, but only few in number [4; 5; 6; 7]. No quantitative data or mapping has been done on existing land use in Dhaka city [1; 8]. Using ground observation technique, official land use statistics have been prepared for Dhaka Metropolitan in 1991 [1;9]. However, as the rapid urbanization has impact on the changing LST, it is very important to detect the land use changing pattern and correlate these with LST. As there is a lack of spatial data, satellite remote sensing is the best way to acquire reliable information to enhance the surface temperature and UHI studies. In recent years few LST and LULC studies has been followed such as relating the LST with urban development and vegetation changes by [10]. But these studies couldn't identify and mapped the higher LST producing land covers and also they didn't provide the UHI effect in this area. There are also some recent studies showed that the increase of impervious surface is close related with increasing land surface temperature (LST), urban heat islands (UHI) effects and associated air pollution in the world [11; 12]. So, proper monitoring the changes of Land use- Land cover (LULC) is required to address the direct effect on the changing LST, UHI of Dhaka city. Concerning these issues, our intention is to use satellite remote sensing techniques to delineate and monitor as well as to correlate the change of LULC, LST and UHI of Dhaka city in Bangladesh from 1989 to 2016.

Remote sensing is used nowadays for urban planning and observations [13]. Landsat Thematic Mapper (TM) and Enhances Thematic Mapper (ETM+) images has a long history of use in many smaller-scale studies of LULC, LST,UHI in many parts of the world [14; 15; 5; 11; 16; 17]. The radiant temperature collected from satellite is termed as surface temperature in different studies [18]. LST can be defined as the skin temperature of Earth's surface and controls most physical, chemical and biological processes [19]. LST can be measured both on the ground and from satellite data but satellite data must be calibrated with ground measurements and performed on a homogeneous test sites to avoid spatial heterogeneity [20]. The UHI phenomenon has been studied by observing the land surface temperature (LST) primarily by NOAA AVHRR data [18; 21; 22; 23; 24; 25; 26]. But their spatial resolution was poor and can only be used small scale urban temperature mapping. So the spatial resolution of Landsat Thematic Mapper (TM) Thermal Infrared (TIR) data has been used to calculate and observe the LST. But smaller scale studies of UHI have been successfully enhanced by using Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (ETM+) with resolution of 120m and 60m respectively [11;14; 15].The distribution of LST has been studied all over the worlds for decades. Landsat 8 OLI/TIRS sensor was inaugurated in 2013 with nine visible-shortwave and two thermal infrared bands which has limited number of use till now for urban features delineation in the world and no study for Dhaka city conducted using this sensor's images. The prime objectives of this study is to prepare LULC, LST and UHI maps of Dhaka urban area from the year of 1989 to 2015 using Landsat TM, ETM+, and OLI/TIRS sensors images. The second aim is to correlate and monitor the LULC, LST, and UHI from 1989 to 2015 in this study area.

2. LOCATION AND EXTENT OF THE STUDY AREA

Our study comprises about 285.72 Km2 from the total area of Dhaka City about 306 Km2 [1] (Fig. 1). The longitude of the study area is 90^0 20 '0''E to $90^0$29'0'' E and the latitude of the study area is $23^0$42'0'' N to $23^0$54'0'' N. The area extends from Tongi canal (Tongi Khal) towards North, Turag River towards west, Balu River to the East and Buriganga River towards South. Towards North, major areas are Uttara, Tongi, Uttar Khan, and Dhaka Airport. The south is densely populated and comprises old town, Matijheel, Hazaribag, some other parts near Buriganga river bank. Demra, Jatrabari. Mirpur and other adjoining areas lie towards West while Purbachal, Khilgaon, and other neighboring areas lie towards Eastern part of the study area. The peripheral part of the city is less densely populated than the central part of the city.

3. MATERIALS AND METHODS

We used four Land sat satellite sensor's images in this study such as Lands at TM, ETM+, OLI and TIRS, acquired from USGS archives with free of cost considering availability and good quality with same season from 1989, 2000, 2010 and 2015 (Table 1). These images were both radio metrically and geometrically corrected. Meteorological data such as ambient temperature and relative humidity was collected from local station of Bangladesh Meteorological Department for each year of our study. Atmospheric transmissivity during the image acquisition time was estimated using NASA

Atmospheric Correction Parameter Calculator [31]. The satellite image derived LSTs were validated using a handheld digital thermometer.

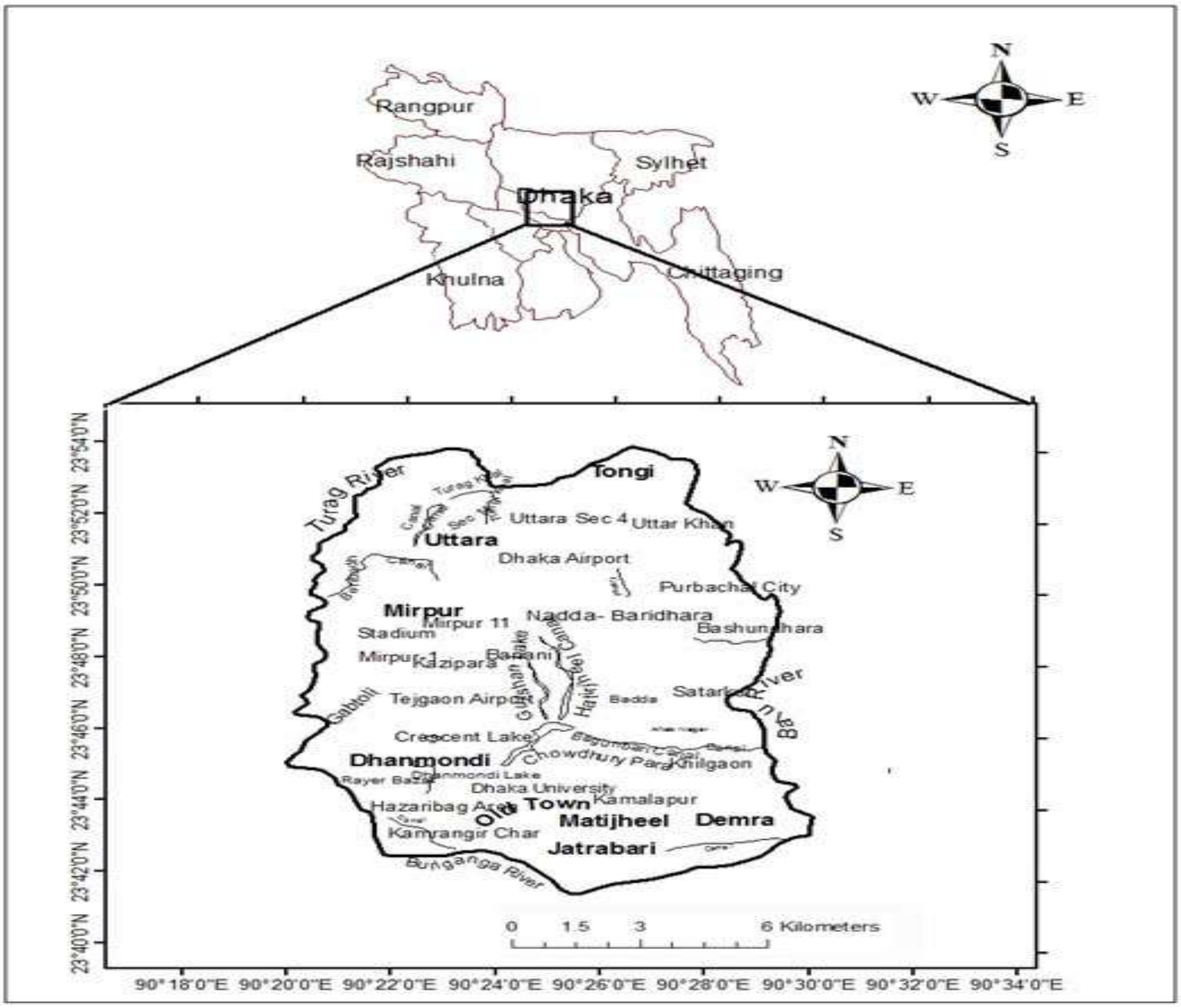

Figure1. *Location Map of the Study Area*

Table1. *Sensor types, acquisition date and resolution of the collected images*

Sensor Platform	Acquisition Date	Resolution
Landsat 4	13 February, 1989	30 m
Landsat 7	28 February, 2000	30 m
Landsat 5	15 February, 2010	30 m
Landsat 8	17 March, 2015	30 m

We employed the unsupervised classification technique for land use-land cover mapping of the study area from 1989 to 2015 using the ISODATA (Iterative Self-Organizing Data Analysis Technique) method of ERDAS IMAGINE 2014. Using such unsupervised classification approach, 15 classes were created at first and then merges same information classes by "Recoding", into four identifiable spectral LULC classes such as water bodies, bare land, vegetation and urban structures. These spectral or thematic LULC classes were observed for temporal changes over the study area. We applied the mono-window algorithm for estimating land surface temperature of the study area using the single thermal infrared band of Landsat TM, ETM+ and the band 10 of TIRS sensor's image [27]. Spectral emissivity is one of the key parameter considered during the LST calculation of the study area which was calculated using the NDVI (normalized differential vegetation index) based emissivity method. At first, the NDVI value was calculated using the red and near infrared bands of the applied Landsat image of the study by the following equation [28].

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

Here, NIR and RED represent the reflectance of near Infrared and red regions of the used Landsat images. NDVI usually has a value in between -1.0 to +1.0. In an NDVI image, the vegetated areas are seen as lighter tone and un-vegetated areas are visible as darker tone by highlighting near infra-red band of an image.

The NDVI values were used to calculate surface emissivity of the study area for each year of study, which is an inherent property of land that is used to convert surface heat energy into radiant energy using the following equation [29]:

$$E = 0.985P_v + 0.960(1 - P_v) + 0.06\,P_v(1 - P_v) \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Here, Pv (Equation 5) is known as "Vegetation fraction" which ranges from 0 to 1. Pv=(1-i/is)/((1-i/is)-k(1-i/iv)), i= NDVI of mixed pixels,is=NDVI of pure soil pixels, iv=NDVI of pure vegetation pixels, and $K = (\rho_{2v} - \rho_{1v})/(\rho_{2s} - \rho_{1s})$, ρ_{2v}= Reflectance of pure vegetation in near infrared region, ρ_{1v}= Reflectance of pure vegetation in red region, ρ_{2s}= Reflectance of pure soil in the near infrared region, ρ_{1s}= Reflectance of pure soil in the Red region.

Before applying the mono-window algorithm for LST estimation, we followed some steps to derive the brightness or effective sensor temperature of land surface without considering the atmospheric transmissivity and emissivity of the study area. Firstly, thermal band was converted into radiance values from their DN values for each of the corresponding years. Then we used the following equation 3 to get the satellite brightness temperature.

$$T_b = K_2/\log(K_1/L_\lambda) + 1) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Here, T_b=Brightness or sensor temperature (K), K_1= First calibration constant ($Wm^{-2}sr^{-1}$), K_2= Second calibration constant (K), L_λ= Spectral radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$),

The necessary parameters were obtained from Landsat handbook, and the radiance converted bands. The next step for the LST estimation was to use the brightness temperatures for the calculation of kinetic or true land surface temperature using mono-window algorithm of equation 4.

$$T_s = \{a(1 - C_6 - D_6) + [b(1 - C_6 - D_6) + C_6 + D_6] \times T_b - D_6 T_a\}/C_6 \ldots\ldots\ldots..(4)$$

Where, T_s= Land Surface Temperature (LST), a (Constant)= -67.355351, b (Constant)= 0.458606, C_6=$\epsilon\tau$, ϵ= Emissivity,τ= Atmospheric Transmissivity, $D_6 = (1 - \tau)(1 + (1 - \epsilon))\tau$, $T_a = 19.2704 + 0.91118\,T_0$ (For mid-latitude winter) and T_0 is the air temperature.

For evaluation and validation purposes, some ground-based measurements have been performed over our study area. The target was to match the image derived LST values of 2015 along with LULC with ground observations. The areas, which represented higher or unusual temperatures, were given special consideration for the ground-based observation of temperature.

4. Results and Discussion

We have identified four different LULC types such as water bodies, bared land, vegetation, and urban structures using four Landsat images from 1989 to 2015 of the Dhaka city area in Bangladesh (Fig. 2). Water bodies were covered about 2414.52 ha, 1998.36 ha, 1683 ha and 1447.38 ha area respectively in the year of 1989, 2000, 2010 and 2015. The highest coverage of water bodies was observed about 8.45% in 1989 and lowest about 5.07% of the total study area in 2015. Water bodies were about 6.99% in 2000 and 5.89% in 2010 of the total study area i.e., overall declining trend of water bodies during the study period and the total decrease of water bodies is about 967.14 ha (or 40.06%) from 1989 to 2015 (Fig. 3). Towards Southeastern part of the city, the losses of water bodies were very significant because of rapid urbanization. The areas covering vegetation were 6634.80 ha, 6488.55 ha, 4912.65 ha, and 3993.21 ha respectively in the year of 1989, 2000, 2010 and 2015. These were 23.22%, 22.71%, 17.19%, and 13.98% respectively considering the total study area for respective years of study (Fig. 2). Vegetation coverage was also decline rapidly throughout the study period in this city. We found about 39.81% of vegetation lost from 1989 to 2015 due to the urbanization of human activities in the Dhaka city. The Eastern peripheral part has been affected more by the vegetation loss. On the other hand, the structured urban areas have been found as increasing trend i.e., about 4996.44 ha, 8396.28 ha, 8116.29 ha, and 9367.11 ha area coverage respectively in the year of

1989, 2000, 2010 and 2015, which were about 17.49%, 29.39%, 28.41% and 32.78% of the total study area respectively for the study years (Fig.2; Fig.3). So, there is about 56.66% of urban growth from 1989 to 2015 in this rapidly growing city of Dhaka in Bangladesh. The higher growth areas are consistent with the areas which lost vegetation and water bodies. Bared land means uncultivated and sand fills area that covered about 50.84%, 40.91%, 48.51% and 48.14% of the total study area respectively in the year of 1989, 2000, 2010 and 2015. Decreasing trend of bared land indicates urbanization of cultivated or vegetated coverage area from 1989 to 2000, but bared land increased up to about 20% from 2000 to 2015 because of landfilling of low land or water bodies for urbanization in and around the Dhaka city.

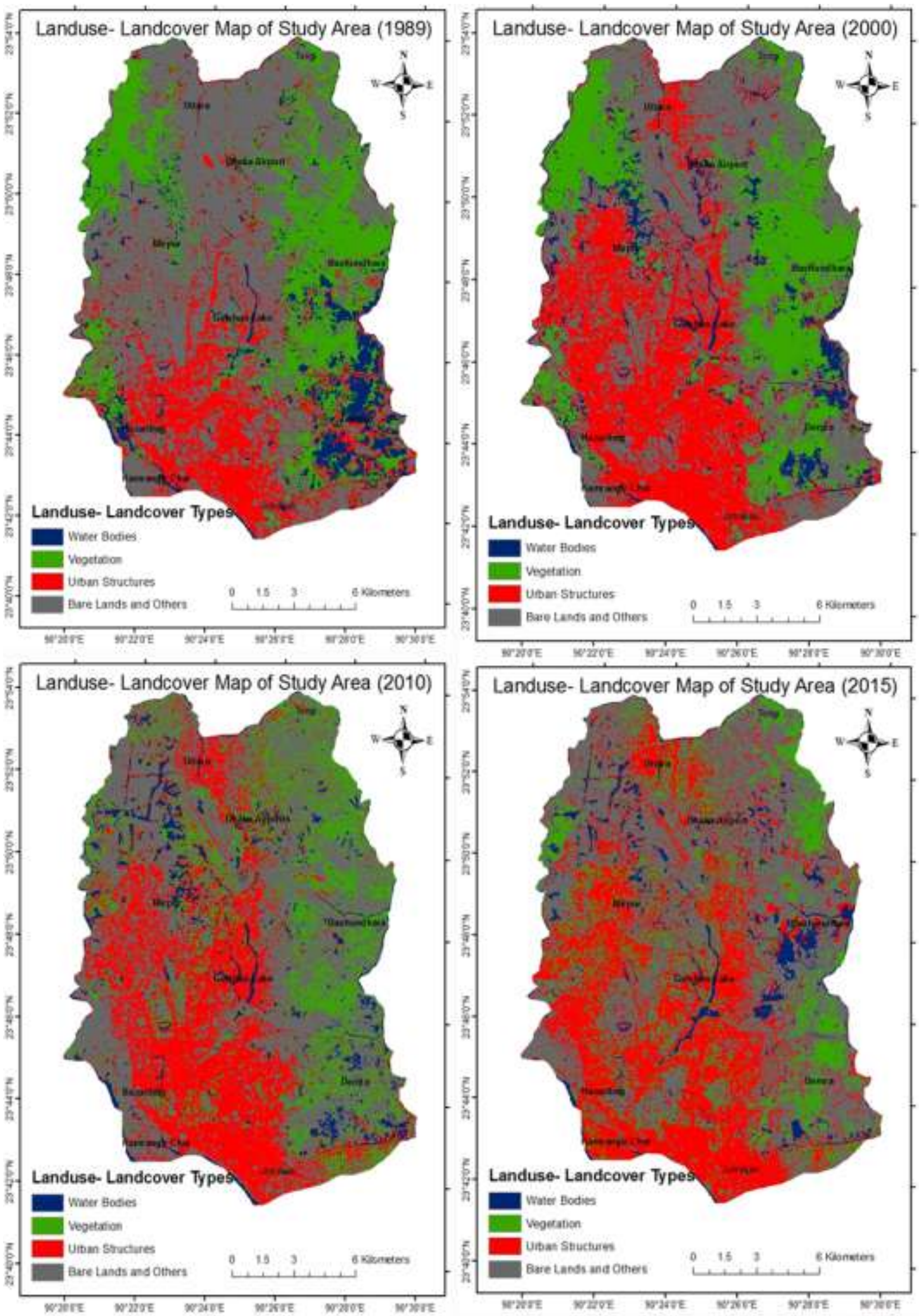

Figure2. *Land use-land cover map of the study area from 1989 to 2015.*

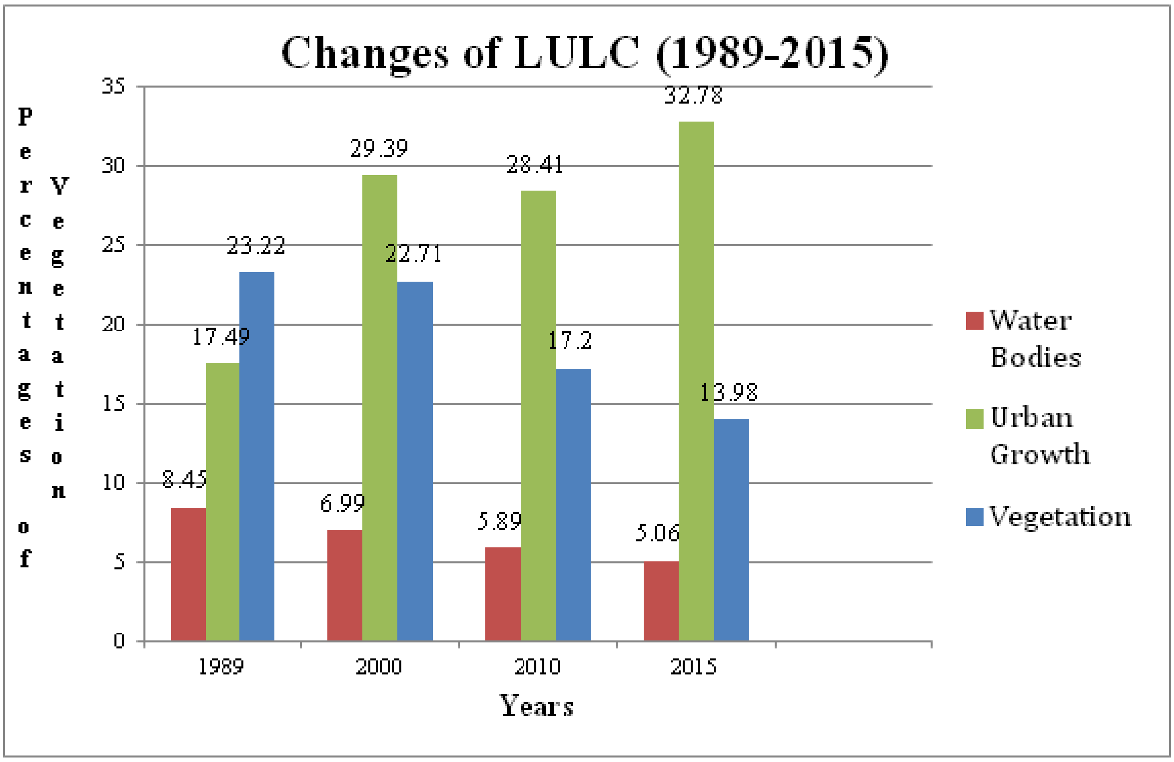

Figure3. *Graph depicting the changes of different LULC with time in the study area.*

Table2. *Minimum, maximum and average values of land surface temperature in different years*

Temperature/ Year	1989	2000	2010	2015
Minimum (c)	15	20	25	20
Maximum (c)	48.2	41	54	51.03
Mean (c)	31.8	30.5	39.5	35.5
Ambient Temperature (c)	20.15	20.15	20.15	28.5

LST has been calculated using mono-window algorithm as we used the single thermal infrared data of Landsat for the year of 1989, 2000, 2010 and 2015 (Fig. 4). Spectral emissivity and atmospheric transmissivity are two important parameters needed to derive the LST using the mono-window algorithm. Spectral emissivity was calculated using the NDVI based emissivity estimation method, obtained the value from 0.90 to 0.99 for the land covers of the study area. Atmospheric transmissivity was obtained about 80-95% during the four image acquisitions from 1989 to 2015, which was estimated using the NASA atmospheric parameter calculator. Using the estimated LST, we have identified the urban heat islands and later on correlate the LST with LULC of the study area for the year of 1989, 2000, 2010 and 2015. The particular LST indicating LULC types have been determined from matching our prepared thematic classified LULC maps and careful observation of the Landsat images. Field observation also provided useful information for LULC and LST correlation. The lowest LST in 1989 was 15^0C, which was indicative of healthy vegetation in and around the city (Fig.4) (Table 2). These areas showing lowest LST range of 15-20^0C covered 373.23 ha of the study area or 1.31% of the study area. This 15-20^0C of temperature range has been observed along the peripheral part of the city. The highest LST was found as 48.2^0C, and this temperature range of 45-48.2^0C was indicated by only a single pixel, at an industrial zone, close to the center of the city. The other temperature ranges showed variable land cover types. But relatively lower LST indicative land cover types were vegetation whereas higher LST indicative land covers were densely built urban structures and industries. All land cover types which exhibited higher LST than 30^0C have been found as urban built up areas. The temperature ranges of 30-35^0C have created several Urban Heat Islands (UHI) which were marked on the map according to their sizes. For this year, all the UHIs indicate industrial zones in Tejgaon, Mirpur, old town and other industrial areas of Dhaka city (Fig. 4).

In 2000, the lowest LST has been found as 20^0C, and the temperature range of $20\text{-}25^0$C indicated mostly vegetation. The highest LST was 41^0C, and it included a part of the industrial area on the Northwest Mirpur. The temperature range $40\text{-}41^0$C lies in this area. Above 25^0C, most of the landcover types have been detected as urban structures of variable heights. But careful observation revealed that the urban structures with higher height exhibited higher temperature due to different kinds of rooftop materials, higher received solar energy and their higher heat emitting characteristics. The land surface temperature range of $35\text{-}40^0$C indicated bare land areas along the Eastern part of the city. This was the sand filled areas which we couldn't identify through LULC classification. But we observed the changes of such particular higher LST indicating surfaces from other year’s Landsat images and confirmed the presence of sand filling through comparing present day Landsat images and field observations. Different higher LST zones in this year created several UHIs. UHI 1 indicates the sand filled areas along the Eastern part of the city where housing projects were extending. Towards Northwest, similar sand filled areas and industries were responsible for UHI effect have been marked as UHI 9, UHI 10, and UHI 11. Also UHI 2, UHI 3 and UHI 5 indicated industries in other parts of the city. Towards Southern and Southwestern part of the city, various urban structures created heat islands capable of higher heat storage, which we denoted as UHI 4, UHI 6, UHI 7 and UHI 8 (Fig. 4).

In 2010, the lowest LST was 25^0C. The temperature range of $25\text{-}30^0$C was indicative of vegetated lands like previous observations, which covered 440.82 ha, or 1.54% of the study area (Fig. 4). The highest LST has been observed as 54^0C at a single pixel on a sand filled area in the East. The LST range of $50\text{-}54^0$C and above 40^0C were all-indicative of sand filled areas. The sand filled areas were mostly along the peripheral part, where urban structures were starting to develop as extended housing projects. LST in the range of $35\text{-}40^0$C the landcovers has been found mostly as urban structures. Such structures in the old town have been found as responsible for creating UHI 1. These structures also included several smaller industries, responsible for higher LST in this region. The larger industries in the Central and Northwest industrial areas have created UHIs which we denoted as UHI 5 and UHI 12 respectively. The sand filled areas towards Eastern, Northwestern and Northeastern part of the city created several UHIs such as, UHI 2, UHI 4, UHI 6, UHI 8, UHI 10, UHI 11, and UHI 13. The UHI 9 and UHI 17 included airport runways. The other marked UHIs included various smaller- larger industries, densely populated areas and urban structures. The UHI 7, UHI 14, UHI 15 and UHI 16 were included in these classes (Fig.4).

In 2015, the highest LST observed was 51.03^0C and the lowest LST was 20^0C. The lowest LST range of $20\text{-}25^0$C was indicative of vegetation and covered 22.23 ha which was 0.08% of the study area (Fig.4). The Eastern peripheral parts of the city near Balu River were the representative areas for such land covers. As this image was representative of the beginning of monsoon period, few seasonal vegetated lands have been identified. The climatic variation and relatively higher ambient temperature in this month exhibited vegetated lands for the LST value up to 35^0C. The LST values from 35^0C to 45^0C indicated various urban structures. The LST range $40\text{-}45^0$C indicated various sand filled areas along the peripheral part of the city. The LST range of $45\text{-}50^0$C in this year has created several UHIs. UHI 1 has been denoted as the major sand filled areas in the study area. Similar sand filled areas have been denoted as UHI 9 and UHI 7 in different parts of the study area. Towards Northwest and West, near Uttara and Mirpur embankment several of such sand filled areas have been found. UHI 2 and UHI 6 have been denoted for those areas respectively. UHI 4 and UHI 5 were indicative of airport runways where stationary aircraft possibly increased the land surface temperature. The industrial areas towards Southwest were also responsible for creating UHIs, which have been denoted as UHI 3 and UHI 8.

In discussion, urban structures have been observed with an increase of LST from 1989 to 2015 (Fig. 5). This could be probably an indication of other anthropogenic heats increase and denser urban structures. Most of the higher temperatures have been observed in the land filled sites and other industrial zones. Using sand as a land filling materials is very much related to the increasing urban LST. The lower urban structures have lower LST than the urban structures with higher height. The vegetated lands showed lower LST values in all of the years in our study (Fig.5). We took 23 ground based measurements using GPS and temperature measuring probe. We tried to correlate these results with the 2015's Landsat 8 image keeping precision with field date and time. Most of the LST obtained by Landsat 8 image of 2015 processing matched well with these ground observations. The uncorrelated surface temperature of other years between satellite image and ground measurement is mostly due to the changes of LULC. As the city area is rapidly evolving, it is most likely to happen that the area covering vegetation at present most likely would change into structured urban areas after few years. Similarly, lower urban structures can be turned into higher structures due to rapid urban development. In our observation, the sand filled areas showed higher LST in the image, but less temperature was found during the ground measurement. It is due to the error of our measuring probe. The probe was measuring temperature below the surface, but at that time Satellite was recording the top of the surface temperature. There was also a problem with recording the surface temperature of urban structures. But the method was mostly successful in the other extents. The 23 points of ground observation of LULC have been taken as reference data for comparing with satellite-derived information and running accuracy assessment. After validating the LULC types observed in the image with the field data, the following level of accuracy has been determined from the accuracy report (Table 3). The overall classification accuracy was obtained about 95.45%.

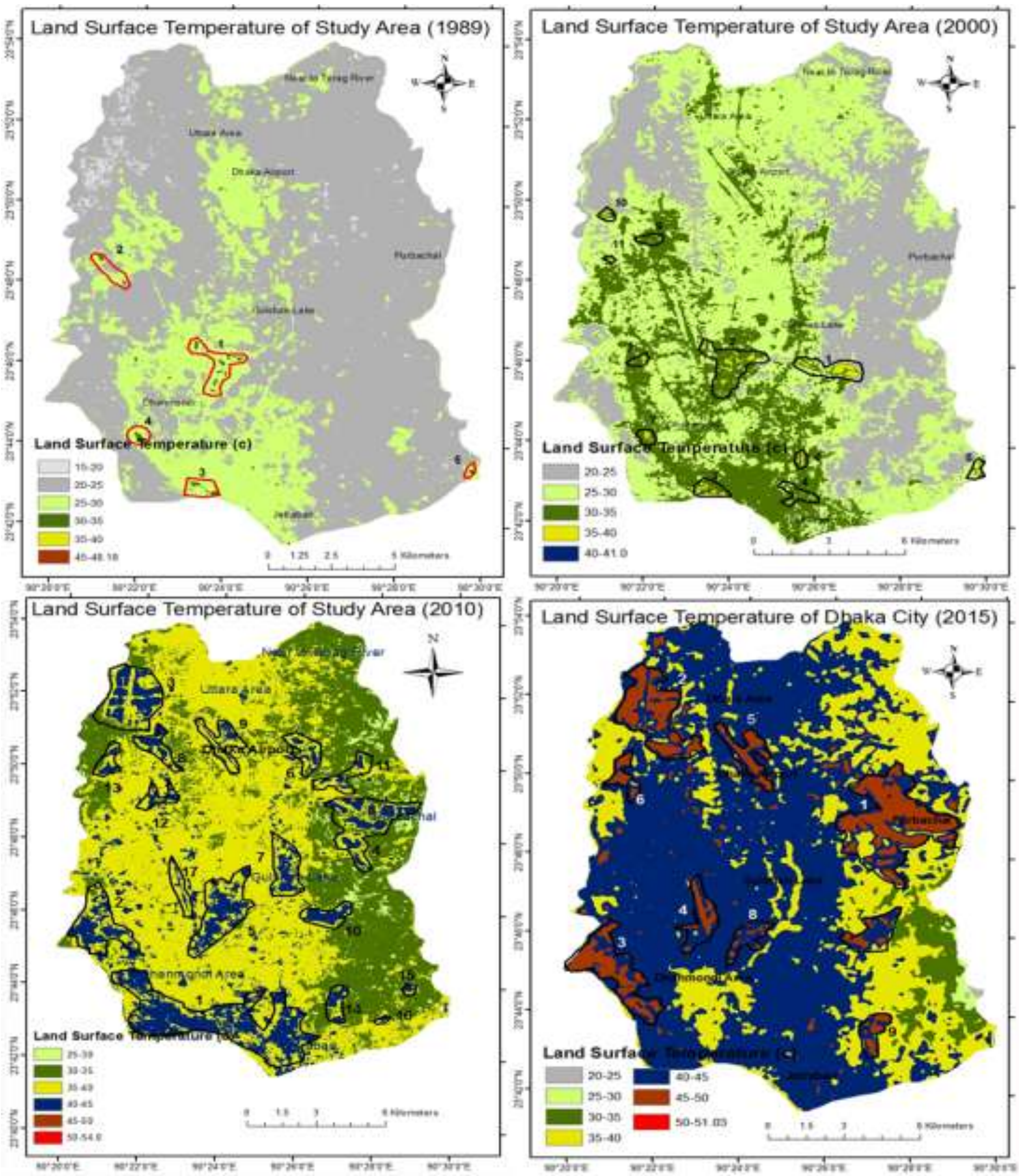

Figure4. *Land surface temperature of the study area from 1989 to 2015. Urban heat island showed as polygons with number.*

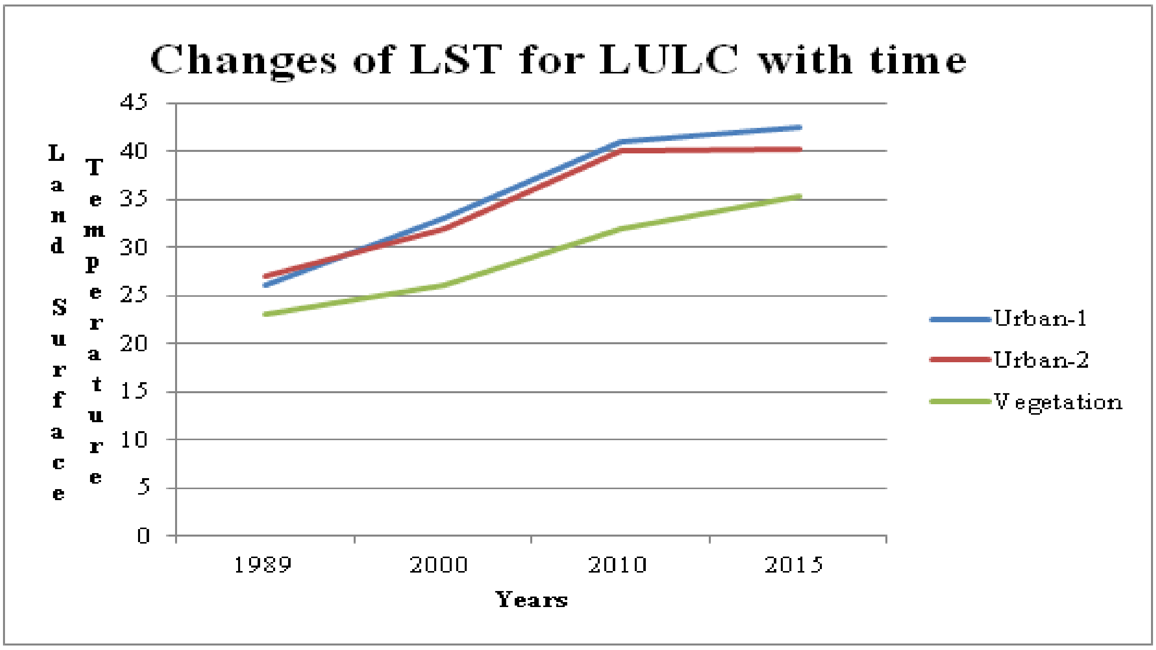

Figure5. *Graph showing the changes of LST with years for different types of LULC. Urban-1 indicates urban structures with lower height, Urban-2 indicates urban structures with higher height, and Vegetation indicates smaller and higher vegetation, grassland.*

Table3. *Accuracy Assessment of Individual Landuse- Landcover Types*

	Referenced Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water Body	1	1	1	90%	100%
Bare Lands and Others	12	11	11	91.67%	100%
Urban Structures	6	7	6	100%	85.71%
Vegetation	3	3	3	100%	100%
Totals	22	22	21		

5. Conclusion

From the LULC maps, it has been well understood that there have been losses of vegetated lands, water bodies and an increase of structured urban areas in our study period. The decrease of vegetation and water bodies is much related to the growth of urban areas. For increasing population, those water bodies, wetlands, and vegetated areas have been destroyed, and new urban built up areas have been established. The process of sand filling to build more houses is also responsible for increasing LST. The lowest LST during 1989 was 15^0C, and the highest LST was 48.18^0C using the mono-window algorithm. During 2015 these values have been increased to 20^0C and 51.03^0C respectively. The highest LST exhibiting LULC in 1989 was urban structures whereas in 2015 has been found as mostly sand filled areas. The lowest LST indicating land covers in the study period has been always found as vegetation. The various ground surface temperature collected in the study area have been found similar to the satellite-based measurements with few exceptions. Considering the above factors, the study could be taken as a reference in identifying the vulnerable zones for UHI, which have been producing more LST in the city area. Thus it would be helpful to further planning and ensure an eco-friendly environment in the Dhaka city. The study inferred that the applied methods shows quite efficient techniques to monitor and correlate the LULC, LST and UHI of Dhaka city using the Landsat images from 1989 to 2015.

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