



## Technical Paper

## Impact of LULC Changes on LST in Rajshahi District of Bangladesh: A Remote Sensing Approach



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### Abstract

Urbanization has been contributing more in global climate warming, with more than 50% of the population living in cities. Rapid population growth and change in land use / land cover (LULC) are closely linked. The transformation of LULC due to rapid urban expansion significantly affects the functions of biodiversity and ecosystems, as well as local and regional climates. Improper planning and uncontrolled management of LULC changes profoundly contribute to the rise of urban land surface temperature (LST). This study evaluates the impact of LULC changes on LST for 1997, 2007 and 2017 in the Rajshahi district (Bangladesh) using multi-temporal and multi-spectral Landsat 8 OLI and Landsat 5 TM satellite data sets. The analysis of LULC changes exposed a remarkable increase in the built-up areas and a significant decrease in the vegetation and agricultural land. The built-up area was increased almost double in last 20 years in the study area. The distribution of changes in LST shows that built-up areas recorded the highest temperature followed by bare land, vegetation and agricultural land and water bodies. The LULC-LST profiles also revealed the highest temperature in built-up areas and the lowest temperature in water bodies. In the last 20 years, LST was increased about 13°C. The study demonstrates decrease in vegetation cover and increase in non-evaporating surfaces with significantly increases the surface temperature in the study area. Remote-sensing techniques were found one of the suitable techniques for rapid analysis of urban expansions and to identify the impact of urbanization on LST.

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## 1 INTRODUCTION

Cities are facing higher urbanization problems in developing countries than developed countries, and the proportion of urban growth is estimated in medium and small-sized cities (Grimmond, 2007; Karl *et al.*, 1988; Lilly, 2009; McKinney, 2002; Rahman *et al.*, 2018). The rapidly growing urban population significantly changes the land use / land cover (LULC) and creates negative impacts on urban land surface temperature (LST) (Argüeso *et al.*, 2014; Bahi *et al.*, 2016; Habitat,

2016). In recent years, population of Rajshahi city is growing immensely along with the urban development as population of Rajshahi city was about 1200256 (1991), 1535635 (2001), 2286874 (2011) and 24,06874 (2014) (Clemett *et al.*, 2006; Rajshahi Development Authority, 2008; BBS, 2013). This rapid growth brings city expansion, transformation of different LULC and affected the LST in Rajshahi district (Aguilar *et al.* 2003; Kafy *et al.*, 2019; Kafy *et al.*, 2019b;

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Rajshahi Development Authority, 2008). Thus, the evaluation of urban LULC change and its influence on LST is important to create an environmental friendly city.

The rapid population growth and LULC change are closely related (Grimmond, 2007; Rahman *et al.*, 2018; Speth, 2005). The significant growth of population affects severely on ecosystem, social aspect and human health (Aguilar *et al.*, 2003; Al-Hathloul and Rahman, 2003; Trolle *et al.*, 2019). Rapid conversion of LULC influenced by population growth and urban development modifying the thermal condition (Argüeso *et al.*, 2014; Niyogi, 2019; Rasul *et al.*, 2015; Tran *et al.*, 2017; Zhou *et al.*, 2011) and higher LST results in urban heat islands (UHI). It leads to degradation of Earth environment and human health (Hart and Sailor, 2009; Kumar *et al.*, 2012; Lilly, 2009; Maimaitiyiming *et al.*, 2014; Mallick *et al.*, 2008; Priyadarsini, 2012; Rahman *et al.*, 2017; Shatnawi and Abu Qdais, 2019). Geographic Information System (GIS) and Remote Sensing techniques are effective and powerful tools for analysis of LULC changes and LST (Dewan and Corner, 2013; Lilly, 2009; Scarano and Sobrino, 2015; Zhou *et al.*, 2011). Several studies have demonstrated the LULC change and its impact on LST using GIS and multi-temporal remote sensing data (Ahmed, 2011b; Celik *et al.*, 2019; Dewan and Corner, 2013; Lilly, 2009; Maduako *et al.*, 2016; Mallick *et al.*, 2008; Pal and Ziaul, 2017; Shatnawi and Abu Qdais, 2019; Tran *et al.*, 2017).

In Bangladesh, studies on LULC changes and LST are available for Dhaka, Khulna and Chittagong city only (Ahmed, 2011a, 2011b; Ahmed *et al.*, 2013; Dewan and Corner, 2013; Hussain *et al.*, 2016). However, this type of work has not been carried out for one of the largest district (Rajshahi) of Bangladesh. Rajshahi district shows tremendous LULC changes, increase in surface temperature and become one of the predominant problems for Rajshahi in last 20 years. Therefore, the present work investigates the effect of LULC changes on LST for the year of 1997, 2007 and 2017 in the Rajshahi district using multi-temporal and multi-spectral Landsat 8 OLI and Landsat 5 TM satellite data sets.

## 2 STUDY AREA

Rajshahi district is located in the Northwest region of Bangladesh between 24°12' to 24°42' N latitude and 88°15' to 88°50' E longitude. This district is the social, economic and administrative hub of the Northern region of Bangladesh (Figure 1). Topographically, surface

elevation is ranging from 1 to 18 m, the area is almost flat. The district (2428 km<sup>2</sup>) consists of 9 Upazilas, 13 Municipalities and 147 Wards. (Clemett *et al.*, 2006; Rajshahi Development Authority, 2008). It predominately has tropical wet and dry climate. The average temperature is between 22 to 25 °C with 1448 mm rainfall (BBS, 2011). Historically, Rajshahi district is known for rural agrarian community. However, after the construction of Jamuna Bridge and industrialization, this area is significantly experiencing rapid urbanization. The rapid urbanization remarkably changed the intensity of winter and summer season during the last couple of decades which is detrimental to environment, livelihood and agricultural production of this district.

## 3 DATA AND METHODOLOGY

The study deals with multi-temporal Landsat 4-5 Thematic Mapper (TM), and Landsat 8 Operational Land Imager (OLI) satellite images obtained from US Geological Survey (USGS) website (<https://earthexplorer.usgs.gov>) where path is 138 and row is 43 (Table 1) for the years, 1997, 2007 and 2017. All the images contain 30m spatial resolution. The Landsat images (Level 1 Terrain Corrected product) were projected to UTM zone 46 North projection using WGS-84 datum. To avoid the seasonal variation all the Landsat images were downloaded maximum one-month interval (Kafy *et al.*, 2019; Kafy *et al.*, 2017). Images were captured from cloud-free environment in late autumn of September, October and November for preparation of LULC and LST distribution maps (Good and Giordano, 2019; Kafy *et al.*, 2018; Kafy *et al.*, 2019; Kafy *et al.*, 2017). Image processing, image classification, image change detection was processed in ERDAS Imagine 15 software. LST distribution and mapping were conducted in ArcMap 10.6.

### 3.1 Classification of Land Use / Land Cover

The LULC categorized into four types: water bodies, built-up area, vegetation cover and bare land. The determined training areas are used to classify satellite image complying maximum likelihood supervised classification (MLSC). The accuracy assessment of land use classification (overall accuracy, Kappa coefficient, and accuracy validation) was applied. Several studies described the method of mostly used MLSC for image classification (Kafy *et al.*, 2018; Kafy *et al.*, 2019). For accuracy assessments, 350 points were randomly selected for evaluating each classified map using Google Earth images.

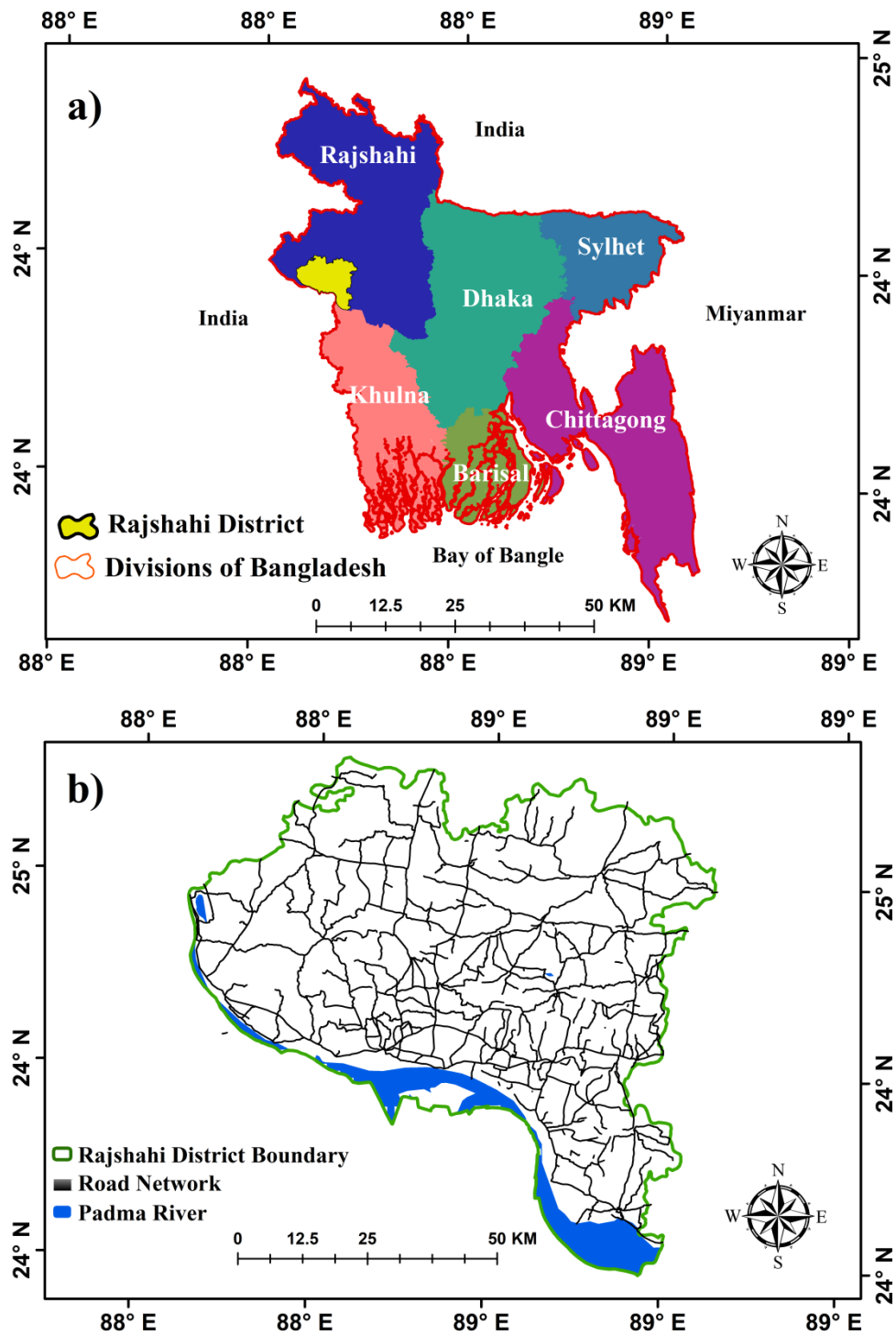


Figure 1. Study area: Rajshahi District in Bangladesh

Table 1. Landsat images

| Satellite images | Date of acquisition         | Sensor | Path/row | Bands       | Spectral range (Wavelength $\mu\text{m}$ ) | Spatial resolution (m) |
|------------------|-----------------------------|--------|----------|-------------|--------------------------------------------|------------------------|
| Landsat 4-5      | May 9, 1997;<br>May 5, 2007 | TM     | 138/43   | 1           | 0.45-0.52                                  | 30                     |
|                  |                             |        |          | 2           | 0.52-0.60                                  | 30                     |
|                  |                             |        |          | 3           | 0.63-0.69                                  | 30                     |
|                  |                             |        |          | 4           | 0.76-0.90                                  | 30                     |
|                  |                             |        |          | 5           | 1.551.75                                   | 30                     |
|                  |                             |        |          | 6           | 10.4012.50                                 | 120 resampled to 30    |
|                  |                             |        |          | 7           | 2.082.35                                   |                        |
| Landsat 8        | May 16, 2017                | OLI    | 138/43   | 1           | 0.43-0.45                                  | 30                     |
|                  |                             |        |          | 2           | 0.45-0.51                                  | 30                     |
|                  |                             |        |          | 3           | 0.64-0.67                                  | 30                     |
|                  |                             |        |          | 4           | 0.53-0.59                                  | 30                     |
|                  |                             |        |          | 5           | 0.85-0.88                                  | 30                     |
|                  |                             |        |          | 6           | 1.57-1.65                                  | 30                     |
|                  |                             |        |          | 7           | 2.11-2.29                                  | 30                     |
|                  |                             |        |          | 8           | 1.36-1.38                                  | 15                     |
|                  |                             |        |          | 9           | 0.50-0.68                                  | 30                     |
|                  |                             |        |          | 10 (TRIS1)  | 10.60-11.19                                | 100 resampled to 30    |
|                  |                             |        |          | 11 (TRIS 1) | 11.50-12.51                                | 100 resampled to 30    |

Source: (<https://earthexplorer.usgs.gov>)

### 3.2 Land Surface Temperature Derivation

The Digital Numbers (DN) of the thermal bands (Band 6 in Landsat 5 TM and Bands 10 in Landsat 8 TIRS) were used to estimate the LST. In the primary stage, spectral radiances ( $L_\lambda$ ) of the Landsat 5 TM and Landsat 8 TIRS bands were calculated by using the equation (1) and equation (2), respectively. Finally,  $L_\lambda$  was used to derive the LST in Degree Celsius using the equation (3).

$$L_\lambda(\text{Landsat 5 TM}) = L_{\min} + \frac{L_{\max} - L_{\min}}{Q_{\text{cal}_{\max}} - Q_{\text{cal}_{\min}}} \times \text{DN} \quad (1)$$

$$L_\lambda(\text{Landsat 8 OLI}) = \text{ML} \times \text{DN} + \text{AL} \quad (2)$$

$$\text{LST} = \frac{T_B}{1 + \left\{ \left( \lambda \times \frac{T_B}{\rho} \right) \times \ln(\varepsilon) \right\}} - 273.15 \quad (3)$$

where, ML (0.0003342) is multiplicative rescaling factor (band-specific), and value of AL is 0.1, which is a additive rescaling factor (band-specific) (Kamran et al., 2015; Sholihah and Shibata, 2019). The values for Landsat TM,  $L_{\max}$  and  $L_{\min}$  were collected from satellite metadata file. The wavelength of emitted radiance  $\lambda$  is 11.5  $\mu\text{m}$ .

$\rho = h \times c / \sigma = 1.438 \times 10^{-2} \text{ mK}$  (where,  $h$  indicates Plank's constant which is equal to  $6.626 \times 10^{-34} \text{ Js}$ ,  $c$  indicates the velocity of light, which is equal to  $2.998 \times 10^8 \text{ ms}^{-2}$  and  $\sigma$  is the Boltzmann constant ( $5.67 \times 10^{-8} \text{ Wm}^2\text{k}^{-4} = 1.38 \times 10^{-23} \text{ JK}^{-1}$ ).  $\varepsilon$  is the land

surface emissivity which is ranged between 0.97 and 0.99.

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}, \text{ where } T_B \text{ is the satellite brightness}$$

temperature and the constant  $K_1$  and  $K_2$  values for 1) Landsat-5:  $K_1$  is 607.7 and  $K_2$  is 1260.6 and 2) Landsat 8:  $K_1$  is 774.9 and  $K_2$  is 1321.07, respectively.

## 4 RESULTS AND DISCUSSIONS

### 4.1 Land Use Land Cover

The LULC (1997, 2007 and 2017) (Figure 2) was calculated from classified images (Table 2). LULC maps demonstrate a rapid increase in built-up areas (6.80%) and significant decreased in vegetation and agricultural land (-7.74%) from 1997 to 2017. Moderate increase and decrease in bare land (2.84%) and water bodies (-1.89%) also noticeable. In 1997, the area under water bodies was 303km<sup>2</sup>, which slightly reduce to 257 km<sup>2</sup> in year 2017. In 1997, the built-up area (179 km<sup>2</sup>) was a small in the city center. In 2007, the total urbanized area was increased massively which replaced the areas of water bodies and vegetation. The rapidly increased (344 km<sup>2</sup>) urbanized area was scattered in the outer portion of the city boundary and suburban area by the year 2017. The vegetation and agricultural land was the predominant land use type in all the years but was significantly decreased from 1235 km<sup>2</sup> to 1047 km<sup>2</sup> in

1997-2017. Maximum vegetation and agricultural land initially converted to bare lands and later it changed into the built-up areas. Therefore, the bare lands were moderately increased from 711km<sup>2</sup> to 780km<sup>2</sup> in 1997 to 2017.

#### 4.2 Accuracy Assessment of Classified LULC maps

Table 3 demonstrates the overall accuracy, Kappa coefficient and land use classification. For each period, the overall accuracy is over 87%, and in comparison to the year 1997 and 2017, the overall accuracy was higher

in 2017. The value of Kappa coefficient was above 0.85 for all the images.

When the coefficient of Kappa is higher than 0.75, the degree of accuracy is categorized as very good (Congalton and Green, 2008; Foody, 2002; Pontius Jr and Millones, 2011; Story and Congalton, 1986). In order to validate the LULC classifications, a comparison was done between the sampling points (300 points) and their corresponding point on Google Earth images in the same time period. The validation values for all the periods are more than 90%. It can be concluded that the good accuracy was estimated in overall accuracy assessments, Kappa coefficient statistics and validation.

Table 2. Distribution of LULC

| Year            | 1997            |       | 2007            |       | 1997-2007  | 2017            |       | 2007-2017  | 1997-2017  |
|-----------------|-----------------|-------|-----------------|-------|------------|-----------------|-------|------------|------------|
| LULC classes    | Area            |       | Area            |       | Change (%) | Area            |       | Change (%) | Change (%) |
|                 | km <sup>2</sup> | %     | km <sup>2</sup> | %     |            | km <sup>2</sup> | %     |            |            |
| Water Body      | 303             | 12.48 | 275             | 11.33 | -1.15      | 257             | 10.58 | -0.74      | -1.89      |
| Built-Up Area   | 179             | 7.37  | 285             | 11.74 | 4.37       | 344             | 14.17 | 2.43       | 6.80       |
| Vegetation Land | 1235            | 50.86 | 1113            | 45.84 | -5.02      | 1047            | 43.12 | -2.72      | -7.74      |
| Bare Land       | 711             | 29.28 | 755             | 31.10 | 1.81       | 780             | 32.13 | 1.03       | 2.84       |

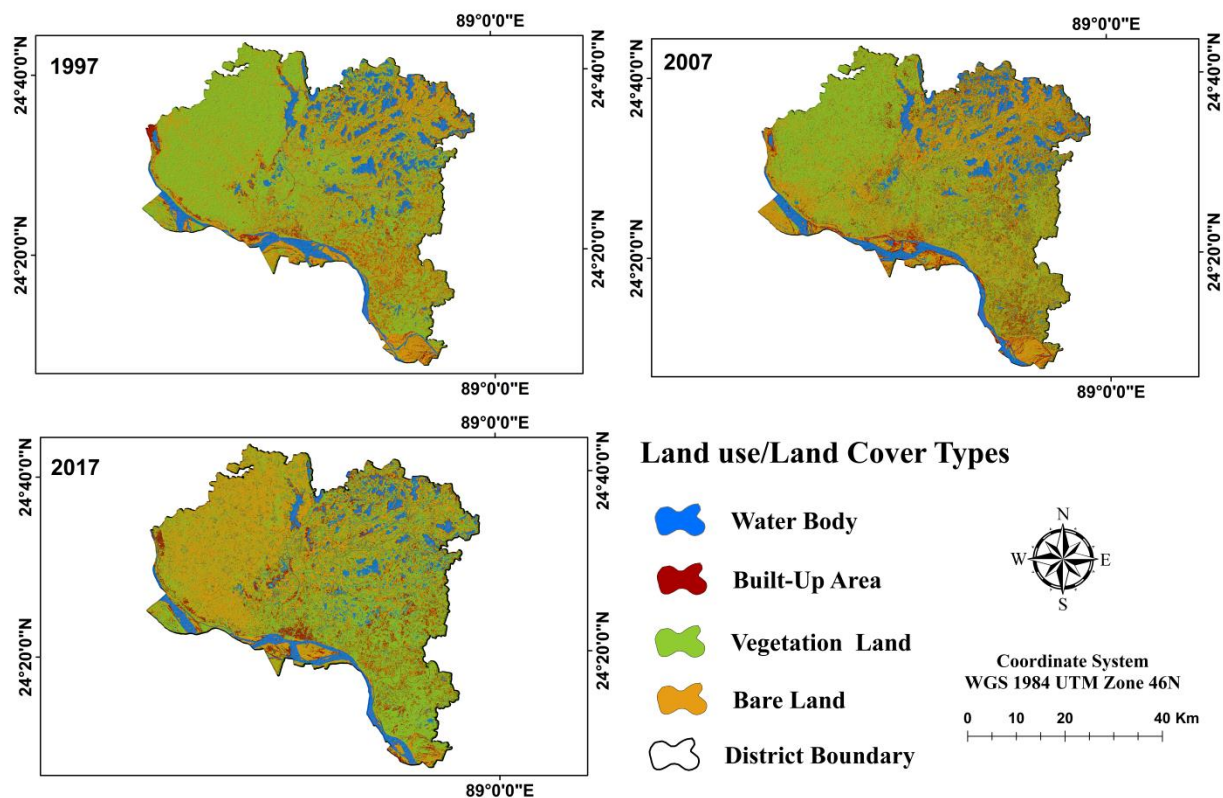


Figure 2. Land Use Land Cover



### 4.3 Changes in LULC

It is clear from Figure 3 and Table 4 that most LULC units have been changed in last 20 years. The changing rate of bare land (22.42%) is higher and positive followed by built-up areas (12.75%). The values in the parenthesis in the legend of the Figure 2 illustrate the percentage of changed area under different category. The positively experienced area is 31.22%, negatively experienced area is 34.47% and stable land proportion is 34.31%. Water body and vegetation cover show negative while built-up and bare land experienced positive changes. During the entire study period, maximum transformation rate was found for vegetation land (25.21%) followed by bare land (10.34%). The majority of the unchanged pixels (60.14%) were found in the period of 1997-2007 and maximum changes in the pixels (65.69%) were found in the period of 1997-2017. The most intense dynamics of change were concentrated

in the central contiguous urban area where constant unidirectional transfers of other lands to built-up areas. Land under vegetation, agriculture and wetland adjacent to the urban area are extremely susceptible to be replaced by the residential or commercial land use.

### 4.4 Changes in Land Surface Temperature

Figure 4 and Table 5 indicate a spatial pattern and areal distribution of LST in three phases e.g. 1997, 2007 and 2017. Clear reddish hue shows higher temperature and bluish color shows low LST in all maps. Such spatial patterns of LST concentration and temporal shift LST pattern highlight the change in LULC classes rapidly. Figure 6a-c emphasizes on the condition of temperature of 1997-2017. Usually, LST is confined within the range of 17-25 °C during 1997, 18-33 °C during 2007 and 26-42 °C during 2017. Out of total area (2428 km<sup>2</sup>), 40.28% area represents temperature from 28-30 °C in 1997

Table 3. Accuracy assessment

| Year | User accuracy (%) |               |            |           | Producer accuracy (%) |               |            |           | Classification accuracy | Kappa statistics |
|------|-------------------|---------------|------------|-----------|-----------------------|---------------|------------|-----------|-------------------------|------------------|
|      | Water body        | Built-up area | Vegetation | Bare soil | Water body            | Built-up area | Vegetation | Bare soil |                         |                  |
| 1997 | 100               | 85            | 85         | 80        | 100                   | 100           | 71.43      | 100       | 90.00%                  | 0.866            |
| 2007 | 100               | 75            | 100        | 85        | 100                   | 100           | 100        | 66.67     | 87.67%                  | 0.876            |
| 2017 | 100               | 85            | 100        | 80        | 100                   | 100           | 83.33      | 100       | 91%                     | 0.893            |

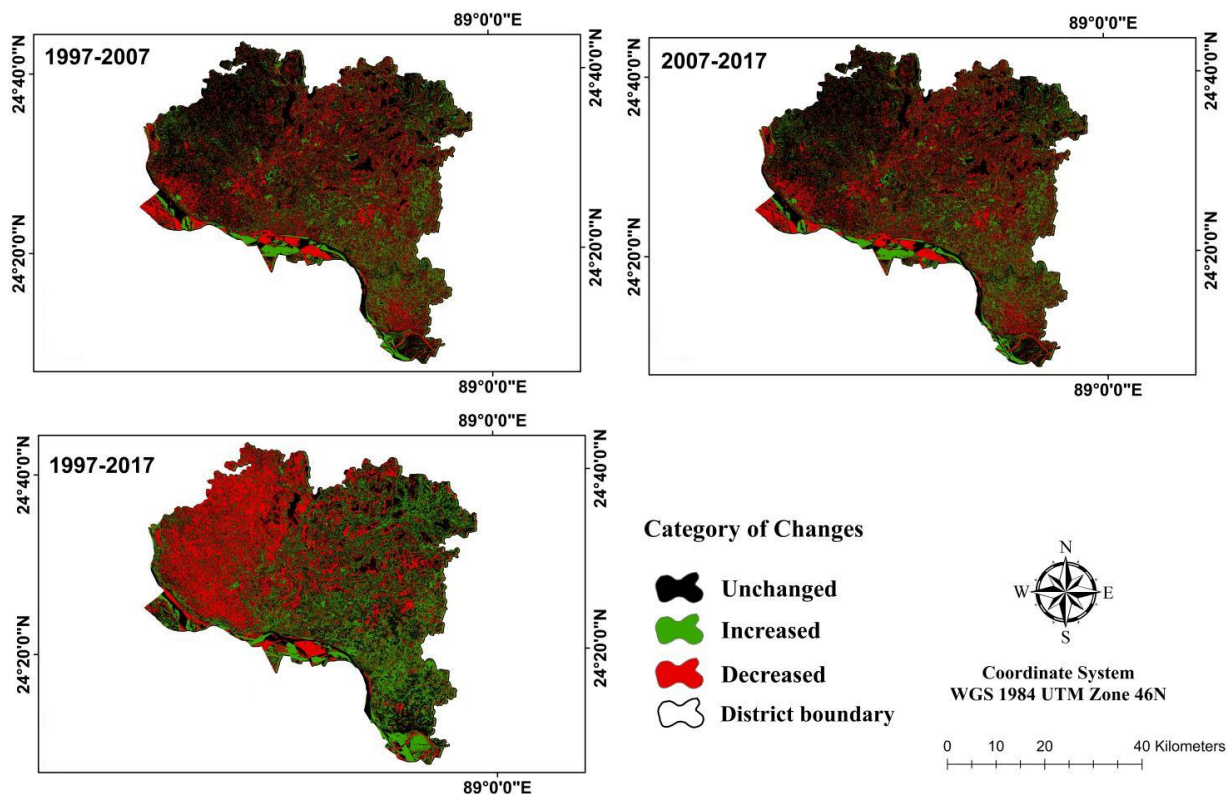


Figure 3. LULC changes from 1997 to 2017

followed by 44.05% area in 2007. The urban core areas are sensitive to high concentration of LST. From 1997 to 2017, the temperature was heaved up to and 37.63% area was faced 37-39 °C in year 2017. This growth is wholly arithmetic but more realistic growth of the temperature was measured using the spatial average and it designates that since 1997-2017, approximately 13 °C

LST has increased. The Northeastern part of the study area exhibits lowering in temperature due to higher vegetation and agricultural land whereas the southwestern part exhibits the rise in LST due to rapid urban expansion and declining of water bodies as well as vegetation cover.

Table 4. Change matrix and transformation rate of LULC (1997 to 2017)

| Changes                                | Water bodies | Built-up area | Vegetation | Bare land |
|----------------------------------------|--------------|---------------|------------|-----------|
| Area change to (km <sup>2</sup> )      | 0.00         | 309.48        | 35.26      | 544.46    |
| Area converted from (km <sup>2</sup> ) | 170.28       | 19.25         | 612.11     | 251.07    |
| Transformation rate (%)                | 7.01         | 0.79          | 25.21      | 10.34     |
| Increasing rate (%)                    | 0.00         | 12.75         | 1.45       | 22.42     |
| Decreasing rate (%)                    | 8.03         | 0.00          | 10.25      | 0.00      |

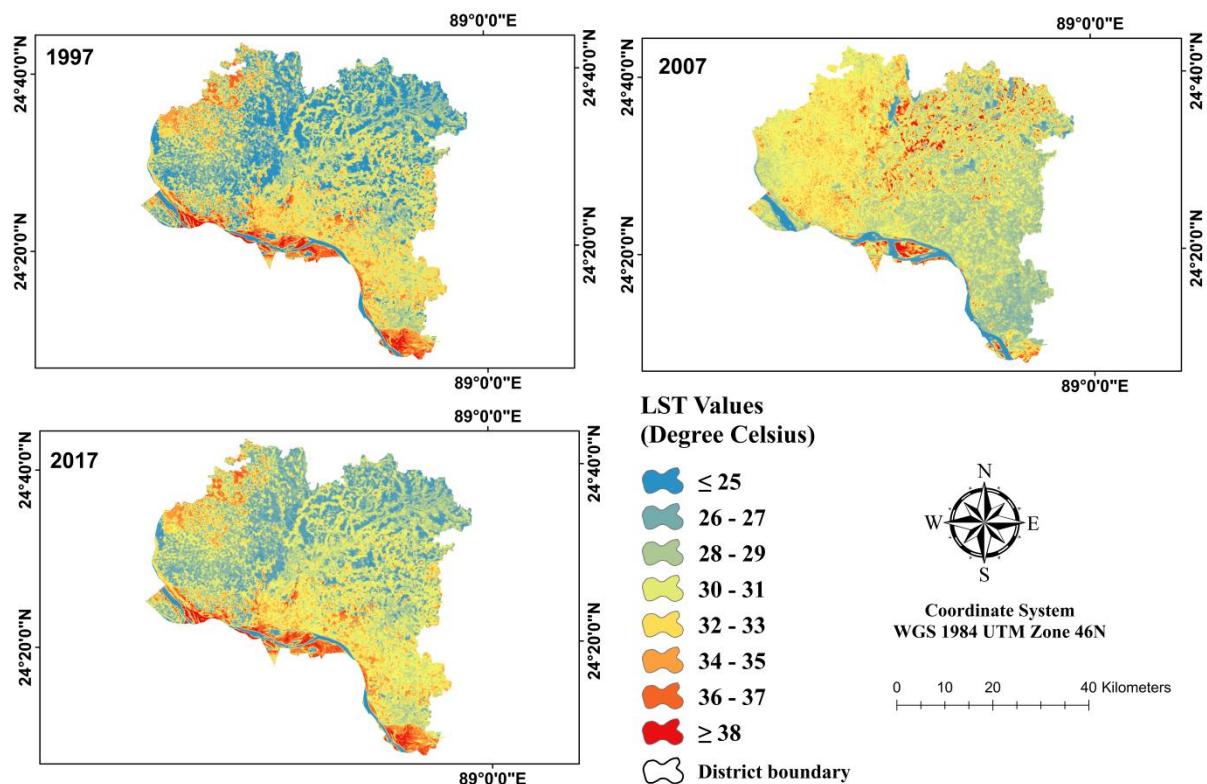


Figure 4. Distribution of LST

Table 5. Distribution of LST

| Ranges of LST (°C) | Area (1997)     |       | Area (2007)     |       | Area (2017)     |       |
|--------------------|-----------------|-------|-----------------|-------|-----------------|-------|
|                    | km <sup>2</sup> | %     | km <sup>2</sup> | %     | km <sup>2</sup> | %     |
| ≤25 °C             | 266.73          | 10.94 | -               | -     | -               | -     |
| 26-27 °C           | 696.15          | 28.55 | 627.3           | 25.68 |                 |       |
| 28-29 °C           | 982.26          | 40.28 | 1076.1          | 44.05 | 70.89           | 2.91  |
| 30-31 °C           | 493.17          | 20.23 | 736.44          | 30.15 | 246.33          | 10.10 |
| 32-33 °C           | -               | -     | 3.06            | 0.13  | 618.63          | 25.36 |
| 34-35 °C           | -               | -     | -               | -     | 918             | 37.63 |
| 36-37 °C           | -               | -     | -               | -     | 396.27          | 16.24 |
| ≥38 °C             | -               | -     | -               | -     | 189.72          | 7.78  |
| Total              | 2428            |       | 2428            |       | 2428            |       |

#### 4.5 Validation of Estimated LST

The LST is obtained from the thermal bands of Landsat 4-5 TM and Landsat 8 OLI images through the simplest method. Though for retrieving LST, this is the simplest method it agonizes with certain limitations. Firstly, clear sky is major requirement to obtain accurate readings in LST retrieval using satellite remote sensing techniques. Hence, cloud coverage can create an acute problem. Secondly, all the surface materials don't have unique emissivity value in a specific area (Chen *et al.*, 2006; Dar *et al.*, 2019; Neteler, 2010). These problems will drive to the unrealistic LST estimation in a region. To validate the LST estimation from remotely sensed data, maximum and minimum surface temperature data procured from the Bangladesh Metrological Department (BMD) for the year May1997, 2007 and 2017 in the day time. The deviation between estimated LST and recorded LST has shown in Table 6. The deviations have been calculated based on BMD recorded LST estimation. Negative deviation in LST indicates estimation is higher than the recorded temperature and positive deviation value indicates lower recorded value from recorded temperature.

The highest deviation was noticed in maximum and minimum temperature for the year 2017 (-4.78 °C) and (-1.75 °C), respectively. In 2007, maximum and minimum deviation in temperature was (-3.89 °C) and (3.7 °C), respectively. Finally, on the basis of BMD estimation, highest maximum deviation was found for year 2017 (-14.05%). Temperature difference for both remotely sensed estimated and BMD recorded LST is 13.4 °C and 5.7 °C, respectively in last 20 years.

Considering all the limitations of remote sensing derived LST estimation, the deviation between estimated and recorded LST is acceptable and can be used further analysis in future like LST simulation and temperature condition index in any region.

#### 4.6 LULC Vs LST profiles

The emitted radiative energy from the surface of the ground, which includes rooftops, surfaces of pavement, vegetated area, bare soil and water, is recorded from the remote sensed LST. Three cross-sections were made across the study area to represent the LULC wise LST, and the average LST of each type of LULC (Figures 5, 6 and 7). Because of the higher concentration of LST values in Southern and Western zone two cross-sections (CD and EF) was made in a Southwest direction. From the profile it was found that urban core area with dominant built-up land experienced LST > 25 °C in 1997, > 32 °C in 2007, and > 38 °C in 2017, respectively. Also, higher LST recorded > 24°C, > 31°C and > 36°C for bare land in three different year cross-sections. Associate with the built-up area and bare land other two land use (water bodies and vegetation land) recorded the lowest temperature ranging from < 19°C to <35°C. According to Table 7, the minimum temperature recorded for year 1997 and 2017 in water bodies (18°C and 26°C) and for 2007 in vegetation and agricultural land (19°C). Following that, the maximum temperature was recorded for the year 1997 and 2017 in built-up areas (25°C and 38°C) and for 2007 in bare land (33°C).



Table 6. Validation of remotely sensed LST

| Year                               | 1997    |         | 2007    |         | 2017    |         |
|------------------------------------|---------|---------|---------|---------|---------|---------|
| Source of estimated/recorded LST   | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
| Remotely Sensed Estimated LST (°C) | 25.38   | 17.45   | 33.49   | 18.5    | 38.78   | 26.65   |
| BMD recorded LST (°C)              | 28.3    | 21      | 29.6    | 22.2    | 34      | 24.9    |
| Deviation (°C)                     | 2.92    | 3.55    | -3.89   | 3.7     | -4.78   | -1.75   |
| Deviation (%)                      | 10.31   | 16.9    | -13.14  | 16.67   | -14.05  | -7.028  |

Table 7. LULC and LST distribution

| LULC          |                         | 1997    | 2007    | 2017   |
|---------------|-------------------------|---------|---------|--------|
| Water body    | Area (km <sup>2</sup> ) | 209.23  | 152.88  | 95.55  |
|               | %                       | 8.62    | 6.30    | 3.94   |
|               | Min. Temp.(°C)          | 18.06   | 22.84   | 26.42  |
|               | Max. Temp. (°C)         | 21.06   | 19.69   | 33.86  |
| Built-up area | Area (km <sup>2</sup> ) | 498.33  | 662.97  | 838.88 |
|               | %                       | 20.52   | 27.31   | 34.55  |
|               | Min. Temp. (°C)         | 22.06   | 32.85   | 35.03  |
|               | Max. Temp. (°C)         | 25.38   | 33.35   | 38.78  |
| Vegetation    | Area (km <sup>2</sup> ) | 1228.43 | 1113.28 | 779.59 |
|               | %                       | 50.59   | 45.85   | 32.11  |
|               | Min. Temp. (°C)         | 20.38   | 18.5    | 27.92  |
|               | Max. Temp. (°C)         | 22.36   | 29.17   | 35.98  |
| Bare soil     | Area (km <sup>2</sup> ) | 407.19  | 417.97  | 659.54 |
|               | %                       | 16.77   | 17.21   | 27.16  |
|               | Min Temp. (°C)          | 23.81   | 29.15   | 36.12  |
|               | Max. Temp. (°C)         | 24.62   | 33.49   | 36.37  |

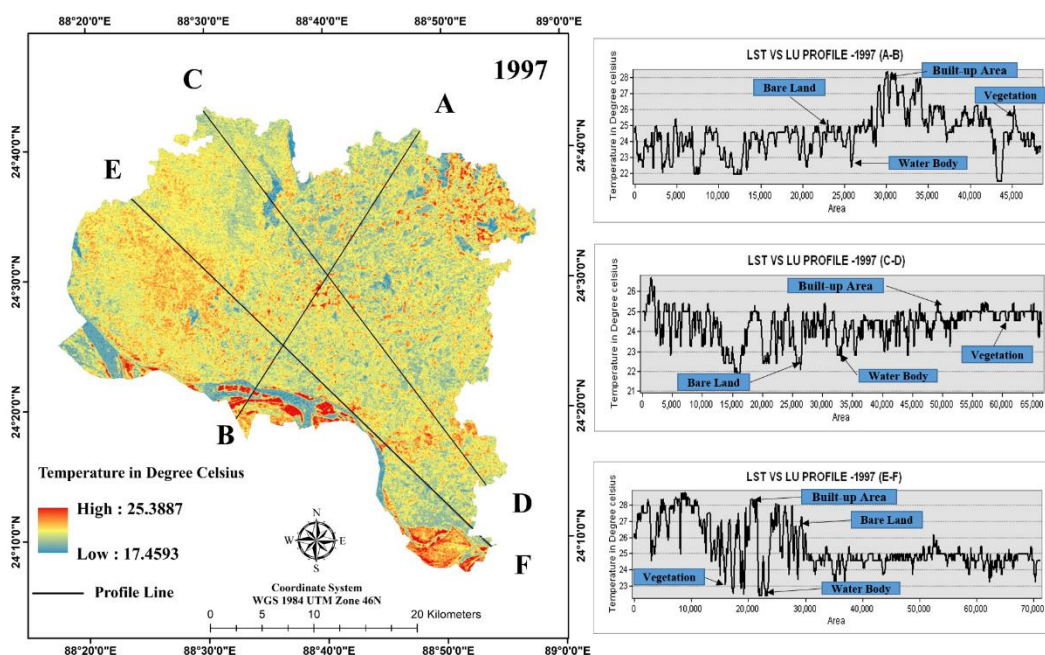


Figure 5. Land Surface Temperature profiles with LULC (1997)

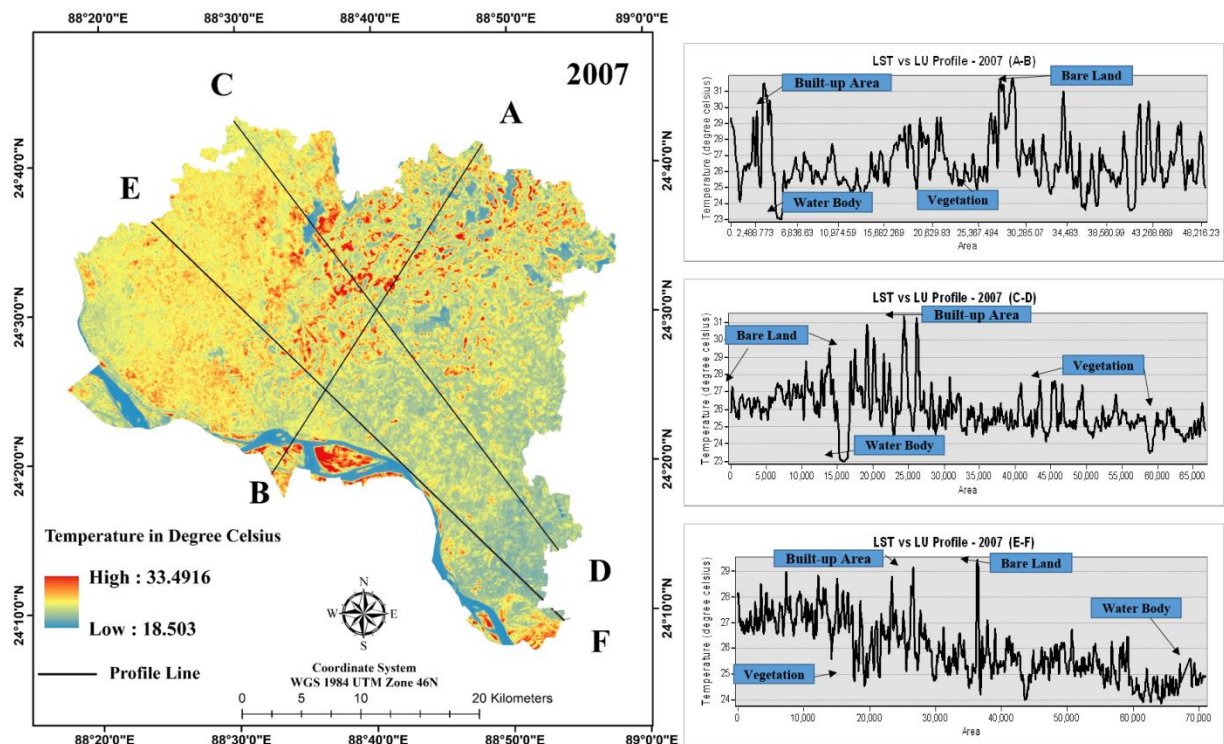


Figure 6. Land Surface Temperature profiles with LULC (2007)

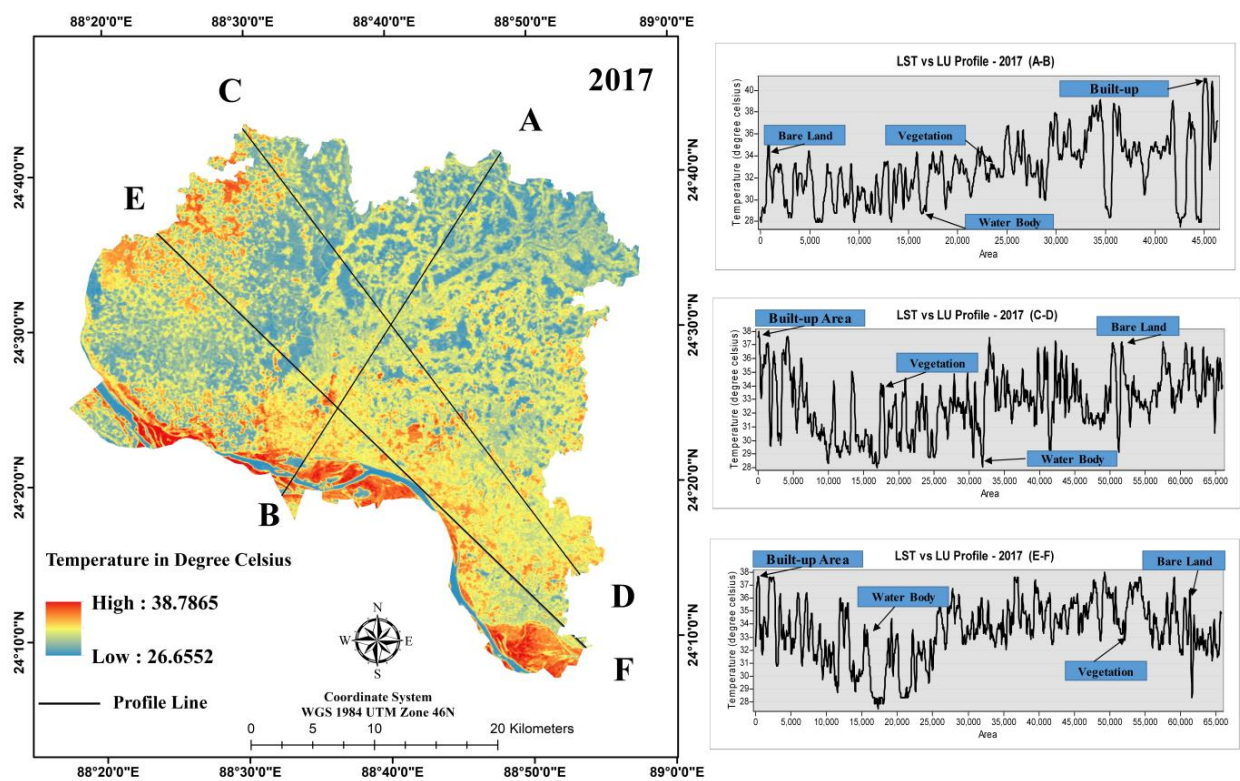


Figure 7. Land Surface Temperature profiles with LULC (2017)

## 5 CONCLUSION

Based on the Landsat images of 1997, 2007, and 2017, we examined the trend of LULC changes and fluctuation of LST in Rajshahi district, Bangladesh. It was found that there was an increase in the urban area from 1997 to 2017 about 165 km<sup>2</sup>, where 188 km<sup>2</sup> and vegetation area was lost. LST shows a rapidly increasing trend in city areas, while in areas occupied by water bodies shows less. In the last 20 years, highest LST was increased by 13°C. 63% area was faced 34-35 °C in the year 2017. It should be noted that rapid growth of urban area is the key driving process of LULC changes and subsequent rise in LST. Without a radical decentralization policy, however, it is difficult to prevent the rapid urbanization growth. A massive increase in LST can damage the human health and components of the ecosystem. The local government, urban planners and environmental engineers of Rajshahi can consider the rapid urban growth and the formation of LST based on the results in this study. The outcomes also provide the updated information and improved understanding for the urban planners in developing an inclusive policy for a city and make a city more comfortable and sustainable for the future.

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## ABBREVIATIONS

**GIS:** Geographic Information System; **LULC:** Land Use / Land Cover; **MLSC:** Maximum Likelihood Supervised Classification; **LST:** Land Surface Temperature.

## CONFLICT OF INTEREST

The authors confirm no conflicts of interest.

## REFERENCES

- Aguilar, A. G., Ward, P. M. and Smith C. B., 2003. Globalization, regional development, and mega-city expansion in Latin America: Analyzing Mexico City's peri-urban hinterland. *Cities*, 20(1), 3-21. DOI: [https://doi.org/10.1016/S0264-2751\(02\)00092-6](https://doi.org/10.1016/S0264-2751(02)00092-6)
- Ahmed, B., 2011a. Modelling spatio-temporal urban land cover growth dynamics using remote sensing and GIS techniques: A case study of Khulna City. *Journal of Bangladesh Institute of Planners*, 4, 15-32.
- Ahmed, B., 2011b. Urban land cover change detection analysis and modeling spatio-temporal Growth dynamics using Remote Sensing and GIS Techniques: A case study of Dhaka, Bangladesh.
- Ahmed, B., Kamruzzaman, M., Zhu, X., Rahman, M. S., and Choi, K., 2013. Simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. *Remote Sensing*, 5(11), 5969-5998. DOI: <https://doi.org/10.3390/rs5115969>
- Al-Hathloul, S. and Rahman, M. A., 2003. Dynamism of metropolitan areas: The case of metropolitan Dammam, Saudi Arabia. *J. Gulf Arab. Penins. Stud*, 29, 11-43. DOI: <https://doi.org/10.5539/jsd.v8n9p52>
- Argüeso, D., Evans, J. P., Fita, L. and Bormann, K. J., 2014. Temperature response to future urbanization and climate change. *Climate Dynamics*, 42(7-8), 2183-2199. DOI: <https://doi.org/10.1007/s00382-013-1789-6>
- Bahi, H., Rhinane, H., Bensalmia, A., Fehrenbach, U. and Scherer, D., 2016. Effects of urbanization and seasonal cycle on the surface urban heat island patterns in the coastal growing cities: A case study of Casablanca, Morocco. *Remote Sensing*, 8(10), 829. DOI: <https://doi.org/10.3390/rs8100829>
- BBS [Bangladesh Bureau of Statistics], District Statistics 2011, Rajshahi. Ministry of Planning Government of The People's Republic of Bangladesh.
- Celik, B., Kaya, S., Alganci, U. and Seker, D. Z., 2019. Assessment of the relationship between land use/cover changes and land surface temperatures: A case study of thermal remote sensing. *FEB-Fresenius Environmental Bulletin*, 3, 541.
- Chen, X.-L., Zhao, H.-M., Li, P.-X. and Yin, Z.-Y., 2006. Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. *Remote sensing of environment*, 104(2), 133-146. DOI: <https://doi.org/10.1016/j.rse.2005.11.016>
- Clemett, A., Amin, M. M., Ara, S. and Akan, M. M. R., 2006. Background Information for Rajshahi City, Bangladesh WASPA Asia Project Report 2 (Vol. 2).
- Congalton, R. G. and Green, K., 2008. *Assessing the accuracy of remotely sensed data: principles and practices*: CRC press.
- Dar, I., Qadir, J. and Shukla, A., 2019. Estimation of LST from multi-sensor thermal remote sensing data and evaluating the influence of sensor characteristics. *Annals of GIS*, 1-19. DOI: <https://doi.org/10.1080/19475683.2019.1623318>
- Dewan, A. M. and Corner, R. J., 2013, 2012. The impact of land use and land cover changes on land surface temperature in a rapidly urbanizing megacity. *IEEE International Geoscience and Remote Sensing Symposium*. DOI: <https://doi.org/10.1109/IGARSS.2012.6352709>
- Foody, G. M., 2002. Status of land cover classification accuracy assessment. *Remote sensing of environment*, 80(1), 185-201. DOI: [https://doi.org/10.1016/S0034-4257\(01\)00295-4](https://doi.org/10.1016/S0034-4257(01)00295-4)
- Good, T. and Giordano, P. A., 2019. Methods for constructing a color composite image.
- Grimmond, S. U. E., 2007. Urbanization and global environmental change: Local effects of urban warming. *Geographical Journal*, 173(1), 83-88. DOI: [https://doi.org/10.1111/j.1475-4959.2007.232\\_3.x](https://doi.org/10.1111/j.1475-4959.2007.232_3.x)
- Habitat, U. N., 2016. Urbanization and development: Emerging futures. *World cities report*, 3(4), 4-51.
- Hart, M. A. and Sailor, D. J., 2009. Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island. *Theoretical and Applied Climatology*, 95(3-4), 397-406. DOI: <https://doi.org/10.1007/s00704-008-0017-5>
- Hussain, M., Alak, P. and Azmz, I., 2016. Spatio-temporal



- analysis of land use and land cover changes in Chittagong city corporation, Bangladesh. *Int. J. Adv. Remote Sens. GIS Geogr*, 4, 56-72.
- Kafy, A. A., Faisal, A. A., Khan, H. A. H. and Sheel, P. K., 2018. Exploring the association of surface water body change and rapid urbanization in Rajshahi City Corporation (RCC) area using RS and GIS. Paper presented at the 1st National Conference on Water Resources Engineering (NCWRE 2018), Chittagong, Bangladesh.
- Kafy, A. A., Islam, M., Ferdous, L., Khan, A. R. and Hossain, M. M., 2019. Identifying most influential land use parameters contributing reduction of surface water bodies in Rajshahi City, Bangladesh: A Remote Sensing Approach. *Remote Sensing of Land*, 2(2), 87-95. DOI: <http://dx.doi.org/10.21523/gcj1.18020202>
- Kafy, A. A., Rahman, M. S. and Ferdous, L., 2017. Exploring The Association of Land Cover Change And Landslides In The Chittagong Hill Tracts (CHT): A Remote Sensing Perspective.
- Kafy, A., Hossain, M., Prince, A. A. N., Kawshar, M., Shamim, M. A., Das, P. and Noyon, M. E. K., 2019b. *Estimation of Land Use Change to Identify Urban Heat Island Effect on Climate change: A Remote Sensing Based Approach*. Paper presented at the International Conference on Climate Change (ICCC-2019), Dhaka, Bangladesh.
- Kamran, K. V., Pirnazar, M. and Bansouleh, V. F., 2015. Land surface temperature retrieval from Landsat 8 TIRS: comparison between split window algorithm and SEBAL method. Paper presented at the Third International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2015). DOI: <https://doi.org/10.1117/12.2192491>
- Karl, T. R., Diaz, H. F. and Kukla, G., 1988. Urbanization: Its detection and effect in the United States climate record. *Journal of climate*, 1(11), 1099-1123. DOI: [https://doi.org/10.1175/1520-0442\(1988\)001<1099:UIDAEI>2.0.CO;2](https://doi.org/10.1175/1520-0442(1988)001<1099:UIDAEI>2.0.CO;2)
- Kumar, K. S., Bhaskar, P. U. and Padmakumari, K., 2012. Estimation of land surface temperature to study urban heat island effect using LANDSAT ETM+ image. *International journal of Engineering Science and technology*, 4(2), 771-778.
- Lilly, R., A. and Devadas, M. D., 2009. *Analysis of Land Surface Temperature and Land Use/Land Cover Types Using Remote Sensing Imagery - A Case In Chennai City, India*. Paper presented at the The seventh International Conference on Urban Climate., held on 29 June – 3 July 2009, Yokohama, Japan.
- Maduako, I. D., Yun, Z. and Patrick, B., 2016. Simulation and prediction of land surface temperature (LST) dynamics within Ikom City in Nigeria using artificial neural network (ANN). *Journal of Remote Sensing and GIS*, 5(1), 1-7.
- Maimaitiyiming, M., Ghulam, A., Tiyp, T., Pla, F., Latorre-Carmona, P., Halik, Ü., Sawut, M. and Caetano, M., 2014. Effects of green space spatial pattern on land surface temperature: Implications for sustainable urban planning and climate change adaptation. *ISPRS Journal of Photogrammetry and Remote Sensing*, 89, 59-66. DOI: <https://doi.org/10.1016/j.isprsjprs.2013.12.010>
- Mallick, J., Kant, Y., and Bharath, B., 2008. Estimation of land surface temperature over Delhi using Landsat-7 ETM+. *J. Ind. Geophys. Union*, 12(3), 131-140.
- McKinney, M. L., 2002. Urbanization, biodiversity, and conservation. *Bioscience* 52, 883-890. DOI: [https://doi.org/10.1641/0006-3568\(2002\)052\[0883:UBAC\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2)
- McKinney, M. L., 2006. Urbanization as a major cause of biotic homogenization. *Biol Conserv*, 127, 247-260. DOI: <https://doi.org/10.1016/j.biocon.2005.09.005>
- Neteler, M., 2010. Estimating daily land surface temperatures in mountainous environments by reconstructed MODIS LST data. *Remote Sensing*, 2(1), 333-351. DOI: <https://doi.org/10.3390/rs1020333>
- Niyogi, D., 2019. Land surface processes. *Current Trends in the Representation of Physical Processes in Weather and Climate Models* (349-370), Springer. DOI: [https://doi.org/10.1007/978-981-13-3396-5\\_17](https://doi.org/10.1007/978-981-13-3396-5_17)
- Pal, S. and Ziaul, S., 2017. Detection of land use and land cover change and land surface temperature in English Bazar urban centre. *The Egyptian Journal of Remote Sensing and Space Science*, 20(1), 125-145. DOI: <https://doi.org/10.1016/j.ejrs.2016.11.003>
- Pontius Jr, R. G. and Millones, M., 2011. Death to Kappa: Birth of quantity disagreement and allocation disagreement for accuracy assessment. *International Journal of remote sensing*, 32(15), 4407-4429. DOI: <https://doi.org/10.1080/01431161.2011.552923>
- Priyadarsini, R., 2012. Urban heat island and its impact on building energy consumption *Advances in building energy research*, 267-276, Routledge.
- Rahman, M. S., Mohiuddin, H., Kafy, A.-A., Sheel, P. K. and Di, L., 2018. Classification of cities in Bangladesh based on remote sensing derived spatial characteristics. *Journal of Urban Management*. DOI: <https://doi.org/10.1016/j.jum.2018.12.001>
- Rahman, M., Aldosary, A. S. and Mortoja, M., 2017. Modeling future land cover changes and their effects on the land surface temperatures in the Saudi Arabian eastern coastal city of Dammam. *Land*, 6(2), 36. DOI: <https://doi.org/10.3390/land6020036>
- Rajshahi Development Authority, 2008. Working paper on Existing Landuse, Demographic and Transport (revised). M. C. A. Development Design Consultants Limited 47, Dhaka-1212 (Ed.). Government of The People's Republic of Bangladesh Ministry of Housing and Public Works.
- Rasul, A., Balzter, H. and Smith, C., 2015. Spatial variation of the daytime Surface Urban Cool Island during the dry season in Erbil, Iraqi Kurdistan, from Landsat 8. *Urban climate*, 14, 176-186. DOI: <https://doi.org/10.1016/j.uclim.2015.09.001>
- Scarano, M. and Sobrino, J. A., 2015. On the relationship between the sky view factor and the land surface temperature derived by Landsat-8 images in Bari, Italy. *International Journal of remote sensing*, 36(19-20), 4820-4835. DOI: <https://doi.org/10.1080/01431161.2015.1070325>
- Shatnawi, N. and Abu Qdais, H., 2019. Mapping urban land surface temperature using remote sensing techniques and artificial neural network modelling. *International Journal of remote sensing*, 1-16. DOI: <https://doi.org/10.1080/01431161.2018.1557792>
- Sholihah, R. I. and Shibata, S., 2019. Retrieving Spatial Variation of Land Surface Temperature Based on Landsat OLI/TIRS: A Case of Southern part of Jember, Java, Indonesia. Paper presented at the IOP Conference Series: Earth and Environmental Science. DOI: <https://doi.org/10.1088/1755-1315/362/1/012125>
- Speth, J. G., 2005. *Global Environmental Challenges: Transitions to a Sustainable World*: Orient Blackswan.

- Story, M. and Congalton, R. G., 1986. Accuracy assessment: A user's perspective. *Photogrammetric Engineering and remote sensing*, 52(3), 397-399.
- Tran, D. X., Pla, F., Latorre-Carmona, P., Myint, S. W., Caetano, M. and Kieu, H. V., 2017. Characterizing the relationship between land use land cover change and land surface temperature. *ISPRS Journal of Photogrammetry and Remote Sensing*, 124, 119-132. DOI: <https://doi.org/10.1016/j.isprsjprs.2017.01.001>
- Trolle, D., Nielsen, A., Andersen, H. E., Thodsen, H., Olesen, J. E., Børgesen, C. D., Refsgaard, J. C., Sonnenborg, T. O., Karlsson, I. B. and Christensen, J. P., 2019. Effects of changes in land use and climate on aquatic ecosystems: Coupling of models and decomposition of uncertainties. *Science of the Total Environment*, 657, 627-633. DOI: <https://doi.org/10.1016/j.scitotenv.2018.12.055>
- Zhou, W., Huang, G. and Cadenasso, M. L., 2011. Does spatial configuration matter? Understanding the effects of land cover pattern on land surface temperature in urban landscapes. *Landscape and urban planning*, 102(1), 54-63. DOI: <https://doi.org/10.1016/j.landurbplan.2011.03.009>

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