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Impact of Urbanization on Landuse-Landcover, Land Surface Temperature and Urban Heat Islands using Multispectral Satellite Images: An Implication in the District Towns of Northwestern Bangladesh

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ABSTRACT

The urbanization processes and its keen relationship with the spatio-temporal variability of land use-land cover (LULC), land surface temperature and urban heat island (HI) within the district towns in the Rangpur division of Bangladesh has been assessed using multi-spectral Landsat satellite images from 1991 to 2021.The supervised classification approach was used to retrieve LULC types such as water body, built-up area, bare land, agricultural land and vegetation cover. The results of LULC suggest that agricultural and bare land have decreased during the last 30 years in the study areas. The vegetation cover shows an average increase and built-up area has increased progressively from 1991 to 2021. Conspicuously the water bodies, agricultural and bare lands have reduced due to the expansion and rapid growth of settlement areas or urbanization. The spatio-temporal variability of Land Surface Temperature (LST) over the study area responsible for the development of the urban heat islands (UHIs) is assessed using the mono-window algorithm. The areal extents of the UHIs are spreading out day by day and have become most extensive in 2021. Correlation of LULC types with the HI and LST indicated that lower temperature zones were found in the water bodies, vegetated and agricultural lands whereas higher temperature zones were found in the bare lands or highly built-up areas within the district towns. Ground truth data have been validated well with the image processed results with an overall 86.25% classification accuracy which indicates a good level of accuracy of the detected LULC using satellite images. Thus, the research work will help in understanding the land cover dynamics, increasing LST and heat island growth, which could be further used for mitigating the socio-economic hazards faced by the communities in and around the study areas.

Introduction

The research involved the processing and interpretation of Landsat imagery during a 30-years period in Pourashavas of Rangpur division. Rapidly changing landuse-landcover patterns of a particular region as a result of urbanization leads to unsustainable development by reducing vegetation cover and facilitating the heat islands formation processes by elevating land surface temperature (Ramachandra et al., 2012). As a result, the fast transformation of LULC due to urban expansion has significant influences in the momentum of biodiversity, ecosystems, as well as local and regional climate (Luck & Wu, 2002; Ahmed et al., 2013). The urbanization process is closely associated with socioeconomic development and the alleviation of poverty. It is, however, associated with substantial, irrevocable biophysical changes in land use which result in the loss of croplands and other terrestrial carbon pools, as well as threats to biodiversity, hydrologic systems, and local and regional climate change (Borges et al. 2016; Balling and Brazel, 1988). Through rapid development the rural areas are transforming into urban areas at an unprecedented rate in recent human history, and this is having a significant impact on ecosystem function (Bhattacharya et al., 2015). Bangladesh is currently facing rapid urbanization and subsequent elevated LST in most of the regions (Gazi et al., 2020). In recent times, some notable studies remarked the alarming increasing of unplanned urbanization and the threats as well (Bhattacharjee et al., 2021; Faisal et al. 2021, Fattah et al., 2021; Kafy et al., 2021).

The Rangpur division's geographical location makes it vulnerable to many natural hazards and some human

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induced impacts. Several significant factors such as rapid growth in population, unplanned urbanization, coal and hard rock mining activities, dried out river channels, extensive agricultural development and climate change effects such as drought, deforestation, floods etc. are accelerating the occurrences of such hazardous events (Akter et al., 2021; Sultana et al., 2021). Landuse–landcover (LULC) change in Bangladesh's northwestern region imposes a significant challenge to the region's long-term environmental impacts, necessitating regional-scale monitoring of biophysical parameters and changes in their mutual relationships through time and space. Rapid urbanization causes changes in land use patterns, which are linked to the rising land surface temperatures (LST) and the expansion of urban heat islands (UHI). The primary goal is to investigate the spatiotemporal variability of LULC changes in relation to land surface temperature (LST) and urban heat island development in the district towns (pourashava/city) of Bangladesh's Rangpur division.

Rangpur division includes the newly set up Rangpur city and seven major towns. There are several studies relating to cities in the literature for LULC, but none have focused on the patterns and processes of LULC and LST change in towns as a whole. To comprehend the urbanization process and evaluate its impact on the environmental sustainability of Bangladesh's northwest Rangpur divisional region, it is necessary to look at the region as a whole.

The study includes the pre-processing, analysis and interpretation of satellite images of the pourashava of Rangpur division over a 30-years period, as well as field work to collect land cover data and land surface temperature from various locations. Since, the northwestern part of Bangladesh is one of the hottest areas, it is essential to evaluate LST in this region. If satellite image-based spatial monitoring of LST could be done on a frequent basis, the consequences of UHI may be reduced. Satellite-based LST monitoring has received increasing attention in recent years and is now routinely employed in many parts of the world.

Through the selection and analyses of appropriate satellite images with medium spatial resolution and sensor types, this study can help in achieving the desired objectives of upcoming researches. It will also help in understanding the land cover dynamics and heat island growth, which may be further used for mitigating socio-economic hazards (climate change, loss of farmlands and biodiversity, flood, drought etc.) faced by communities living in and around the study area.

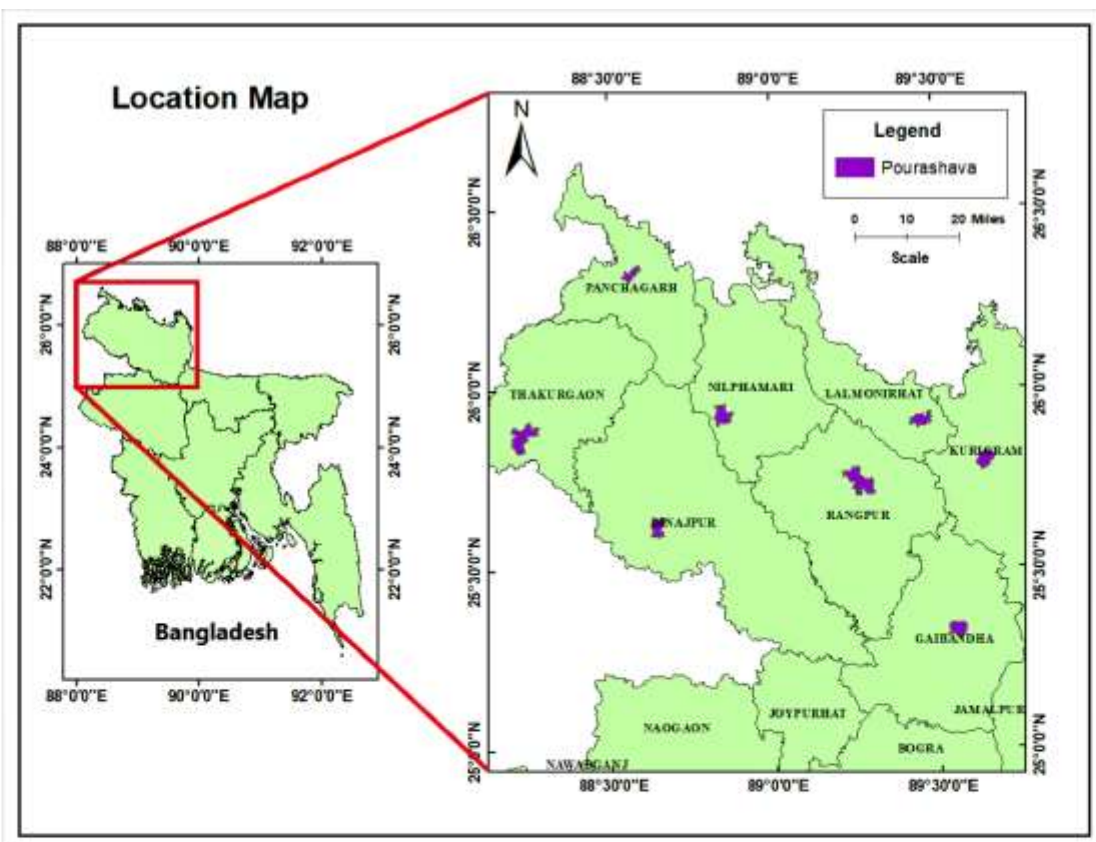

Figure 1: Location of the study area, Pourashava of Rangpur division, Bangladesh

Study Area

The study areas of this research work are located in the Northwestern part of Bangladesh i.e., Rangpur division (Figure 1). The name of studied eight District towns (Pourashava/City) in Rangpur division are Panchagarh Pourashava (1152 ha), Thakurgaon Pourashava (3794 ha), Nilphamari Pourashava (2222 ha), Lalmonirhat Pourashava (1763 ha), Kurigram Pourashava (2073 ha), Gaibandha (1928 ha), Rangpur City (4111 ha) and Dinajpur Pourashava (1750 ha) (BBS, 2011). Pourashava (District Town) of the eight Districts are the target area of this research. The climate in the Rangpur division is intense tropical monsoon, with two main seasons: a dry season from November to March and a rainy season from June to October (Murad & Islam, 2011).

In the midst of the monsoon, the NW region of Bangladesh experiences an occasional short dry period lasting up to 23 days called as monsoon break (Bhuiyan et al., 2017). The annual rainfall averages between 1500 and 3000 mm, with a regional average of about 1583 mm (Murad and Islam, 2011). Because of its subtropical location, temperature variations are much more prominent in Bangladesh's northwestern region (Karmakar, 2019). Maximum temperature ranges from 36°C in April/May to 25°C in January, with occasional high of 38.5°C (Karmakar, 2019). In August, the minimum temperature is 20°C; while in January, it is 10 to 20°C. The humidity levels increase consistently during the monsoon season, drop significantly at the end of dry season. Sunshine levels are low during monsoon and high from November to May (Bhuiyan et al, 2017).

Table 1: Satellite Images with their Acquisition Date and Spatial Resolution List of satellite images with their date of acquisition and spatial resolution

Year	Sensor Platform	Acquisition Date	Resolution
1991	Landsat 5 TM	12-16-1990	30 m
		01-21-1991	
2001	Landsat 5 TM	01-28-2001	
		01-19-2001	
2011	Landsat 5 TM	01-24-2011	
		01-31-2011	
2021	Landsat 8 OLI	01-03-2021	
		01-10-2021	

Materials and Methods

Multispectral Landsat satellite images (of TM/OLI/TIRS sensors) were used in this study (Table 2). The images were processed with the help of two widely used geospatial software (ERDAS Imagine and ArcGIS). The images were downloaded/obtained at free of cost from the United States Geological Survey (USGS) archive.

During field investigations, a handheld digital thermometer was used to collect ground truth data on land surface temperature (LST), and GPS was used to record the exact location of the ground truth data. The device is capable of measuring temperature in both "Fahrenheit" and "Celsius" scale. The sensitive steel probe of the gadget was inserted into the ground to a depth of roughly half to one inch to measure land surface temperature, and the digital indicator displayed the distinctive temperature of that surface.

Landuse-Landcover (LULC) Mapping

The downloaded images (L1TP) were radiometrically and atmospherically corrected by incorporating ground control points and a digital elevation model (DEM) for topographic displacement. Composite of the images has been produced for further interpretation. After that, mosaicking and sub-setting of the study area was done with the shape files of the pourashavas of Rangpur division using ERDAS Imagine 14 Software. Here in this study, an approach was taken to prepare the land cover by using supervised classification method. Supervised image classification is the process by which each image in a dataset is identified by using of labeled training samples based on authors' prior knowledge of the study area. The training sample was prepared by the producer by identifying and assigning pixel with similar spectral characteristics into unique groups using their visual characteristics. After preparing the training sample maximum likelihood classification algorithm was adopted to cluster the pixels in assigned classes. The entire study area was classified into five major classes (Table 2).

Table 2: Supervised (LULC) classes

Class	Description	Color
Water Body	All water bodies including freshwater lakes, rivers and streams.	
Built up	Includes all residential, commercial and industrial development features.	
Bare Lands	Lands with very little or no cover.	
Agricultural Land	Open lands having sparse vegetation cover including grass and agriculture.	
Vegetation Cover	All dense vegetation types including trees, shrubs, forests etc.	

Land Surface Temperature and Urban Heat Island Mapping

One of the aims of this study is to monitor land surface temperature (LST) and urban heat islands (UHI) of the district towns of Rangpur division in Bangladesh. Thermal bands of Landsat TM/TIRS sensor are used for the retrieval of the LST. The LST is considered as the skin temperature of the ground. LST depends on the albedo, the areal coverage of vegetation and the amount of soil moisture (Buchhorn et al., 2020). LST is usually a combination of vegetation and bare soil temperatures (Weng & Schubring, 2004). Because both react quickly to changes in incoming solar radiation caused by cloud cover and aerosol load alterations, as well as diurnal

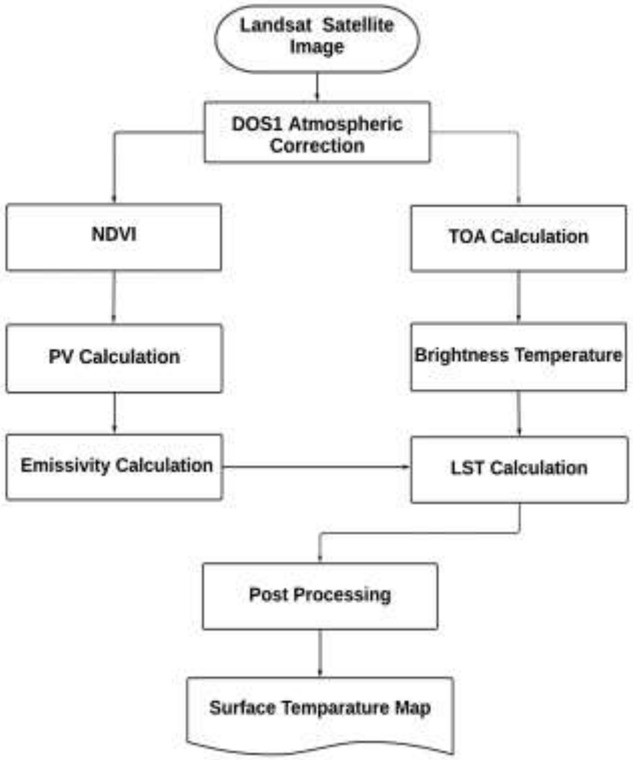

Figure 2: Steps involved in LST calculation

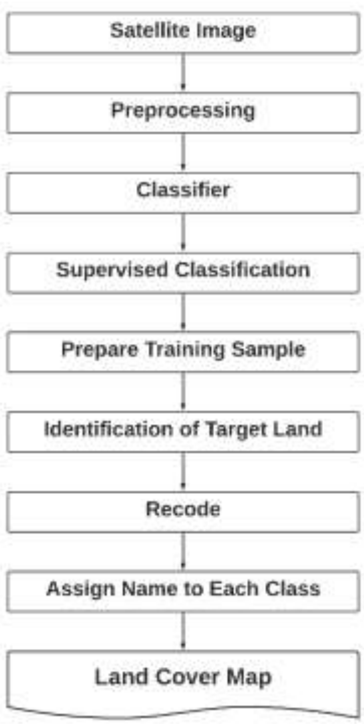

Figure 3: Steps involved in LULC classification

fluctuations in illumination, the LST exhibits rapid variations as well. As a result, the LST has an impact on the energy partitioning between the ground and vegetation, as well as the temperature of the surface air (Jensen, 2009). There are several steps to retrieve LST which are given as the flow chart in figure 3. First, the digital number representation of the signals received in the thermal sensors on board is converted to top of atmosphere radiance (***L$_\lambda$***) in W/ (m^2 *ster* μm) using the metadata with the images after applying the formula noted in the handbook of Landsat 5/8 data user. Then, Eq. 5 was used to convert the top of atmospheric radiance measurements to at-satellite brightness temperature (Zanter, 2016).

$$T_\lambda = \frac{K_2}{ln(\frac{K_1}{L_\lambda+1})} - 273.15 \quad \text{------------------(5)}$$

Where, ***T$_\lambda$***= at-satellite brightness temperature in °C, **L$_\lambda$** = at- satellite radiance in W/ (m^2 *ster* μm), K1 and K2 are prelaunch calibration constants and are given in the metadata file. The temperature calculated here is not the actual LST.

The ground true LST were retrieved using the following formula (Artis & Carnahan, 1982)

$$LST = \frac{T_\lambda}{1 + \left(\frac{\lambda * T_\lambda}{\rho}\right) lne} \quad \text{------------------(6)}$$

Where, ***T$_\lambda$*** = at-satellite brightness temperature in °C, ***λ*** = wave- length of emitted radiance in μm, ***ρ*** = h*c/j (1.438x10^{-2}mK), **j** = Boltzmann con- stant (1.38x10^{-23}J / K), **h** = Planck's constant (6.626x10^{-34}Js), **c** = velocity of light (2.998x108m/s), **e** = emissivity of land surface.

Here, NDVI based emissivity method was applied to retrieve land surface emissivity of the ground surface using the following equation

$$e = 0.004Pv + 0.986 \quad \text{------------------ (7)}$$

Where, Pv is the vegetation proportion which is calculated by Eq. 8 (Carlson et al., 1997)

$$Pv = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2 \quad \text{------------------(8)}$$

Where, normalized difference vegetation index (NDVI) is used to evaluate the content of vegetation present in an area. The at-satellite reflectance of NIR and Red band are used to construct NDVI image using the Eq.9

$$NDVI = (R_{NIR} - R_{Red})/(R_{NIR} + R_{Red}) \quad \text{-------- (9)}$$

Finally, the UHIs for each District towns were identified using retrieved LST, where the UHIs are showed higher values of LST than the background LST.

Ground data collection is important for the validation of the data acquired from the image processing. A field work has been conducted from 22rd January, 2021 to 30th January, 2021 for the collection of ground data over the study area. Several ground observations points have been selected for field measurements with a view to validate the LULC types and LST obtained by image processing. Some factors such as land cover type, temperature extremity, accessibility etc. have been considered while selecting the observation points. Over the eight Districts of Rangpur division, a total of 80 points have been selected for ground truth data collection of LULC of which

LST data were collected at 49 points. LST could not be measured in all the observation points where LULC types were collected due to the impervious ground surface.

Results

Landuse-Landcover Mapping

The supervised image classification technique has been used to categorize the study areas into five distinct land cover classes as water body, built up areas, barren land, agricultural land, and vegetation. The training sample was prepared and maximum likelihood classification algorithm has been adopted afterwhile. The areas covered by individual LULC classes were calculated for the years of 1991, 2001, 2011, and 2021 to identify and evaluate the spatio-temporal dynamics in LULC and depicted in maps for each district town of Rangpur division (Figure 4). The accuracy of the classified images was assessed by creating random points using the data management tools of ArcGIS 10.3 and the historical images of Google Earth Pro (Table 3).

Table 3: Accuracy assessment summary statistics for LULC in this study

LULC Type	Referenced Total	Classified Total	Number Correct	Producer's Accuracy (%)
Water Body	50	52	43	86.00
Built up	35	38	31	88.07
Bare Lands	15	16	13	86.46
Agricultural Lands	20	21	17	85.00
Vegetation	9	10	8	88.81
Totals	129	137	127	86.25

The Panchagar Pourashava is the most underdeveloped district town of Rangpur division in terms of urbanization considering the coverage of built-up area over total area of the pourashava (around 20%). The total area of the pourashava is also relatively small about 1152 ha (Figure 4). During the year of 1991, only 81.36 ha land was under built up area. Now in 2021, it became 234.45 ha (Figure 5). During the study period of 1991-2021, the built-up area has an increase of 188.16%. And yet the level (20%) of urbanization is very low here. The bare land of this town has increased by 100.15% from 115.92 ha in 1991 to 232.02 ha in 2021 whereas agricultural land has been decreased from 817.2 ha to 319.59 ha during the same time period (1991-2021). This scenario signifies that the amount of fallow land has been increasing in this town and people are unwilling to do agriculture. The vegetation cover has increased from the year of 1991 to 2001 by 158.22 ha (Figure 5). In 2011, it further increased and became 337.05 ha. In the following years, the vegetation cover shows a little decrease trend. Water body area of this town has increased slowly from about20 ha in 1991 to 36 ha in 2021 resulting from the widening of its rivers. The water body has increased by nearly 16 ha during the study period.

The Thakurgaon Pourashava is the district town of Thakurgaon. Considerable increase in the level (35%) of urbanization has taken place in this town over the last 30 years (Figure 4 & 5). During the study period, the built-up area has increased by 98.41%. The total built up area was 441.63 ha, 726.48 ha, 923.4 ha, and 876.24 ha in the year of 1991, 2001, 2011, and 2021 respectively. From the year of 1991 to 2011, the bare land remained almost unchanged (1367 ha). But from the year of 2011 to 2021, it has decreased drastically and became only 556.29 ha. This positive change is because of the increase in agricultural practice. During the year of 1991, 1030 ha land was under cultivation. But this has decreased and continued decreasing till 2011. From the year of 1991 to 2011, agricultural land has decreased by 68.78%. In 2021, it has increased by 1299.69 ha. The total vegetation cover has also increased from the year of 1991 to 2011 by 217.62 ha, and then, remained almost unchanged. The water body area of this town is very low and shows a seasonal change.

The Dinajpur Pourashava is a district town of Dinajpur District. Changes in LULC are prominent in this pourashava during the study period (Figure 4). Decrease in the bare land and increase in built up area is the general scenario of this District town (Figure 5). The total built up area was 437.49 ha, 609.3 ha, 519.84 ha, and 716.31 ha in the year of 1991, 2001, 2011, and 2021 respectively. From 1991 to 2001, the built-up area has increased by 63.37%, mostly, replacing the bare land. Firstly, the bare land shows a decreasing pattern from the year of 1991 to 2011, and then, again increased from the year of 2011 to 2021. A decrease of the bare land of about 309.51 ha has been calculated during the study period. The agricultural land also shows both increasing and decreasing trends. This happened mainly because of the demand and price of the agro-products and irrigation facilities. Vegetation covers slightly increased of around 60 ha from 480 ha to 540 ha during the year of 1991 to 2001. In the following years, the total area of vegetation cover remains unchanged. Water body area is the most static land cover type except slight yearly fluctuation.

The built-up area of Nilphamari Pourashava has been characterized by very little change during the time period of 1991-2011 (Figure 4). But, from the year of 2011 to 2021, this land use type shows a sharp increase; increased by 182.61 ha resulting from contemporary urban sprawl process. The total area of the bare land fluctuates over periods. From the year of 1991 to 2001, the bare land area increased from 272.52 ha to 483.75 ha (Figure 5). Afterward, the bare land area decreased sharply and then remained almost unchanged. The agricultural land of this area decreased sharply over time. The total reduction of agricultural land from the year of 1991 to 2021 is 559.8 ha and the reduction percentage is 78.1%. Figure 4 shows that these agricultural lands were converted into vegetation cover. Hence, the vegetation cover area has increased over time. During the year of 1991, 636.93 ha area was covered with vegetation. In 2001, it became 791.01 ha. In 2011, vegetation covers further increased by 265.41 ha and became 1056.42 ha. After that, vegetation cover shows a slight decrease by 7.43%. Water body area shows a visual relationship with bare land area. An inverse relationship between this two land cover types is either for water logging, or due to seasonal variation.

Rangpur, the divisional city of Rangpur division, experiences considerable changes in LULC from 1991 to 2021 (Figure 4). During the year of 1991, only 718.83 ha was covered with built up areas (Figure 5). In 2021, it became 1635.75 ha. An increase of built-up area by 127.56% has been well detected from the year of 1991 to 2021 as a result of unprecedented land conversion. The total area covered with bare land was 1092.15 ha in 1991. In 2001, it decreased by 4.5% and became 1043.01 ha. During the time period from 2001 to 2011, the bare land decreased by highest 35.65%. The total reduction of bare land areas from the year of 1991 to 2021 is 560.16 ha (by 51.29%). The agricultural land shows a total decrease by 50.44% resulting from urban sprawl and new pond digging for fisheries. The agricultural land covered 1373.85 ha, 826.02 ha, 917.37 ha, and 680.85 ha in the year of 1991, 2001, 2011, and 2021 respectively. The vegetation cover has increased by 643.77 ha from the year of 1991 to 2001 due to a tree plantation program of the Govt. in the both sides of the roads and awareness raised from social movements regarding green spaces. Afterward, the vegetation cover started decreasing and decreased 353.97 ha from 2001 to 2021. This is a visible indication of the importance of social movements for raising awareness. The water body of Rangpur city shows an increase of about 44.46 ha during the study period. This is because some people converted agricultural lands into new ponds for fisheries in the peri-urban areas.

The LULC dynamics of Gaibandha Pourashava is mainly determined by the agricultural activity of the inhabitants and water logging. Changes in the built-up area describe that the infrastructure development works are very slowly here (Figure 4). The Gaibandha Pourashava, the district town of Gaibandha, is still underdeveloped, and fails to attract migrants to live there. An increase of built-up area of about 185.76 ha took place during the 30-year study period (Figure 5). The total area of the bare land has been controlled by the agricultural land. In 1991, the area of bare land and agricultural land was 642.6 ha and 555.48 ha. While, in 2001, bare land was only 87.21 ha and agricultural land was maximum 865.89 ha. In 2011, the bare land again increased to 475.56 ha but agricultural land decreased to only 103.77 ha. This is, may be, due to water logging or other water related phenomenon. The vegetation cover of Gaibandha Pourashava shows gradual increase. The total area of vegetation cover is 171.63 ha, 503.91 ha, 644.04 ha, and 706.23 ha respectively in the year of 1991, 2001, 2011, and 2021. The vegetation cover has increased at an average rate of 10.38 ha/yr. during the study period. Water body area was 150.57 ha in 1991. In 2001, it decreased by 46.62 ha and became 103.95 ha. Then, in 2011, the water body again increased and became 222.66 ha. After that, the water body decreased to 38.88 ha in 2021. The depicted scenario indicates the water logging related problems of Gaibandha Pourashava.

Change in landuse-landcover has been prominent in Lalmonirhat Pourashava (Figure 4). Here, built-up area shows a gradual increasing pattern. During the year of 1991, only 416.61 ha area was covered by this land use type (Figure 5). In 2021, it became 677.79 ha. An increase of built-up area by 62.69% has been observed from the year of 1991 to 2021. The bare land has decreased slowly during the study period. The total area of the bare land was 229.14 ha, 196.47 ha, 170.64 ha, and 165.69 ha in the year of 1991, 2001, 2011, and 2021 respectively. Undulating change has taken place in agricultural land. The area of agricultural land has increased from the year of 1991 to 2001, and then, decreased from the year of 2001 to 2011. From the year of 2011 to 2021, agricultural land has further decreased by 161.46 ha. In 1991, the vegetation cover was 658.17 ha. In 2001, it increased by 13.14 ha and became 671.31 ha. Afterward, vegetation cover decreased sharply from 671.31 ha in 2001 to 268.83 ha in 2021. The total reduction of vegetation cover from the year of 1991 to 2021 is 389.34 ha and the percentage is 59.15. The water body area was almost unchanged during 1991 and 2001. Then the total water body area has increased dramatically replacing the vegetation cover resulting from water logging.

The dynamics of LULC in Kurigram Pourashava shows the similar characteristics as Gaibandha Pourashava (Figure 4) where the built-up areas are shows a little increase by 10.05 ha/yr. the total area of water body, bare land, and agricultural land are interchanging and interlinked. Figure 5 shows that, during the period of 2011 to 2021, built up area jumped from 686.25 ha to 900.27 ha. This sharp increase in built up area signifies the accelerated scenario of the industrialization in the urban and peri-urban areas. Here, bare land area has shown an increasing trend from the year of 1991 to 2021. In 1991, 2001, 2011, and 2021, the total area of bare land was 252.09 ha, 350.46 ha, 438.12 ha, and 478.44 ha respectively. An inverse scenario has been seen in the changing pattern of agricultural land. The agricultural land has decreased from 771.3 ha, in the year of 1991, to 271.08 ha, in the year of 2021 (BBS, 2011). Moreover, every year flash flood causes huge destruction of crops and people has to count loss in agricultural properties. Accordingly, the total amount of fallow land has been increasing there. Vegetation cover of Kurigram Pourashava shows a static characteristic, although, a very little increase by 0.77% per year has taken place during the study period. The water body of Kurigram Pourashava has decreased considerably from the year of 1991 to 2001 resulting from outward migration of Brahmaputra River. Afterward, the water body area of the pourashava remained static except seasonal variation.

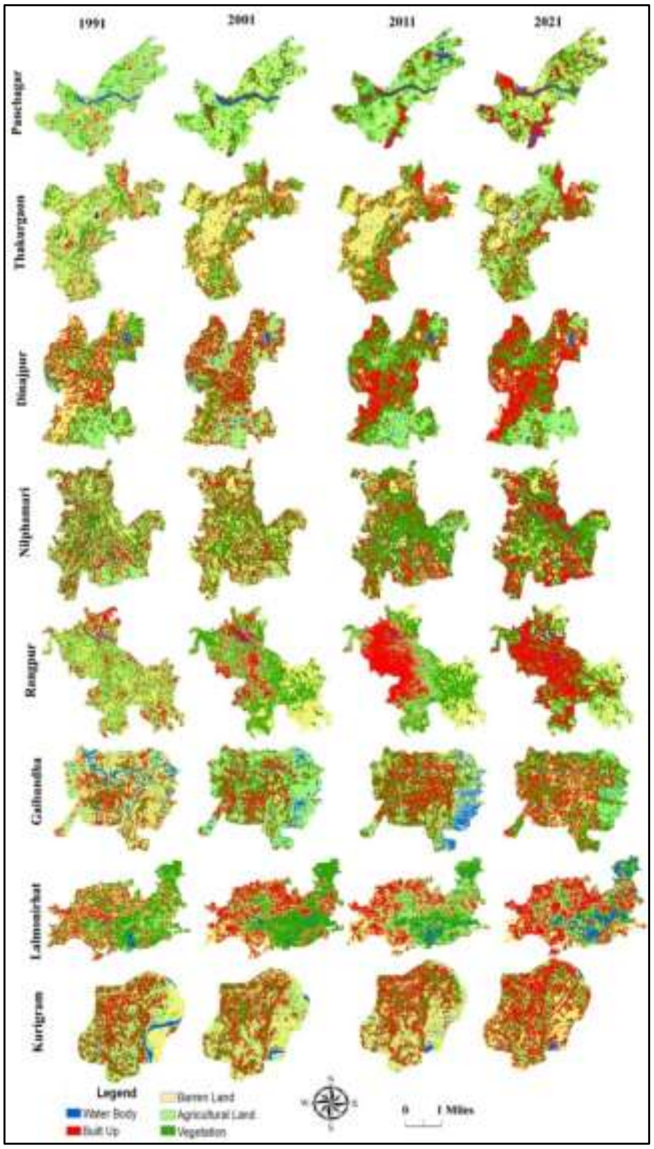

Figure 4: Spatio-temporal distribution of landuse-landcover of eight District towns (Pourashava) within the Rangpur division from 1991 to 2021

Land Surface Temperature (LST) and Urban Heat Island (UHI)

The spatial distribution of the LST of the eight pourashavas (district towns) of Rangpur division has been retrieved with mono window algorithm using Landsat images of the year of 1991, 2001, 2011, and 2021 (Figure 6). The UHIs were observed and identified based on the extracted LST.

The maximum, minimum, and average temperature of Panchagar Pourashava shows undulating characteristics during the study period (Figure 7). In 1991, the maximum, minimum, and average temperature was 17.93°C, 13.78°C, and 15.04°C respectively. In 2001, both the maximum and minimum temperature have increased from that of in 1991. The highest maximum temperature was 23.68°C, observed in 2001 while the lowest minimum temperature was 12.84°C, observed in 2021. The average temperature was found minimum in the year of 1991, 15.04°C. The temperature ranges of the observed UHIs were 16-17.93°C in the year of 1991 (Figure 6). More heat islands were detected in the year of 2001 on the same areas. The temperature range of the observed UHIs has increased and became 20-23.68°C in 2001. In 2011, the number of heat islands have further increased and discrete all over the town. The UHI phenomenon was well detected in the year of 2021. During this year, the observed UHIs' area coverage has increased dramatically. On the riverbanks and surrounding the pourasavha, the heat islands have expanded at a considerable amount and become larger. In 2021, the observed HIs had a temperature range of 16-17.52°C.

The highest and the lowest minimum temperatures observed in Thakurgaon Pourashava were 16.36°Cand 14.24°C respectively in 2021 and 1991 (Figure 7). Likewise, the highest and lowest maximum temperatures were 22.82°C in 2011 and 17.47°C in 1991 respectively. The average temperature has firstly, increased and then, decreased over time (Figure 7). In 2021, the average temperature was 17.60°C. In 1991, few UHIs were observed in the southern part of the town with the temperature range of 16-17.47°C (Figure 6). The UHIs have increased in number and formed all over the town in 2001 with the temperature range of about 18-21.06°C. The area of UHIs have increased and intensified in 2011 but the intensity of temperature remained same as 2001. The UHIs have become less extensive in 2021 with the temperature range of 19-20.40°C. In the year of 2021, multiple heat islands were well identified in the bare land and settlement of Thakurgaon Pourasavha area.

The average land surface temperature of Dinajpur Pourashava has increased over time (Figure 7). The average LST was about 15.77°C in the year of 1991. In 2001, it became 18.60°C. The average temperature further increased to 19.32°C in 2011. The LST of Dinajpur Pourashava has increased in terms of both minimum as well as maximum temperature. Maximum temperature 23.25°C was observed in 2001 while minimum temperature 14.24°C was observed in the year of 1991 and 2021. The highest average temperature 19.32°C was in 2011. And, the lowest average temperature, 15.77°C was founded in 1991. The number and area of UHIs have increased from 1991 to 2001 (Figure 6). In 2011, UHIs were observed with a temperature ranging from 17.5°C- 22.82°C. Few heat islands with greater area were observed in the southern part of the town in 2021.

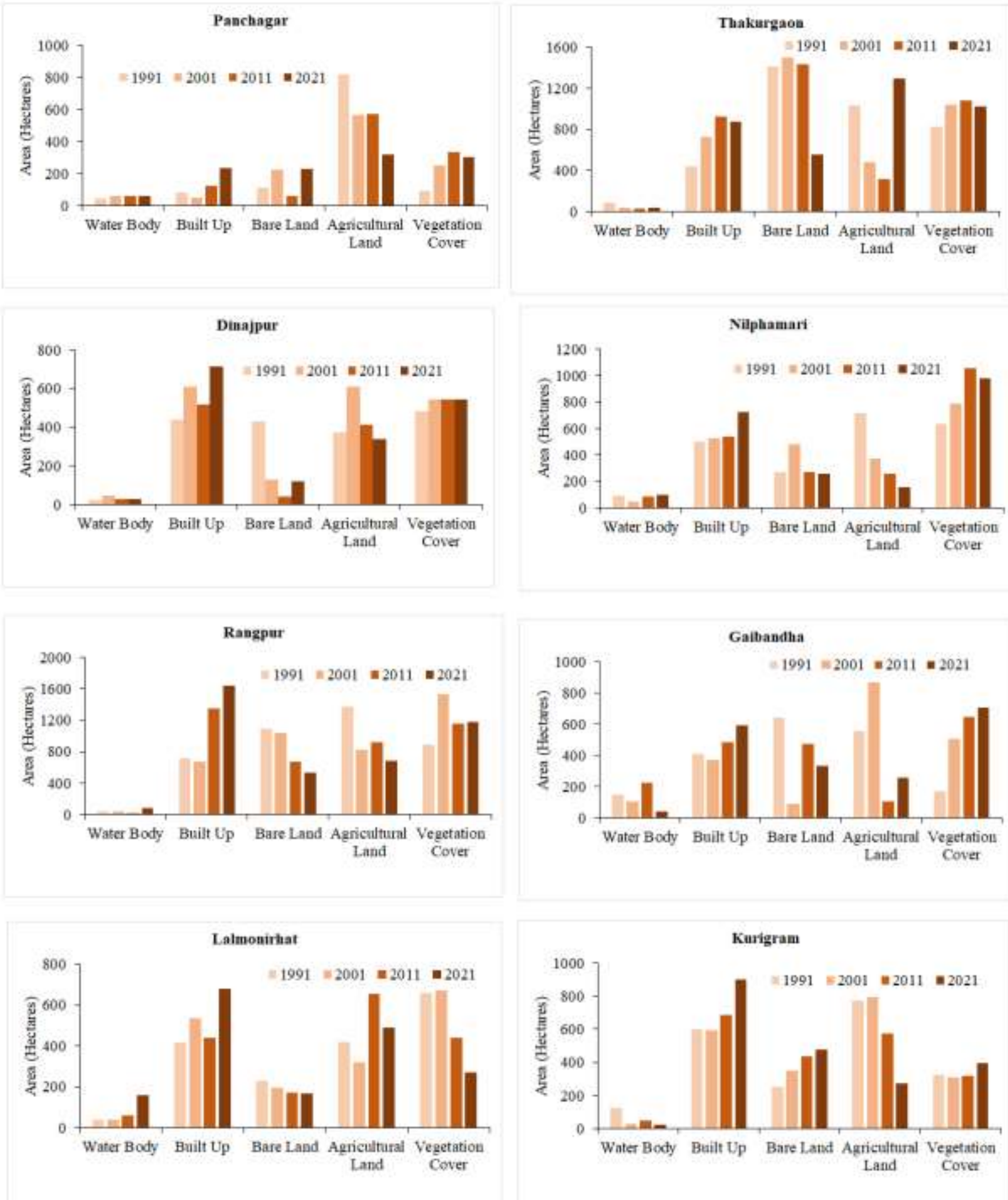

Figure 5: Comparison of LULC types within the eight District towns (Pourashava) of Rangpur division from 1991 to 2021

The maximum, minimum, and average temperature of Nilphamari Pourashava shows little fluctuations during the study period (Figure 7). In 1991, the maximum, minimum, and average temperature was 20.62°C, 17.47°C, and 18.73°C respectively. In 2001, both the maximum and minimum temperature decreased from that of in 1991. The highest maximum temperature was 21.43°C, observed in 2021. And, the lowest minimum temperature was 13.31°C, observed in 2011. The average temperature was found minimum in the year of 2011, 14.42°C. In 1991, several UHIs were found in the whole northern and eastern region with the temperature range of 18-20.62°C. In 2001, the number and area of UHIs were increased with temperature ranging from 19-17.93°C. Urban heat islands in 2011 showed the similar characteristics as 2001. Few large

UHIs were observed in the north-western region of the town in 2021.

The Rangpur Pourashava is the divisional city of Rangpur division comprising an area of about 32623.92 hectares. The spatio-temporal distributions of LST and UHI of Rangpur city were retrieved and found a significant change of those from 1991 to 2021 (Figure 6). The maximum, minimum, and average temperature of this city varies largely over the study period. During the year of 1991, maximum and minimum temperature retrieved was 19.28°C and 9.95°C (Figure 7). In 2001, the maximum temperature has decreased and became 18.38°C, while, the minimum temperature has increased to 14.24°C. This decreasing trend was continued up to 2011, when the maximum temperature was 16.56°C and minimum temperature was 13.31. From the year of 2011 to 2021 the maximum temperature was increased by 2.72°C and minimum temperature has decreased by 3.36°C. Though the average temperature of this area remained almost unchanged over the 30-year study period, the difference between the maximum and minimum temperature has been increasing after 2001. In 1991, a large heat island was observed in the south-eastern region of the pourashava with the temperature range of 16-19.28°C (Figure 6). During the year of 2001, several heat islands were found in the south-western region. Heat islands were observed discrete in the year of 2011 over the central and eastern region. In 2021, some large and severe heat islands were found in the south-eastern part (Figure 6).

During the year of 1991, the Gaibandha Pourashava might have experienced extreme cold temperature. Therefore, in this year, we obtained the minimum and maximum temperature only 2.25°C and 10.92°C respectively in this study (Figure 7). The average temperature was 4.87°C. The southern and eastern part of the city was relatively warmer, but no heat island was observed (Figure 6). In 2001, both the minimum and maximum temperature was high enough to formulate heat island. The minimum, maximum, and average temperature were 15.18°C, 19.28°C, and 16.83°C respectively in the year of 2001. A number of small heat islands were observed all over the town. The difference between the minimum and maximum temperature has decreased in the year of 2011. Some prominent and well identifiable heat islands were found in this year. Observation of LST in the year of 2021 shows heat islands in the eastern part of the town (Figure 6). The highest average temperature was observed in this year. The analysis of LST shows that both the minimum and maximum temperature has increased with time in this town.

In Lalmonirhat town, the maximum temperature was 21.06°C and the minimum temperature was 14.24°C at 1991. The average temperature observed in this town is 17.67°C, 15.60°C, 15.28°C, and 17.21°C in the year of 1991, 2001, 2011, and 2021 respectively (Figure 7). The highest maximum temperature was observed in 1991, 21.06°C and the lowest minimum temperature was found in 2011, 9.47°C. The difference between the maximum and minimum temperature was highest in 2011, 8.46°C. In the images of 1991, a large urban heat island was observed in the central region, temperature ranging from 18°C-21.06°C. Many discrete UHIs were observed in the year of 2001. Growth of UHIs in the western part of the town was more in number (Figure 6). In 2011, two extended HIs and many smaller UHIs were observed. In 2021, multiple heat islands were identified in the urban areas of the Lalmonirhat Pourashava (Figure 6).

The highest and the lowest minimum temperature observed in the Kurigram Pourashava was 14.71°C at 2001 and 4.11°C at 2021 (Figure 7). Likewise, highest and lowest maximum temperature was 20.18°C in 2011 and 18.66°C in 2021. The average temperature has decreased over time. In 2021, the average temperature was only 9.06°C. In 1991, several heat islands were identified on the char lands of the Brahmaputra and Dharla rivers with the temperature range of 16-18.83°C (Figure 6).

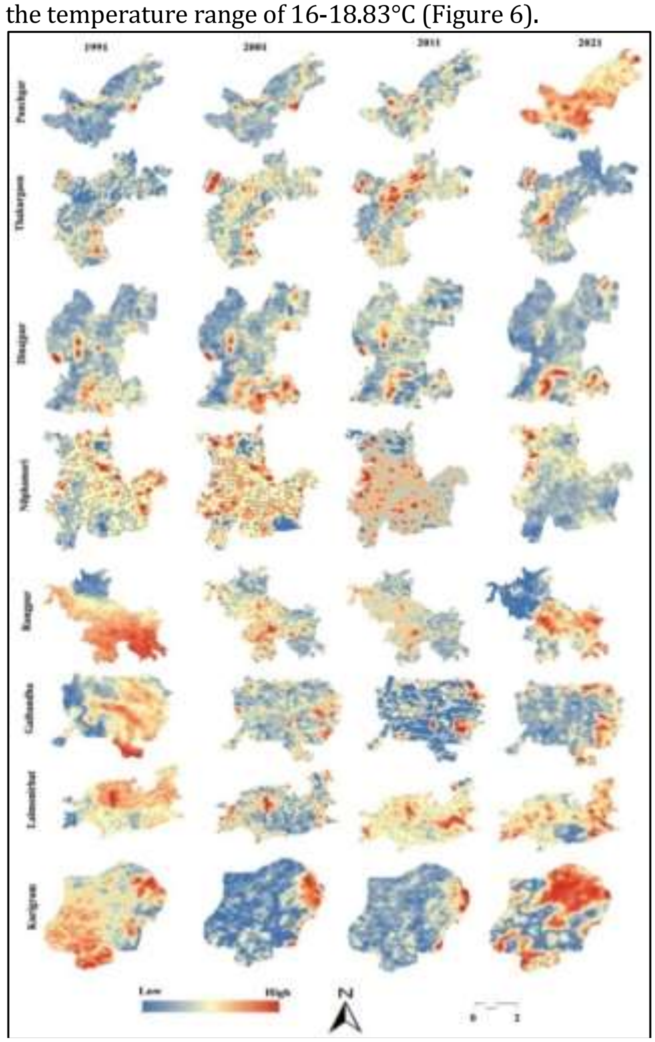

Figure 6: Spatio-temporal distribution of LST and UHI of the eight District towns of Rangpur division from 1991 to 2021

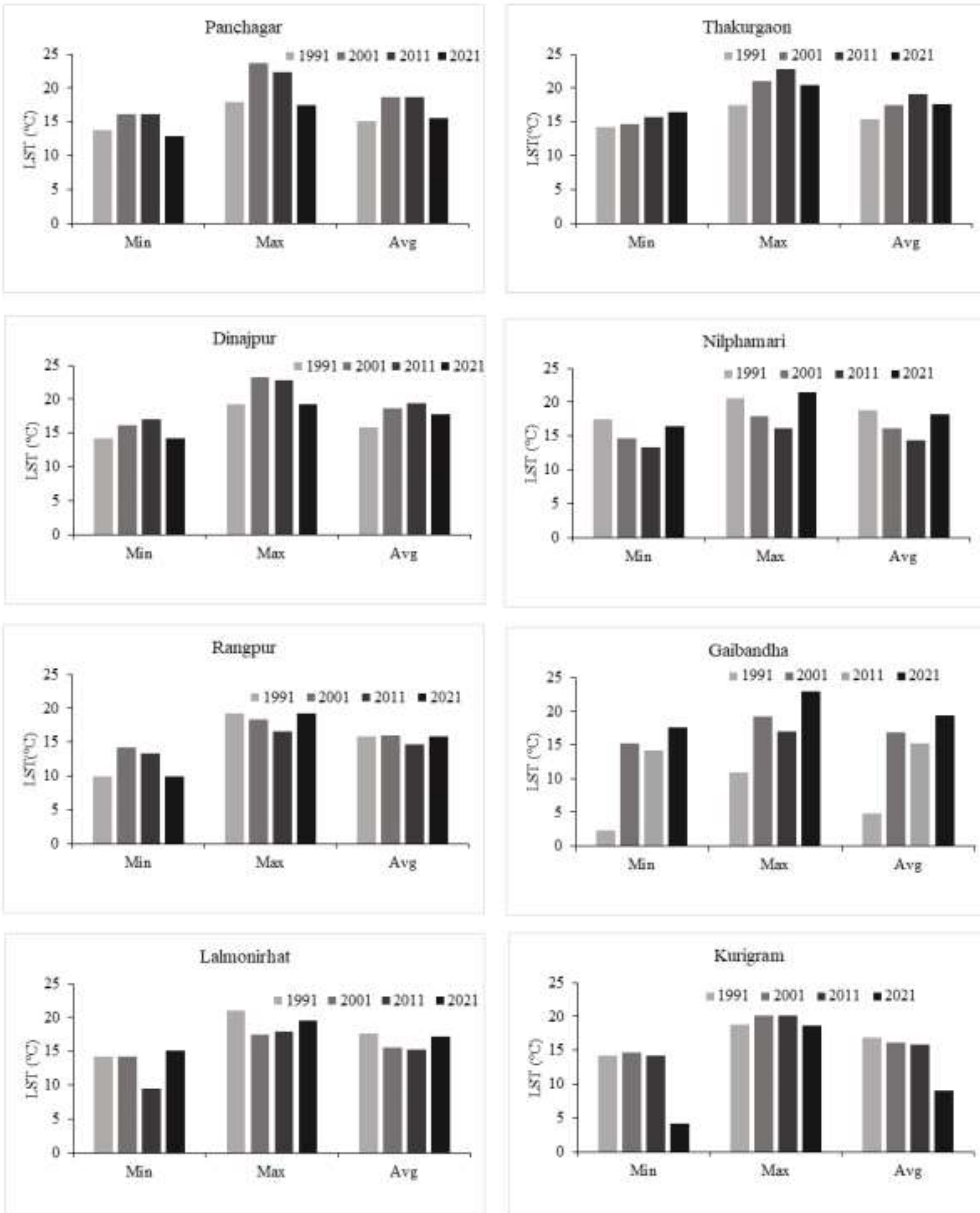

Figure 7: Comparison of LST (minimum, maximum, average) of eight District towns of Rangpur division from 1991 to 2021

The heat islands on the river charlands seemed to be broader in 2001 with the temperature range of about 16-20.17°C. The area of UHIs have decreased in 2001 but the intensity of temperature remained same as 2001. The heat islands have become more extensive in 2021 with the temperature range of 16-20.18°C. In 2021, several heat islands were well identified in the bare land and settlement of the Kurigram Pourashava area (Figure 6).

The image processed LST for the year of 2021 was compared with the 37-ground observed LST (Table 2) which exhibited quite similar trend in the majority of the observation points (Figure 8). Ground truth data for LST measurement was collected for the observation of in situ points, whereas the image processed LST takes into consideration the average LST of the pixel (30m x 30m) around the ground observation points. This is the probable reason of variations of LST in the observation points between field and image-based results.

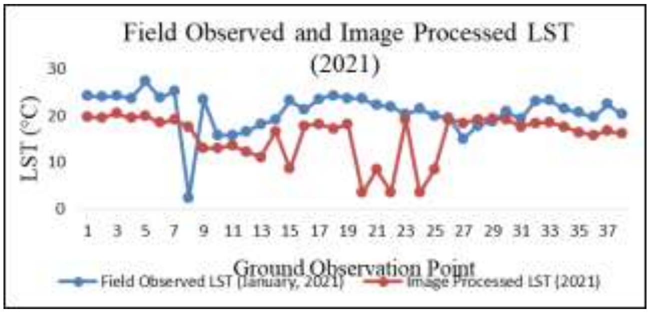

Figure 8: Comparison chart of the field observed and image processed LST of year 2021 within the study area

Discussion

The dynamics of LULC types of the District towns of Rangpur division were compared in percentage in this study between 1991 and 2021 (Figure 9). The results showed that the built-up areas were increased more about 10-15% of the total study areas for each district from 1991 to 2021 (Figure 5). Vegetation covers were also increased in most of the districts except Lalmonirhat. On the other hand, bare and agricultural lands were reduced mostly all District towns except in two Districts such as Panchgar and Kurigram for bared land and Thakurgaon and Lalmonirhat for agricultural land increased. Water bodies were also changed but a little bit in all of the District towns of Rangpur division (Figure 9).

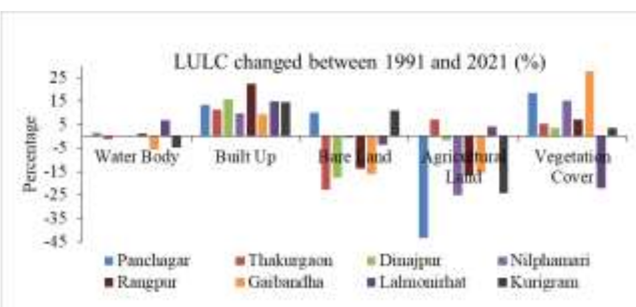

Figure 9: Changes of LULC between 1991 and 2021 in eight District towns of Rangpur division. Positive (%) indicates increased and negative (%) means reduced LULCs

The spatio-temporal distribution of LULC types can be correlated well with the retrieved LST and UHIs of the study areas from 1991 to 2021 (Figure 4 & Figure 6). Majority of the cooler temperatures has been observed in the water bodies and places with healthy vegetation. On the other hand, bare lands and settlement areas display maximum temperature throughout the study period. The impermeable surfaces of the urban structures as well as the sand bars along the rivers display greater LST as well as UHIs. More storage and emission of heat tend to occur in the dense urban structures or in the sand filled areas of the river charlands or bare lands than any other LULC types observed. As a result, impermeable surfaces with higher LST are created and heat islands are formed. In addition, the rapidly decreasing water bodies and forest land are responsible for the reduction of lower temperature zones. The sand-filled river chars or bare terrain left by dried river channels tends to increase higher temperature zones. Increased LST is also aided by intensive agricultural land cultivation. Rapid expansion of the settlement area showed unplanned urbanization, which is accompanied with an increase in the number of urban structures, including buildings, roads, and metallic roofs, among other things. All of these aforementioned places create impermeable surfaces with greater storage and emission capabilities which result in UHI formation conjunctively. Among the year of 1991, 2001, 2011 and 2021, such changes have been observed most significantly.

Conclusion

The rapidly changing land use-land cover (LULC) of the study area correlates quite well with the increasing land surface temperature (LST) and development of urban heat islands. The unplanned urbanization trend and agricultural expansion in order to accommodate and feed the fast-growing population have resulted in huge loss of water bodies, vegetation and bare lands in the District towns of Rangpur division. The overall understanding of LULC change and its keen relationship with LST and UHI formation can be extremely useful in addressing the land management issues and environmental sustainability concerns. No other research initiative for LULC, LST and UHI mapping of the study areas has been taken so far using multi-spectral satellite images. The course of the major rivers flowing over the study area has become much narrower and most of the visible wetlands have been lost in the recent years. Retrieved LST has been used to identify and observe the HIs. UHIs are areas where the land surface temperature is greater than study areas' background temperature.

The correlation of LULC, LST and HI results reveal that the changing land cover is the main reason behind the increasing land surface temperature and HI growth. The lower temperature zones are detected in the water bodies, forest and agricultural lands. On the other hand, higher temperature zones are found in the bare lands or in the river chars and dense settlement or highly urbanized areas around the District towns. The dense settlement or urban structures and sand filled areas of the river chars tend to store and emit more heat than the other LULC types by creating impermeable surfaces and result in higher LST and development of heat islands. The ground truth data of LULC and LST are found to correlate well with the image processed results with few exceptions. The study has been quite effective in evaluating the spatio-temporal variation of land covers and to correlate it with land surface temperature and heat island formation in the study area with the use of multi-spectral satellite images. The vulnerable zones of the study area with rapidly changing land cover dynamics and increasing LST could be identified by taking this study as a reference. This could assist in further mapping and planning for urbanization in and around the study area preventing rapid unplanned urban area expansion that threatens environmental sustainability.

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