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# Changes in Land Use and Land Cover, Normalized Difference Vegetation Index and Land Surface Temperature in the Narsingdi District During 2001 to 2021

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**Abstract**

Rapid urbanization and industrialization cause land use changes, reduce green spaces, and increase the land surface temperature. Green spaces of a city area maintain environmental quality by absorbing air pollutants and reducing land surface temperature. The present study aimed to detect the changes in land use and land cover (LULC), normalized difference vegetation index (NDVI), and land surface temperature (LST) in the Narsingdi district including six Upazilas from 2001 to 2021. The Landsat 7- Enhanced Thematic Mapper Plus (ETM+), the Landsat 8- Operational Land Imager (OLI) imageries and the Moderate Resolution Imaging Spectroradiometer (MODIS) data were used to analyze the LULC, NDVI, and LST by using Google Earth Engine (GEE) and ArcGIS 10.8.2. The images were analyzed into four land use classifications – agricultural land, built-up area, forest vegetation, and water body. Among all the Upazilas, Narsingdi Sadar was the vulnerable area, where agricultural land, forest coverage, and water body decreased significantly by 6.67%, 2.2%, and 4.66%, respectively. The built-up area increased by a considerable amount of 13.53% during the last twenty years. The forest coverage of Narsingdi Sadar Upazila was calculated at only 8.91% in 2021 and decreased from 11.11% in 2001. The NDVI values surprisingly increased in all the Upazilas, but in Narsingdi Sadar, it is comparatively low (0.08) than in other Upazilas. The increasing trend in LST in the Narsingdi Sadar Upazila is alarming, 1.14$^{o}$C from 2001 to 2021 (0.57$^{o}$C/decade). The significant changes in LULC, NDVI, and LST made the Narsingdi Sadar a more critical area in the Narsingdi district. The findings of the study will be helpful to policymakers in making appropriate decisions in future city development.

**Keywords:** Heat Island, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI).

## Introduction

The primary drivers of the fast transformation of land use and land cover (LULC) on the surface of the world are social, economic, and political considerations (Ojima *et al.,* 1994). In order to increase sustainable environmental management (healthy ecosystem functioning) or reverse cultural land degradation, the LULC transformation necessitates greater attention of land, forest, and water management (Quintas-Soriano *et al.,* 2016). The LULC change detection has a great deal of relevance for decision making on disaster risk mitigation and adaptation to climate change because of the amazing remote urban growth, spread of human settlement, and impact on the land surface (Banba and Shaw 2017). The regional climate is changing as naturally vegetated surfaces become

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impermeable builtup surfaces (Argüeso *et al.,* 2013). Urbanization, which is characterized by impermeable built-up surfaces, is the process of replacing natural surfaces with various man-made structures, including commercial and residential buildings, highways, parking lots, and impervious surfaces (Babalola and Akinsanola 2016). The level of humidity in the air is affected by the conversion of natural surfaces to built-up regions and is correlated with atmospheric temperature (Ibrahim and Khatib 2017). The demand for housing, agricultural output, food, and shelter is rising as the world's population rises. By avoiding soil erosion, decreasing nutrient loss, and maintaining the hydrological cycle, vegetation ensures the ecosystem's viability. Thus, one of the significant indications of environmental vulnerability has been the shift in land cover (Nzoiwu *et al.,* 2017). Changes in land cover have an impact on climate through altering the amount of carbon dioxide in the atmosphere as well as the albedo, evapotranspiration, and surface roughness of the land (Zhang and Liang 2018).

The temperature of the skin of the land is represented by the Land Surface Temperature (LST), which is obtained from solar radiation (John *et al.,* 2020). The utilization of diverse construction materials for building different infrastructures is accelerated by urbanization and industrialisation. These building materials have a high thermal conductivity that significantly affects the surface energy balance (Imran *et al.,* 2021). Additionally, as vegetation is the primary source of humidity, the amount of humidity in the air is significantly reduced when vegetated surfaces are replaced by built-up surfaces (Igun and Williams 2018). As a result, when vegetated surfaces are transformed into built-up surfaces, LST is significantly increased because to the excess heat stored in built-up surfaces and the absence of humidity in the air. Normalized Difference Vegetation Index (NDVI) is intended to enhance the study of data on vegetation obtained via remote sensing. According to the studies, NDVI is useful for identifying evergreen vs seasonal forest types, savannah, dense forest, non-forest, and agricultural fields (Pettorelli *et al.,* 2005), and to determine various vegetation properties, including biomass (Tian *et al.,* 2017), chlorophyll concentration in leaves (Pastor-Guzman *et al.,* 2015), plant productivity (Vicente-Serrano *et al.,* 2016), fractional vegetation cover (Dutrieux *et al.,* 2015), and plant stress (Cervantes-Chávez *et al.,* 2016).

Numerous studies have examined changes in Land use land cover (LULC), Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature(LST) that have been seen around the world (Abdullah *et al.,* 2019; Ahmed *et al.,* 2013; Dissanayake 2020; Jalayer *et al.,* 2022; Lin *et al.,* 2020; Naikoo *et al.,* 2020; NourEldeen *et al.,* 2020; Nzoiwu *et al.,* 2017; Ojima *et al.,* 1994; Orhan and Yakar 2016; Pastor-Guzman *et al.,* 2015; Pettorelli *et al.,* 2005; Prăvălie *et al.,* 2022; Qiao *et al.,* 2020; Yang *et al.,* 2011; Zope *et al.,* 2016). Only a small number of studies on Dhaka Metropoliton Area, Mymensing, Gazipur and Rangpur Sadar, Chittagong City Corporation, Khulna City Corporation, Rajshahi City Corporation, Coastal Area and a few other city regions in Bangladesh may be browsed independently (Abdullah *et al.,* 2019; Ahmed *et al.,* 2013; Al Rakib *et al.,* 2020; Fattah *et al.,* 2021; Gazi *et al.,* 2021; Kafy *et al.,* 2021b; Roy *et al.,* 2021; Trotter *et al.,* 2017). But no research has been done on land use land cover changes, NDVI and LST changes in Narsingdi district.

Narsingdi, a neighboring district to Dhaka, is 57 km away from Dhaka city. It belongs to a city that has a high population and vehicle density. Rapid industrialization and the ever-increasing number of vehicles make the Narsingdi industrial area a city of harmful air pollutants (Mia *et al.,* 2015; Shamsher and Abdullah 2013). Even the increasing infrastructure development activities are diminishing the green spaces in the Narsingdi year by year (*pers.comm.*). So, the green spaces in the Narsingdi district are losing their carrying capacity to absorb harmful air pollutants. As a result, it harms the health of the city dwellers of the Narsingdi district. A few pieces of research on the green spaces of cities in Bangladesh are for Dhaka city (Byomkesh *et al.,* 2012; Neema *et al.,* 2013; Rahman *et al.,* 2019). It is important to research how much has changed in land use land cover (LULC), NDVI and its impact on climate and how much temperature has changed in Narsingdi district during the last two decades. The current study used a time series analysis of Landsat and MODIS images to examine the effects of urban and industrial growth on vegetation, agriculture, and other land cover types, the Normalized Difference Vegetation Index (NDVI), and changes in land surface temperature from 2001 to 2021 in Narsingdi district. It also sought to determine the relationships between these parameters. A clear picture of the relationship between alterations in urban land use, urban greenspaces, and surface temperature across time was produced by the comparison. Rapid urbanisation weakened and destroyed the ecosystem, which contributed more to climate change. The study's findings will provide solid proof of LULC, NDVI change, and climate change in Bangladesh's Narsingdi district. The study will serve as a helpful resource for planners, legislators, residents, and researchers studying land use and climate change.

## Materials and Methods

*Research Action*

The study attempted its action in the Narsingdi district of Bangladesh. The data collection started in August 2021 and ended in June 2022. In the first three months, it conducted all of the planning process, laboratory preparation, literature review, and reconnaissance survey. It collected formal data (Acquisition of satellite imageries and shapefiles and pre-processing field observation, and data collection from the field) in November 2021. The study started analyzing the data in December 2021 and continued until May 2022.

*Selection of the Study Area*

The study selected the Narsingdi district as the study area because of the high population density, heavy traffic congestion, and the vicinity of the capital city, Dhaka. The study area is shown in Figure 1.

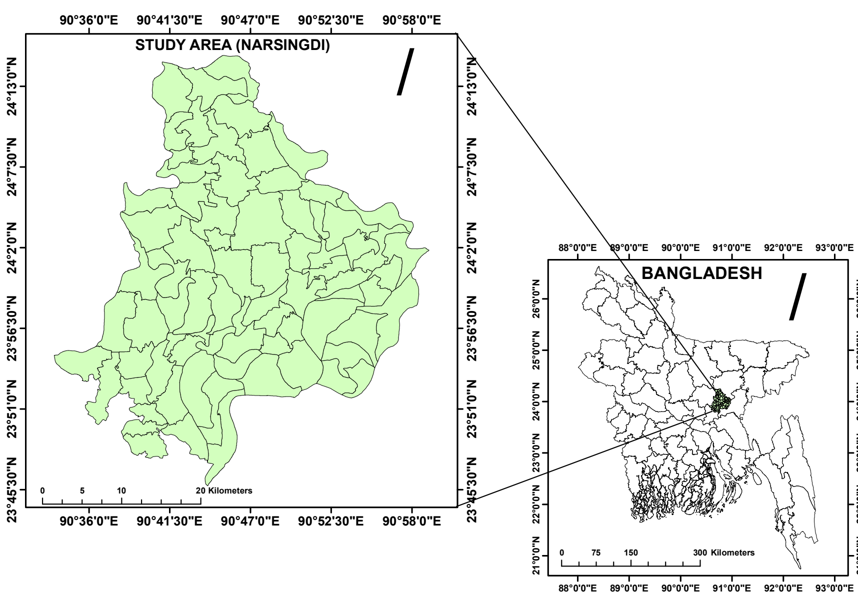



**Figure 1.** The study area (Narsingdi district) in Bangladesh.

*Description of the Study Area*

Narsingdi district is situated from the latitude N 23°46′ to N 24°14′ and from the longitude E 90°35′ to E 90°60′. Kishoregonj at the north, Brahman Baria at the East, Narayangonj and Brahman Baria at the south, and Gazipur at the Western side surround the Narsingdi district. With a total area of 3360.59 $km^2$, Narsingdi district is populated by 2224944 persons with a population density of 1,658/$km^2$ (BBS 2012). She has six Upazilas and 76 most minor local government units, including 70 Union Parishad and six Pourashova. It has 1095 villages spreading out all the local government units. She has 16731 numbers of small industries and 28 heavy industries (GoB 2021). Due to the vicinity of Dhaka city, the Narsingdi district received a huge population and vast industrialization in the meantime. The soil formation of the district is mostly floodplain and grey piedmont. She enjoys uniform temperature, high humidity, and heavy rainfall from June to October. The annual temperature range in this district extends from 12.7°C to 36°C, with an annual rainfall of 2376 mm (BBS 2012). An earlier study reported that the district had 102 tree species including 36 timber, 31 fruit, and 19 fuelwood (Miah and Hossain 2002).

## Methods

This study assessed a series of land-use transitions with associated data to identify green spaces. It used the current study's remotely sensed satellite imageries and field data to visualize the changes in LULC, NDVI, and LST over 20 years through 2001 and 2021.

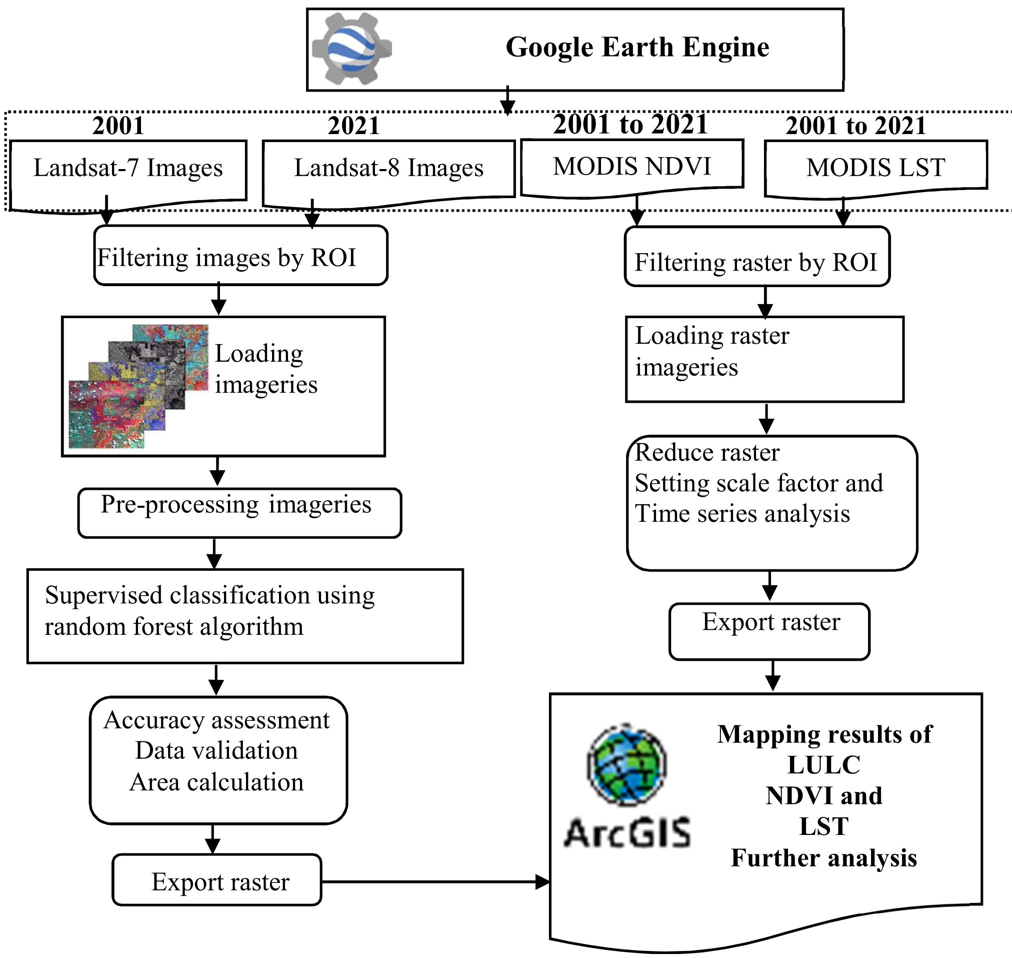



**Figure 2.** The methodological framework of the study.

The satellite imageries included the Landsat archive and the Moderate Resolution Imaging Spectroradiometer (MODIS) data. Also, it collected some ancillary data from different sources like the Forest Department, Local Government Engineering Department (LGED), Protected Planet, and the Department of Environment (DoE). Direct observation in the field was held to collect the ground truthing data. Figure 2 indicates the methodological framework of the study.

### *Obtaining satellite data and its analysis*

It collected satellite imagery from the cloud-free Landsat images of 2001 and 2021. It collected the shapefile of the Narsingdi district from www.divagis.org. It pre-processed the imageries to convert the images into a standard projection and atmospheric correction. The support vector machine supervised classification technique generated land-use change maps. Kappa and the confusion matrix analyzed the classification accuracy. After the Classification, it detected land-use changes over time and space through comparison. The output raster for LULC classification, NDVI, and LST was produced using Google Earth Engine (GEE). For LULC in 2001, the study used the Landsat 7- Enhanced Thematic Mapper Plus (ETM+) imageries. The sensing date was 2001-12-15. For LULC in 2021, the study used the Landsat 8- Operational Land Imager (OLI) imageries. The sensing time was 2021-11-28. For analyzing time series NDVI both in 2001 and 2021, and the yearly mean from 2001 to 2021, the MODIS collection, MODIS/006/MOD13A1 was used. It shows the Terra Vegetation Indices 16-Day Global 500 m resolution. For analyzing time series LST in 2001 and 2021 and the yearly mean from 2001 to 2021, the MODIS collection, MODIS/061/MOD11A2 was used. It shows the Terra Land Surface Temperature and Emissivity 8-Day Global 1km. After constructing the time series chart of NDVI and LST for both in 2001 and 2021 and from 2001 to 2021 with GEE, the year trend and trend for 20 years were visualized using excel. The correlation between LST and NDVI was done both in 2001 and 2021. A trend line was also shown for both years for comparison.

Associated with the green spaces, normalized difference vegetation index (NDVI) was calculated as a means of phenology. Again, LST calculation identified the heat islands in the Narsingdi district. The study used ArcGIS Desktop 10.8.2 to generate a detailed map of the Narsingdi district. For accuracy assessment, the study used ERDAS IMAGINE 2015. Again, ArcGIS 10.8.2 was used to identify the land-use transition. The study provided the time series and land use change maps of the Narsingdi district. Finally, the combination of land use, NDVI, and LST data identified the environmental health of the Narsingdi district. The study collected the base map of the Narsingdi district from the Narsingdi district authority. It helped the study navigate the forest areas and other tree canopies while verifying the changes in the green spaces. It used the GPS (Global Positioning System) set for ground-truthing. For statistical analysis, it used Excel 2013. Land use and land cover (LULC) classification was done using the supervised classification of the GEE, and land use transition from 2001 to 2021 was done using the sampling technique of ArcGIS. The major classification was done based on the field visits in the Narsingdi district. The classes were agricultural land, built-up area, forest vegetation, and water body. The definition of the classes are as follows:

Agricultural land: Agricultural land in this article refers to the specific land where agricultural activities are carried out. However, these agricultural lands are mainly defined as those where seasonal crops are grown, where these lands are under crops at certain times of the year and fallow at other times.

Built-up area: Built-up area in this article refers to the type of land use that defines all types of houses and other infrastructures.

Forest vegetation: In this article, forest vegetation refers to the land use that determines all vegetation other than grasses. It means trees and bamboo clumps, including some shrubs. Horticultural fruit trees are also included in this land use.

Water body: A water body is defined as any body of surface water, such as a lake, river, or pond in this article. No flood-related wetlands are included in this land use.

LULC, NDVI, and LST analysis were considered for the smallest local government unit and Upazila (sub-division) level.

**Results and Discussion**

A considerable amount of land use land cover changes were observed between 2001 and 2021. Both in 2001 and 2021, agricultural land was calculated as the highest land cover class. A significant amount of agricultural land has been converted to other land uses during the last two decades. Almost 12398.54 ha, 11680.20 ha, and 2355.55 ha of agricultural land have been transformed into built-up area, forest vegetation, and water body, respectively. The forest vegetation has also been converted into other land uses - agricultural land (7791.61 ha), built-up area (1016.48 ha), and water body (139.59 ha). Considering the converted land uses, the highest amount of land has found been converted into the built-up area (14090.32 ha) from agricultural land (12398.54 ha), forest land (1016.48 ha), and water body (675.30 ha) from 2001 to 2021. At the same time, the highest amount of agricultural land (26434.29 ha) has found been transformed into other land uses, i.e., built-up area (12398.54 ha), forest vegetation (11680.20 ha), and water body (2355.55 ha). A total of 8947.68 ha forest land has been converted into agricultural land (7791.61 ha), built-up area (1016.48 ha), and water body (139.59 ha). Table 1 clearly depicts all the transformation of land uses in the Narsingdi district from 2001 to 2021.

**Table 1.** Conversion of land use and land class from 2001 to 2021 in Narsingdi district of Bangladesh.

| | LULC | 2021 (ha) | | | | Grand Total | Total converted land (ha) to other uses (2001-2021) |
|---|---|---|---|---|---|---|---|
| | | Agricultural land | Built-up area | Forest vegetation | Water body | | |
| 2001 (ha) | Agricultural land | 50058.00 | 12398.54 | 11680.20 | 2355.55 | 76492.30 | 26434.29 |
| | Built-up area | 2105.80 | 1071.83 | 181.33 | 154.06 | 3513.01 | 2441.19 |
| | Forest vegetation | 7791.61 | 1016.48 | 14318.76 | 139.59 | 23266.44 | 8947.68 |
| | Water body | 4110.97 | 675.30 | 1563.30 | 7151.40 | 13500.97 | 6349.57 |
| | Grand Total | 64066.39 | 15162.15 | 27743.58 | 9800.60 | 116772.72 | |
| | Total converted land (ha) to other uses (2001-2021) | 14008.38 | 14090.32 | 13424.83 | 2649.2 | 14008.38 | 44172.73 |

Among the four classes, agricultural land covered more than any other classes at the smallest local government units and Upazila levels. Table 2 represents the overall land uses in different Upazilas of Narsingdi Sadar between 2001 and 2021. It was the highest in Roypura Upazila, 19982.07 ha and 16505.1 ha, in 2001 and 2021, respectively. In 2001, forest vegetation coverage was found highest in Shibpur (6046.47 ha) and lowest in Narsingdi Sadar (2440.8 ha). After twenty years, the highest forest vegetation was also recorded the highest in Shibpur (8176.68 ha) and lowest in Narsingdi Sadar (1957.59 ha) (Table 2). The highest built-up area was recorded both in 2001 and 2021 in Roypura (1438.38 ha, 5552.28 ha, respectively), whereas water body was found as the highest land cover in Roypura both in 2001 (7036.38 ha) and 2021 (4614.03 ha).

**Table 2.** Land use and land class distribution at the Upazila level in the Narsingdi district of Bangladesh.

| Upazila | 2001 (ha) | | | | 2021 (ha) | | | |
|---|---|---|---|---|---|---|---|---|
| | Agricultural land | Built-up area | Forest vegetation | Water body | Agricultural land | Built-up area | Forest vegetation | Water body |
| Belabo | 7631.91 | 535.68 | 3693.69 | 405.18 | 5497.38 | 1662.93 | 4848.66 | 257.49 |
| Manohardi | 13363.2 | 257.94 | 5495.85 | 442.53 | 12621.69 | 1838.34 | 4795.65 | 303.84 |
| Narsingdi Sadar | 14006.88 | 1237.68 | 2440.8 | 4283.55 | 12541.86 | 4209.12 | 1957.59 | 3260.34 |
| Palash | 6136.74 | 306.45 | 2513.79 | 768.78 | 4981.05 | 1063.44 | 2832.03 | 849.24 |
| Roypura | 19982.07 | 1438.38 | 3328.29 | 7036.38 | 16505.1 | 5552.28 | 5113.71 | 4614.03 |
| Shibpur | 14168.34 | 262.08 | 6046.47 | 972.63 | 10786.5 | 1824.75 | 8176.68 | 661.59 |

The percentage of land uses was also calculated for six Upazilas of the Narsingdi district and presented in Table 3. Agricultural land is the principal land cover class in all the Upazilas and significantly decreased by twenty years of time-lapse. Belabo is the Upazila, where the maximum reduction in agricultural land use was observed from 2001 to 2021 by 17.40%, and the lowest reduction was found at 3.79% in Manohar. Built-up area increased in the last two decades in all six Upazilas at a significant level and the maximum percentage observed in Narsingdi Sadar and Roypura, increased by 13.53% and 12.94%, respectively. Among all the Upazilas, the highest forest coverage was observed in Belabo (30.11%) in 2001, which increased by 9.42% during the last two decades, and in 2021, the total forest coverage in the Upazila was observed at 39.53% of the total land mass. The forest coverage indeed represents a very healthy environment. Besides, from 2001 to 2021, forest coverage increased in Palash, Roypura, and Shibpur Upazilas from 25.85% to 29.12%, 10.47% to 16.09%, and 28.19% to 38.12%, respectively. At the same time, forest coverage decreased in Manohardi and Narsingdi Sadar by 3.58% and 2.20% respectively. From 2011 to 2021, water bodies decreased in all the Upazilas except Palash, which increased from 7.90% to 8.73% (Table 3). The analysis shows that Narsingdi Sadar Upazila was the most vulnerable area because of its land cover decreased significantly by 6.67% in agricultural land, 2.2% in forest coverage, and 4.66% in water body. The built-up area increased by a considerable amount of 13.53% during the last twenty years.

**Table 3.** Percentage of land use and land cover at different Upazilas in Narsingdi district of Bangladesh.

| | 2001 (%) | | | | 2021 (%) | | | |
|---|---|---|---|---|---|---|---|---|
| Upazila | Agricultural land | Built-up area | Forest vegetation | Water body | Agricultural land | Built-up area | Forest vegetation | Water body |
| Belabo | 62.22 | 4.37 | 30.11 | 3.3 | 44.82 | 13.56 | 39.53 | 2.1 |
| Manohardi | 68.32 | 1.32 | 28.1 | 2.26 | 64.53 | 9.4 | 24.52 | 1.55 |
| Narsingdi Sadar | 63.76 | 5.63 | 11.11 | 19.5 | 57.09 | 19.16 | 8.91 | 14.84 |
| Palash | 63.1 | 3.15 | 25.85 | 7.9 | 51.22 | 10.93 | 29.12 | 8.73 |
| Roypura | 62.87 | 4.53 | 10.47 | 22.14 | 51.93 | 17.47 | 16.09 | 14.52 |
| Shibpur | 66.05 | 1.22 | 28.19 | 4.53 | 50.29 | 8.51 | 38.12 | 3.08 |
| Average changes | 64.39 | 3.37 | 22.31 | 9.94 | 53.31 | 13.17 | 26.05 | 7.47 |

At the local government unit level, a total shift in different land uses was observed from 2001 to 2021. The highest agricultural land was calculated as 2013.39 ha and 1676.88 ha in Joynagar, both in 2001 and 2021, respectively (Table 4 and Table 5). Among the seventy-six local government units, the highest forest cover was calculated in Joynagar, 1665.45 ha, and the lowest in Char Dighaldi, 4.68 ha, in 2001. In 2021, Joynagar also represented the highest forest coverage, 2007.45 ha, and the lowest in Mirzar Char, 28.44 ha. The forest coverage significantly increased in all the local government units during 2001-2021. The built-up area was highest in Binyabaid (234.63 ha) and lowest in Joynagar (4.5 ha) in 2001, whereas, in 2021, the highest built-up area was calculated in Paratali (550.08 ha) and lowest in Shibpur Paurashava (39.15 ha). In 2001, the highest coverage of the water body was analysed in Chandpur (1110.24 ha) and the lowest in Manohardi Paurashava (3.78 ha). In 2021, Chandpur also showed the highest water body covered area, but in a decreased amount, 802.71 ha, and Manohardi Paurashava represented the lowest water body (3.69 ha) cover among the local government units (Table 4 and Table 5).

**Table 4.** Land use and land class distribution at the smallest local government units in 2001 in the Narsingdi district of Bangladesh.

| Local government Unit ID | 2001 (ha) | | | | |
|---|---|---|---|---|---|
| | Name of the Local Government Unit | Water body | Built-up area | Forest vegetation | Agricultural land |
| 1 | Adiabad | 154.89 | 11.88 | 164.61 | 776.07 |
| 2 | Alipura | 37.53 | 21.87 | 218.79 | 671.31 |
| 3 | Alokbali | 881.73 | 45.63 | 18.36 | 1377.18 |
| 4 | Amdia | 205.65 | 94.95 | 227.43 | 1258.47 |
| 5 | Amirganj | 178.29 | 48.51 | 107.91 | 1166.76 |
| 6 | Amlaba | 33.12 | 8.46 | 876.06 | 854.64 |
| 7 | Ayubpur | 96.39 | 17.1 | 146.88 | 1409.04 |
| 8 | Baghaba | 126.9 | 15.39 | 455.04 | 1759.14 |
| 9 | Bajnaba | 39.6 | 21.78 | 453.51 | 832.59 |
| 10 | Banshgari | 263.07 | 93.69 | 89.01 | 913.05 |
| 11 | Bara Chapa | 86.85 | 22.77 | 399.69 | 1652.4 |
| 12 | Belabo | 9.36 | 97.56 | 351.27 | 558.36 |
| 13 | Binyabaid | 93.51 | 234.63 | 481.95 | 1105.65 |
| 14 | Chak Radha | 84.51 | 20.16 | 464.31 | 1420.56 |
| 15 | Chalak Char | 17.73 | 25.65 | 412.11 | 936.81 |
| 16 | Chandanbari | 8.1 | 18 | 373.41 | 662.49 |
| 17 | Chanderkandi | 54.9 | 79.83 | 258.3 | 686.34 |
| 18 | Chandpur | 1110.24 | 111.24 | 84.69 | 1327.05 |
| 19 | Char Aralia | 452.97 | 16.38 | 23.22 | 638.82 |
| 20 | Char Dighaldi | 910.89 | 96.66 | 4.68 | 1007.46 |
| 21 | Char Madhua | 393.39 | 44.82 | 63.63 | 627.75 |
| 22 | Char Mandalia | 30.96 | 22.23 | 487.44 | 1221.84 |
| 23 | Char Sindur | 177.3 | 59.49 | 619.74 | 1163.07 |
| 24 | Char Subuddi | 199.35 | 59.85 | 52.65 | 526.05 |
| 25 | Char Ujilaba | 18.9 | 26.46 | 188.37 | 366.21 |
| 26 | Chinishpur | 38.07 | 20.7 | 88.47 | 547.02 |
| 27 | Danga | 148.86 | 90.45 | 197.82 | 1276.83 |
| 28 | Daukar Char | 49.32 | 14.13 | 51.93 | 347.22 |
| 29 | Daulatpur | 50.94 | 12.96 | 629.19 | 768.51 |
| 30 | Dulalpur | 210.51 | 43.11 | 745.65 | 1601.28 |
| 31 | Ekduaria | 15.03 | 27.54 | 415.44 | 1174.5 |
| 32 | Gazaria | 30.78 | 20.97 | 574.11 | 801 |
| 33 | Ghorashal Paurashava | 249.48 | 106.11 | 451.89 | 1391.58 |
| 34 | Gotashia | 106.2 | 23.13 | 499.95 | 1565.82 |
| 35 | Hairmara | 109.26 | 62.82 | 52.47 | 467.01 |
| 36 | Hajipur | 173.43 | 20.34 | 5.22 | 451.08 |
| 37 | Jinardi | 162.36 | 29.43 | 670.23 | 1504.26 |
| 38 | Josar | 57.78 | 11.52 | 724.86 | 1481.04 |
| 39 | Joynagar | 192.78 | 4.5 | 1665.45 | 2013.39 |

*Continued*

| Local government Unit ID | 2001 (ha) | | | | |
|---|---|---|---|---|---|
| | Name of the Local Government Unit | Water body | Built-up area | Forest vegetation | Agricultural land |
| 40 | Kanchikata | 52.02 | 29.7 | 411.21 | 1454.13 |
| 41 | Kanthalia | 22.86 | 18.81 | 180.99 | 901.17 |
| 42 | Karimpur | 650.61 | 87.75 | 13.23 | 1048.95 |
| 43 | Khidirpur | 31.14 | 25.65 | 682.11 | 1290.6 |
| 44 | Lebutala | 15.75 | 25.38 | 701.55 | 1433.07 |
| 45 | Madhabdi Paurashava | 15.03 | 60.3 | 180.9 | 417.69 |
| 46 | Maheshpur | 154.62 | 33.66 | 78.66 | 674.91 |
| 47 | Mahishasura | 38.7 | 187.47 | 299.52 | 1011.42 |
| 48 | Manohardi Paurashava | 3.78 | 9.99 | 149.04 | 359.82 |
| 49 | Marjal | 64.26 | 10.8 | 420.75 | 781.11 |
| 50 | Masimpur | 74.16 | 30.78 | 606.78 | 1574.55 |
| 51 | Meher Para | 39.51 | 50.67 | 174.69 | 654.57 |
| 52 | Mirzanagar | 91.71 | 44.37 | 131.22 | 684.63 |
| 53 | Mirzapur | 85.14 | 33.48 | 256.95 | 888.21 |
| 54 | Mirzar Char | 271.53 | 30.06 | 36.9 | 551.61 |
| 55 | Musapur | 459.54 | 59.67 | 141.66 | 842.85 |
| 56 | Narayanpur | 53.01 | 31.23 | 620.01 | 1264.77 |
| 57 | Narsingdi Paurashava | 84.87 | 77.4 | 105.57 | 628.38 |
| 58 | Nazarpur | 1016.37 | 164.34 | 82.62 | 1413.18 |
| 59 | Nilakhya | 782.73 | 133.92 | 44.1 | 1286.1 |
| 60 | Nuralla Pur U/C | 10.26 | 14.85 | 204.12 | 451.71 |
| 61 | Paikar Char | 75.6 | 129.6 | 200.43 | 993.15 |
| 62 | Palashtali | 294.84 | 50.22 | 164.79 | 1206.36 |
| 63 | Panchdona | 84.06 | 45 | 320.04 | 878.85 |
| 64 | Paratali | 347.04 | 153.09 | 115.56 | 1532.61 |
| 65 | Patuli | 66.6 | 18.81 | 340.29 | 1729.26 |
| 66 | Putia | 96.03 | 80.91 | 408.87 | 1651.77 |
| 67 | Radhanagar | 56.16 | 21.33 | 283.95 | 627.66 |
| 68 | Roypura | 375.39 | 76.59 | 95.04 | 336.51 |
| 69 | Roypura Paurashava | 97.38 | 37.26 | 106.38 | 310.14 |
| 70 | Sadhar Char | 14.49 | 29.16 | 684.9 | 836.64 |
| 71 | Sallabad | 91.08 | 96.75 | 382.23 | 920.43 |
| 72 | Shibpur Paurashava | 19.08 | 9.45 | 143.73 | 420.93 |
| 73 | Shukundi | 24.03 | 14.94 | 334.71 | 843.21 |
| 74 | Silmandi | 35.91 | 123.21 | 334.53 | 966.6 |
| 75 | Sreenagar | 891.18 | 175.32 | 118.71 | 1588.59 |
| 76 | Uttar Bakharnagar | 61.65 | 13.59 | 166.41 | 523.35 |

**Table 5.** Land use and land class distribution at the smallest local government units in 2021 in Narsingdi district of Bangladesh.

| Local government Unit ID | Name of the Local Government Unit | 2021 (ha) | | | |
|---|---|---|---|---|---|
| | | Water body | Built-up area | Forest vegetation | Agricultural land |
| 1 | Adiabad | 34.74 | 219.24 | 363.33 | 490.14 |
| 2 | Alipura | 8.64 | 119.97 | 284.94 | 535.95 |
| 3 | Alokbali | 546.93 | 390.87 | 133.47 | 1251.63 |
| 4 | Amdia | 153.99 | 243.36 | 187.74 | 1201.41 |
| 5 | Amirganj | 41.85 | 197.28 | 314.37 | 947.97 |
| 6 | Amlaba | 12.42 | 104.58 | 1205.37 | 449.91 |
| 7 | Ayubpur | 52.38 | 111.33 | 352.26 | 1153.44 |
| 8 | Baghaba | 44.37 | 295.56 | 989.1 | 1027.44 |
| 9 | Bajnaba | 37.98 | 56.97 | 606.51 | 646.02 |
| 10 | Banshgari | 122.76 | 368.37 | 76.05 | 791.64 |
| 11 | Bara Chapa | 48.6 | 156.51 | 469.98 | 1486.62 |
| 12 | Belabo | 14.31 | 180 | 289.35 | 532.89 |
| 13 | Binyabaid | 86.31 | 319.23 | 479.34 | 1030.86 |
| 14 | Chak Radha | 95.04 | 112.95 | 461.97 | 1319.58 |
| 15 | Chalak Char | 9.99 | 84.06 | 322.83 | 975.42 |
| 16 | Chandanbari | 5.76 | 145.17 | 289.53 | 621.54 |
| 17 | Chanderkandi | 31.68 | 111.87 | 235.08 | 700.74 |
| 18 | Chandpur | 802.71 | 522.27 | 99.18 | 1209.06 |
| 19 | Char Aralia | 180.9 | 249.84 | 104.76 | 595.89 |
| 20 | Char Dighaldi | 752.76 | 312.21 | 78.57 | 876.15 |
| 21 | Char Madhua | 298.53 | 219.06 | 76.68 | 535.32 |
| 22 | Char Mandalia | 34.92 | 280.71 | 477.09 | 969.75 |
| 23 | Char Sindur | 187.83 | 277.02 | 585.99 | 968.76 |
| 24 | Char Subuddi | 179.73 | 79.83 | 138.06 | 440.28 |
| 25 | Char Ujilaba | 10.53 | 148.95 | 177.48 | 262.98 |
| 26 | Chinishpur | 19.71 | 118.62 | 85.59 | 470.34 |
| 27 | Danga | 148.68 | 251.55 | 261.54 | 1052.19 |
| 28 | Daukar Char | 10.89 | 66.78 | 83.52 | 301.41 |
| 29 | Daulatpur | 36.81 | 195.3 | 656.19 | 573.3 |
| 30 | Dulalpur | 156.87 | 229.14 | 859.59 | 1354.95 |
| 31 | Ekduaria | 34.83 | 114.3 | 359.55 | 1123.83 |
| 32 | Gazaria | 17.19 | 222.03 | 467.64 | 720 |
| 33 | Ghorashal Paurashava | 233.1 | 208.8 | 576.09 | 1181.07 |
| 34 | Gotashia | 52.47 | 93.6 | 510.66 | 1538.37 |
| 35 | Hairmara | 50.67 | 77.58 | 101.88 | 461.43 |
| 36 | Hajipur | 80.91 | 126.54 | 72.63 | 369.99 |
| 37 | Jinardi | 262.44 | 104.04 | 940.77 | 1059.03 |
| 38 | Josar | 18.09 | 121.86 | 1695.51 | 439.74 |
| 39 | Joynagar | 85.68 | 106.11 | 2007.45 | 1676.88 |
| 40 | Kanchikata | 21.24 | 125.19 | 336.69 | 1463.94 |
| 41 | Kanthalia | 16.11 | 74.7 | 154.98 | 878.04 |
| 42 | Karimpur | 450.45 | 414.99 | 49.41 | 885.69 |
| 43 | Khidirpur | 14.67 | 230.85 | 543.24 | 1240.74 |
| 44 | Lebutala | 31.95 | 233.55 | 510.48 | 1399.77 |
| 45 | Madhabdi Paurashava | 7.29 | 212.04 | 57.33 | 397.26 |
| 46 | Maheshpur | 83.88 | 108.99 | 137.34 | 611.64 |
| 47 | Mahishasura | 27.36 | 400.77 | 48.96 | 1060.02 |
| 48 | Manohardi Paurashava | 3.69 | 70.02 | 73.62 | 375.3 |

*Continued*

| Local government Unit ID | Name of the Local Government Unit | 2021 (ha) | | | |
|---|---|---|---|---|---|
| | | Water body | Built-up area | Forest vegetation | Agricultural land |
| 49 | Marjal | 25.74 | 198.54 | 753.75 | 298.89 |
| 50 | Masimpur | 106.2 | 195.93 | 605.07 | 1379.07 |
| 51 | Meher Para | 83.34 | 115.2 | 139.86 | 581.04 |
| 52 | Mirzanagar | 35.19 | 153.18 | 260.19 | 503.37 |
| 53 | Mirzapur | 28.26 | 163.44 | 332.1 | 739.98 |
| 54 | Mirzar Char | 240.21 | 251.46 | 28.44 | 369.99 |
| 55 | Musapur | 350.37 | 208.35 | 193.59 | 751.41 |
| 56 | Narayanpur | 18.18 | 472.86 | 669.78 | 808.2 |
| 57 | Narsingdi Paurashava | 59.31 | 328.32 | 33.57 | 475.02 |
| 58 | Nazarpur | 789.48 | 516.6 | 173.79 | 1196.64 |
| 59 | Nilakhya | 568.89 | 399.24 | 144.18 | 1134.54 |
| 60 | Nuralla Pur U/C | 11.79 | 97.74 | 153.99 | 417.42 |
| 61 | Paikar Char | 56.43 | 385.92 | 50.31 | 906.12 |
| 62 | Palashtali | 126.45 | 227.61 | 389.07 | 973.08 |
| 63 | Panchdona | 162.09 | 160.29 | 256.41 | 749.16 |
| 64 | Paratali | 216.72 | 550.08 | 91.8 | 1289.7 |
| 65 | Patuli | 33.03 | 83.7 | 1049.13 | 989.1 |
| 66 | Putia | 74.79 | 282.15 | 441.72 | 1438.92 |
| 67 | Radhanagar | 17.55 | 120.78 | 328.32 | 522.45 |
| 68 | Roypura | 318.06 | 161.73 | 90.45 | 313.29 |
| 69 | Roypura Paurashava | 42.57 | 106.92 | 88.02 | 313.65 |
| 70 | Sadhar Char | 9.54 | 330.57 | 579.96 | 645.12 |
| 71 | Sallabad | 44.73 | 296.64 | 371.7 | 777.42 |
| 72 | Shibpur Paurashava | 18.63 | 39.15 | 184.05 | 351.36 |
| 73 | Shukundi | 8.91 | 109.08 | 245.79 | 853.11 |
| 74 | Silmandi | 42.39 | 310.95 | 280.98 | 825.93 |
| 75 | Sreenagar | 778.59 | 494.01 | 105.39 | 1395.81 |
| 76 | Uttar Bakharnagar | 18.45 | 175.86 | 293.22 | 277.47 |

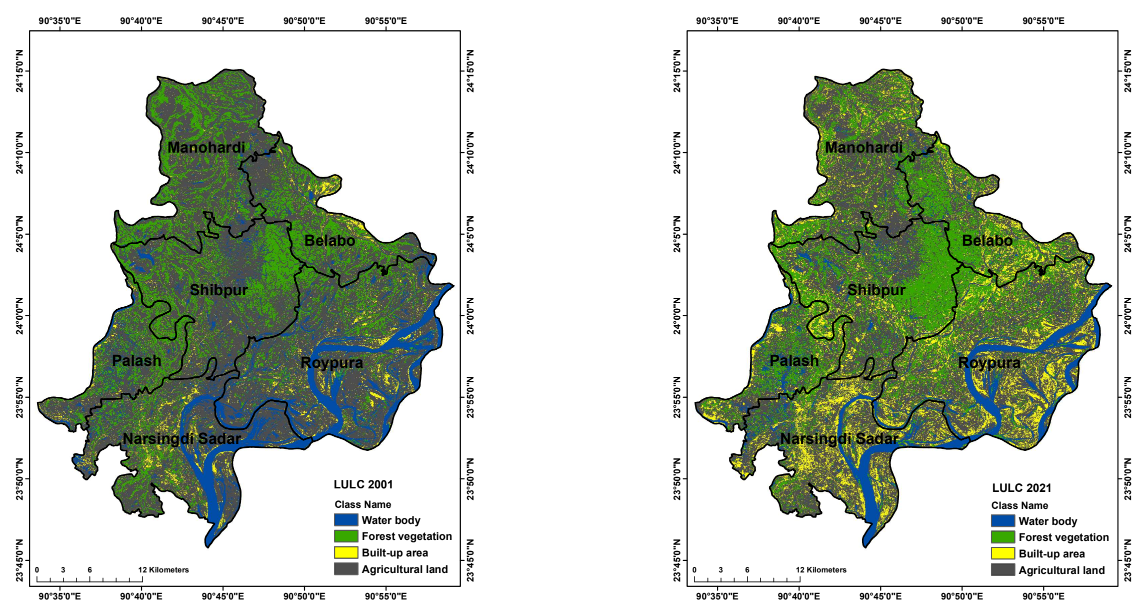



**Figure 3.** LULC map for Upazilas under Narsingdi district of Bangladesh in 2001 and 2021.

The land use and land cover (LULC) has been analyzed for all the Upazilas of the Narsingdi district from 2001 to 2021, and significant changes were observed between the time-lapse, especially in the built-up area. A considerable increase in the built-up area and a decrease in the agricultural area were detected in all the Upazilas. To be specific, most changes are found in Narsingdi Sadar, Roypura, and Belabo, as represented in Figure 3, where a considerable amount of cultivable agricultural land has been converted into a built-up area. A significant increase in forest coverage was noticed in Shibpur and Belabo by comparing them with other Upazilas. The unions – Adiabad, Amlaba, Amirganj, Baghaba, Bajnaba, Jinardi, Josar, Joynagar, Marjal, Palashtali and Patuli showed a significant increase in forest coverage by replacing the agricultural land (Figure 4).

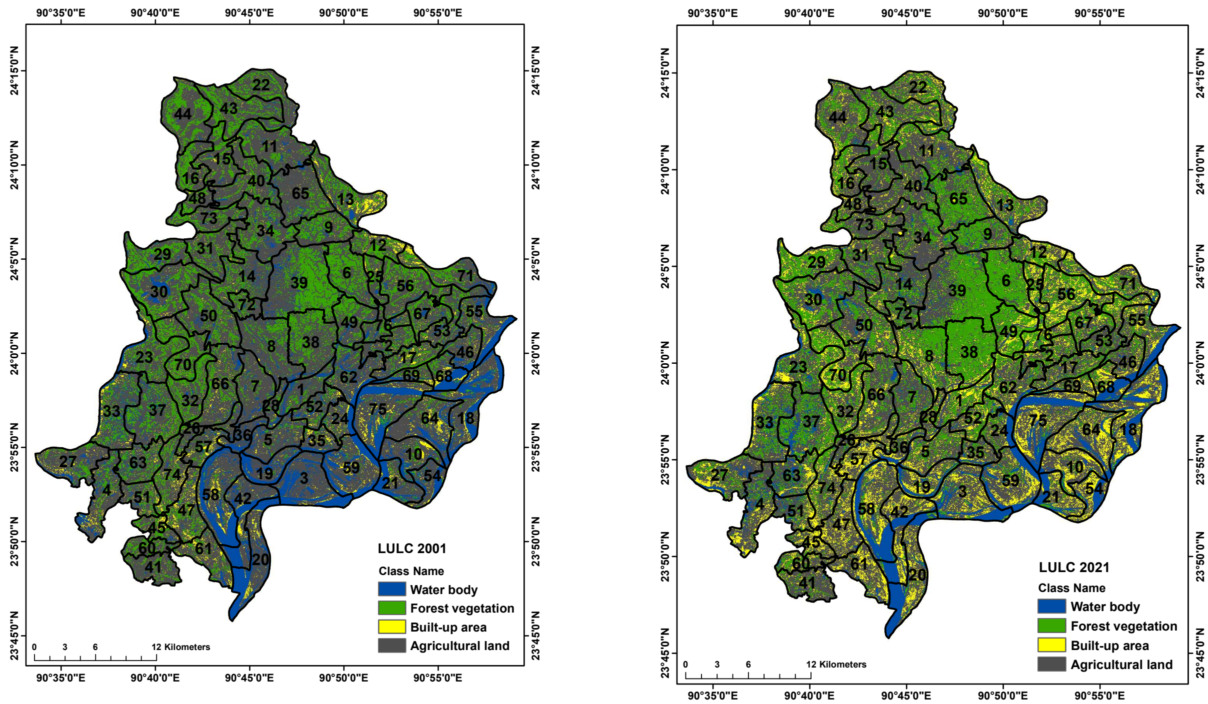



**Figure 4.** LULC map for Unions under Narsingdi district of Bangladesh in 2001 and 2021.

Normalized Difference Vegetation Index

**Table 6.** NDVI distribution at the Upazila level in Narsingdi district in 2001 and 2021 in Bangladesh.

| Upazila name | NDVI-2001 | | | | NDVI-2021 | | | |
|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | STD | Min | Max | Mean | STD |
| Belabo | 0.45 | 0.62 | 0.55 | 0.03 | 0.55 | 0.72 | 0.64 | 0.03 |
| Manohardi | 0.42 | 0.60 | 0.54 | 0.03 | 0.55 | 0.67 | 0.61 | 0.03 |
| Narsingdi Sadar | 0.02 | 0.57 | 0.41 | 0.14 | 0.08 | 0.64 | 0.49 | 0.11 |
| Palash | 0.34 | 0.60 | 0.51 | 0.05 | 0.39 | 0.68 | 0.58 | 0.07 |
| Roypura | 0.03 | 0.63 | 0.41 | 0.15 | 0.14 | 0.70 | 0.54 | 0.12 |
| Shibpur | 0.38 | 0.65 | 0.55 | 0.04 | 0.48 | 0.73 | 0.63 | 0.04 |

The mean value of NDVI was the highest, 0.55±0.03 and 0.55±0.04, both in Belabo and Shibpur in 2001, respectively, and in 2021, it was in Belabo 0.64±0.03. The minimum NDVI was calculated in Narsingdi Sadar (0.02) in 2001 and the maximum in Shibpur (0.65) simultaneously. Compared with 2001, in 2021, the NDVI was also lowest in Narsingdi Sadar (0.08) and highest in Shibpur (0.73) (Table 6). At the minor local government unit level, the mean value of NDVI was the highest, 0.59±0.03, both in Josar and Marjal, in 2001. While in 2021, it was the highest, 0.69±0.03 in Jasar. In 2001 and 2021, the lowest values were calculated in Chandpur (0.24±0.09) and Char Madhua (0.39±0.13), respectively (Table 7).

**Table 7.** NDVI distribution at the smallest local government unit level in Narsingdi district in 2001 and 2021 in Bangladesh.

| Local government Unit ID | Name of the Local Government Unit | NDVI-2001 | | | | NDVI-2021 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | STD | Min | Max | Mean | STD |
| 1 | Adiabad | 0.51 | 0.62 | 0.56 | 0.03 | 0.62 | 0.69 | 0.65 | 0.02 |
| 2 | Alipura | 0.54 | 0.60 | 0.57 | 0.01 | 0.64 | 0.69 | 0.66 | 0.02 |
| 3 | Alokbali | 0.03 | 0.49 | 0.31 | 0.12 | 0.08 | 0.57 | 0.47 | 0.11 |
| 4 | Amdia | 0.30 | 0.50 | 0.45 | 0.05 | 0.46 | 0.58 | 0.55 | 0.02 |
| 5 | Amirganj | 0.42 | 0.59 | 0.54 | 0.04 | 0.53 | 0.66 | 0.62 | 0.03 |
| 6 | Amlaba | 0.52 | 0.61 | 0.57 | 0.02 | 0.62 | 0.72 | 0.67 | 0.03 |
| 7 | Ayubpur | 0.51 | 0.59 | 0.55 | 0.02 | 0.53 | 0.67 | 0.64 | 0.03 |
| 8 | Baghaba | 0.51 | 0.62 | 0.56 | 0.03 | 0.60 | 0.70 | 0.65 | 0.03 |
| 9 | Bajnaba | 0.50 | 0.59 | 0.56 | 0.03 | 0.60 | 0.67 | 0.63 | 0.02 |
| 10 | Banshgari | 0.17 | 0.49 | 0.35 | 0.10 | 0.37 | 0.61 | 0.51 | 0.07 |
| 11 | Bara Chapa | 0.48 | 0.60 | 0.53 | 0.03 | 0.56 | 0.67 | 0.60 | 0.03 |
| 12 | Belabo | 0.46 | 0.58 | 0.53 | 0.04 | 0.56 | 0.68 | 0.62 | 0.03 |
| 13 | Binyabaid | 0.46 | 0.58 | 0.54 | 0.03 | 0.57 | 0.67 | 0.62 | 0.02 |
| 14 | Chak Radha | 0.46 | 0.57 | 0.51 | 0.03 | 0.56 | 0.64 | 0.62 | 0.02 |
| 15 | Chalak Char | 0.50 | 0.59 | 0.54 | 0.02 | 0.59 | 0.66 | 0.62 | 0.02 |
| 16 | Chandanbari | 0.50 | 0.55 | 0.53 | 0.02 | 0.57 | 0.64 | 0.61 | 0.02 |
| 17 | Chanderkandi | 0.39 | 0.58 | 0.52 | 0.06 | 0.57 | 0.69 | 0.63 | 0.03 |
| 18 | Chandpur | 0.07 | 0.46 | 0.24 | 0.09 | 0.20 | 0.58 | 0.42 | 0.09 |
| 19 | Char Aralia | 0.26 | 0.52 | 0.38 | 0.09 | 0.42 | 0.60 | 0.54 | 0.05 |
| 20 | Char Dighaldi | 0.02 | 0.44 | 0.28 | 0.14 | 0.12 | 0.58 | 0.41 | 0.16 |
| 21 | Char Madhua | 0.04 | 0.43 | 0.25 | 0.12 | 0.14 | 0.54 | 0.39 | 0.13 |
| 22 | Char Mandalia | 0.46 | 0.59 | 0.53 | 0.03 | 0.58 | 0.66 | 0.63 | 0.02 |
| 23 | Char Sindur | 0.42 | 0.60 | 0.52 | 0.04 | 0.44 | 0.66 | 0.58 | 0.06 |
| 24 | Char Subuddi | 0.21 | 0.57 | 0.45 | 0.12 | 0.35 | 0.65 | 0.54 | 0.10 |
| 25 | Char Ujilaba | 0.55 | 0.62 | 0.58 | 0.02 | 0.64 | 0.65 | 0.64 | 0.01 |
| 26 | Chinishpur | 0.50 | 0.57 | 0.53 | 0.02 | 0.47 | 0.64 | 0.56 | 0.06 |
| 27 | Danga | 0.40 | 0.55 | 0.47 | 0.04 | 0.39 | 0.60 | 0.50 | 0.06 |
| 28 | Daukar Char | 0.49 | 0.57 | 0.53 | 0.03 | 0.58 | 0.67 | 0.63 | 0.03 |
| 29 | Daulatpur | 0.49 | 0.58 | 0.55 | 0.02 | 0.56 | 0.67 | 0.62 | 0.03 |
| 30 | Dulalpur | 0.38 | 0.56 | 0.51 | 0.04 | 0.48 | 0.66 | 0.60 | 0.03 |
| 31 | Ekduaria | 0.49 | 0.56 | 0.54 | 0.02 | 0.58 | 0.64 | 0.62 | 0.02 |
| 32 | Gazaria | 0.50 | 0.60 | 0.55 | 0.03 | 0.62 | 0.67 | 0.64 | 0.02 |
| 33 | Ghorashal Paurashava | 0.34 | 0.55 | 0.49 | 0.05 | 0.39 | 0.62 | 0.55 | 0.06 |
| 34 | Gotashia | 0.42 | 0.56 | 0.52 | 0.04 | 0.56 | 0.66 | 0.61 | 0.03 |
| 35 | Hairmara | 0.50 | 0.60 | 0.55 | 0.03 | 0.55 | 0.64 | 0.61 | 0.03 |
| 36 | Hajipur | 0.44 | 0.56 | 0.51 | 0.04 | 0.46 | 0.64 | 0.56 | 0.06 |
| 37 | Jinardi | 0.50 | 0.57 | 0.53 | 0.02 | 0.61 | 0.68 | 0.64 | 0.02 |
| 38 | Josar | 0.50 | 0.64 | 0.59 | 0.03 | 0.61 | 0.73 | 0.69 | 0.03 |

*Continued*

| Local government Unit ID | Name of the Local Government Unit | NDVI-2001 | | | | NDVI-2021 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | STD | Min | Max | Mean | STD |
| 39 | Joynagar | 0.43 | 0.65 | 0.55 | 0.06 | 0.54 | 0.72 | 0.65 | 0.05 |
| 40 | Kanchikata | 0.48 | 0.57 | 0.54 | 0.02 | 0.59 | 0.67 | 0.62 | 0.02 |
| 41 | Kanthalia | 0.52 | 0.56 | 0.54 | 0.01 | 0.52 | 0.59 | 0.55 | 0.02 |
| 42 | Karimpur | 0.06 | 0.50 | 0.28 | 0.15 | 0.17 | 0.58 | 0.40 | 0.13 |
| 43 | Khidirpur | 0.53 | 0.60 | 0.56 | 0.02 | 0.55 | 0.66 | 0.63 | 0.03 |
| 44 | Lebutala | 0.51 | 0.59 | 0.55 | 0.02 | 0.55 | 0.66 | 0.60 | 0.03 |
| 45 | Madhabdi Paurashava | 0.46 | 0.56 | 0.51 | 0.03 | 0.37 | 0.57 | 0.47 | 0.07 |
| 46 | Maheshpur | 0.11 | 0.56 | 0.44 | 0.14 | 0.24 | 0.64 | 0.55 | 0.12 |
| 47 | Mahishasura | 0.23 | 0.53 | 0.45 | 0.08 | 0.41 | 0.59 | 0.51 | 0.05 |
| 48 | Manohardi Paurashava | 0.52 | 0.55 | 0.54 | 0.01 | 0.56 | 0.64 | 0.60 | 0.03 |
| 49 | Marjal | 0.54 | 0.63 | 0.59 | 0.03 | 0.62 | 0.70 | 0.67 | 0.02 |
| 50 | Masimpur | 0.46 | 0.60 | 0.53 | 0.03 | 0.56 | 0.66 | 0.63 | 0.02 |
| 51 | Meher Para | 0.42 | 0.50 | 0.46 | 0.03 | 0.50 | 0.55 | 0.52 | 0.01 |
| 52 | Mirzanagar | 0.55 | 0.59 | 0.57 | 0.01 | 0.64 | 0.67 | 0.65 | 0.01 |
| 53 | Mirzapur | 0.50 | 0.59 | 0.56 | 0.02 | 0.56 | 0.67 | 0.63 | 0.02 |
| 54 | Mirzar Char | 0.21 | 0.48 | 0.33 | 0.07 | 0.31 | 0.55 | 0.46 | 0.08 |
| 55 | Musapur | 0.04 | 0.58 | 0.42 | 0.18 | 0.14 | 0.64 | 0.51 | 0.17 |
| 56 | Narayanpur | 0.56 | 0.61 | 0.58 | 0.01 | 0.61 | 0.69 | 0.65 | 0.02 |
| 57 | Narsingdi Paurashava | 0.36 | 0.49 | 0.44 | 0.04 | 0.40 | 0.55 | 0.45 | 0.05 |
| 58 | Nazarpur | 0.09 | 0.53 | 0.30 | 0.12 | 0.18 | 0.59 | 0.44 | 0.10 |
| 59 | Nilakhya | 0.09 | 0.52 | 0.29 | 0.11 | 0.22 | 0.61 | 0.44 | 0.10 |
| 60 | Nuralla Pur U/C | 0.50 | 0.55 | 0.54 | 0.02 | 0.50 | 0.60 | 0.54 | 0.03 |
| 61 | Paikar Char | 0.03 | 0.53 | 0.40 | 0.14 | 0.15 | 0.52 | 0.44 | 0.10 |
| 62 | Palashtali | 0.23 | 0.57 | 0.49 | 0.10 | 0.36 | 0.67 | 0.60 | 0.08 |
| 63 | Panchdona | 0.47 | 0.57 | 0.50 | 0.02 | 0.47 | 0.64 | 0.55 | 0.05 |
| 64 | Paratali | 0.22 | 0.51 | 0.36 | 0.09 | 0.41 | 0.63 | 0.54 | 0.06 |
| 65 | Patuli | 0.50 | 0.57 | 0.55 | 0.02 | 0.58 | 0.68 | 0.65 | 0.02 |
| 66 | Putia | 0.50 | 0.60 | 0.55 | 0.03 | 0.52 | 0.65 | 0.60 | 0.03 |
| 67 | Radhanagar | 0.54 | 0.60 | 0.57 | 0.02 | 0.60 | 0.67 | 0.65 | 0.02 |
| 68 | Roypura | 0.03 | 0.50 | 0.28 | 0.17 | 0.17 | 0.62 | 0.45 | 0.16 |
| 69 | Roypura Paurashava | 0.39 | 0.55 | 0.44 | 0.06 | 0.59 | 0.66 | 0.61 | 0.02 |
| 70 | Sadhar Char | 0.49 | 0.60 | 0.56 | 0.03 | 0.58 | 0.67 | 0.64 | 0.02 |
| 71 | Sallabad | 0.45 | 0.58 | 0.52 | 0.04 | 0.55 | 0.67 | 0.63 | 0.04 |
| 72 | Shibpur Paurashava | 0.48 | 0.54 | 0.52 | 0.02 | 0.59 | 0.65 | 0.63 | 0.02 |
| 73 | Shukundi | 0.51 | 0.57 | 0.53 | 0.02 | 0.58 | 0.64 | 0.61 | 0.02 |
| 74 | Silmandi | 0.46 | 0.56 | 0.51 | 0.03 | 0.42 | 0.64 | 0.55 | 0.05 |
| 75 | Sreenagar | 0.09 | 0.50 | 0.27 | 0.10 | 0.16 | 0.60 | 0.45 | 0.10 |
| 76 | Uttar Bakharnagar | 0.53 | 0.58 | 0.57 | 0.02 | 0.63 | 0.66 | 0.65 | 0.01 |

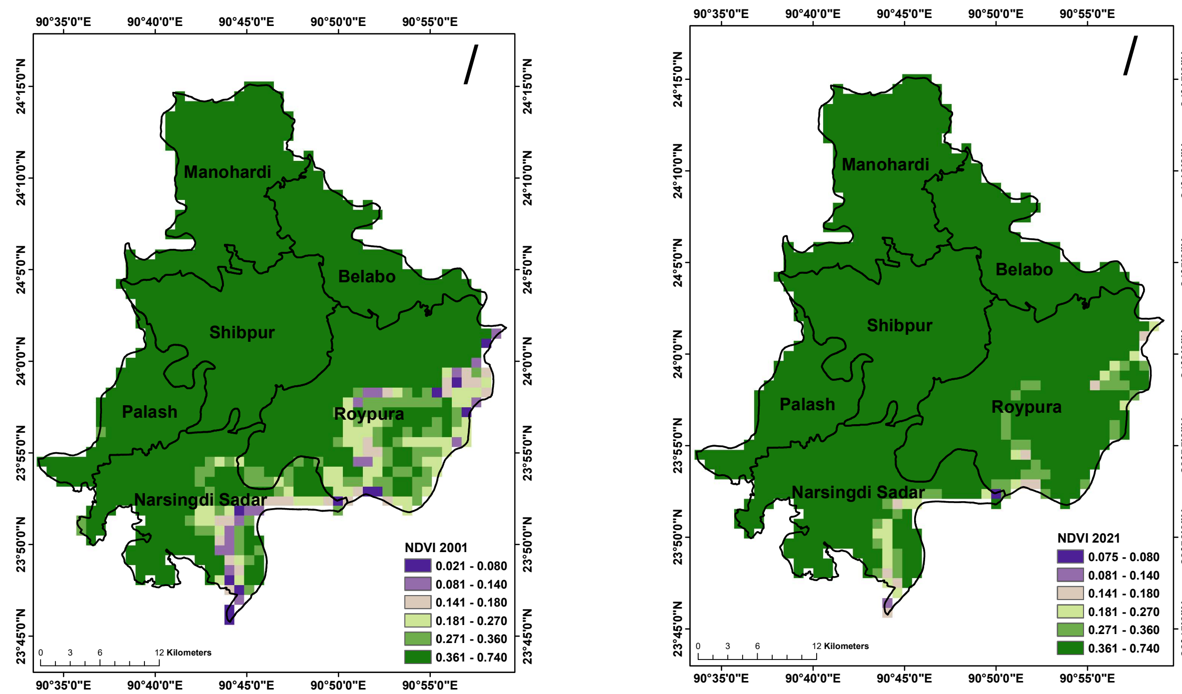



**Figure 5.** NDVI at the Upazila under Narsingdi district of Bangladesh in 2001 and 2021.

The NDVI values were low in Narsingdi Sadar and Roypura Upazilas in 2001, from 0.021 to 0.360. From the land use and land cover analysis, it is observed that the area was primarily agricultural land covered area in 2001. In 2021, the built-up area increased in both the upazilas, but the overall vegetation coverage also increased at the same time, which increased values of NDVI in those areas (Figure 5).

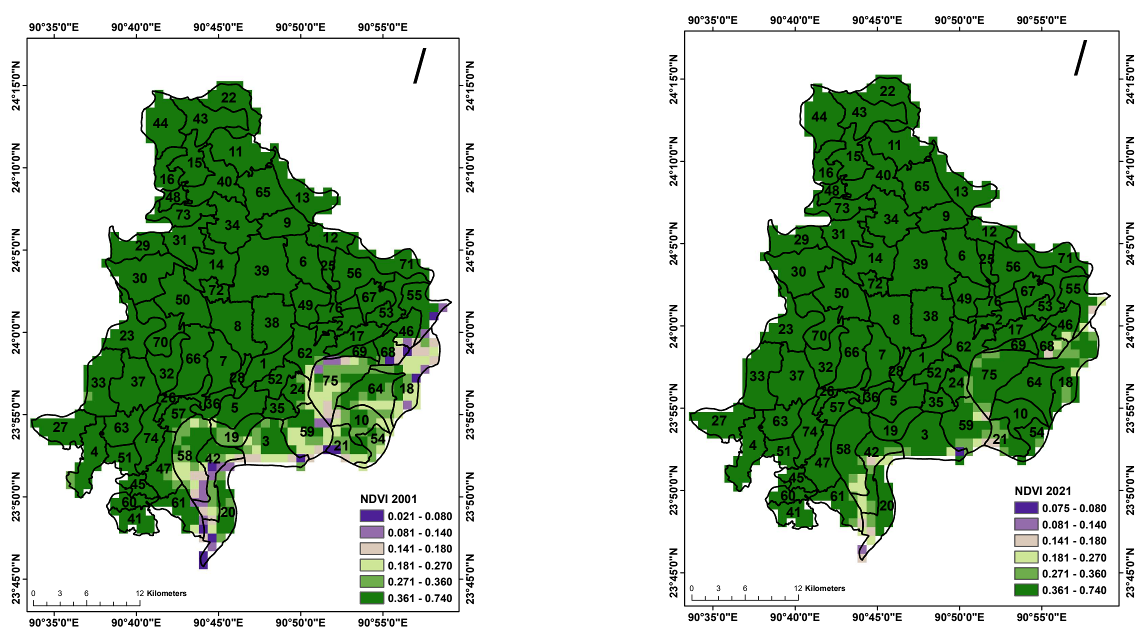



**Figure 6.** NDVI at the smallest local government unit under Narsingdi district of Bangladesh in 2001 and 2021.

By comparing the NDVI among the local government units between 2001 and 2021, it is observed that the lowest values of NDVI (0.021-0.360) were in Alokbali, Banshgari, Chandpur, Char Aralia, Char Dighaldi, Char Madhua, Char Subuddi, Karimpur, Maheshpur, Mahishasura, Mirzar Char, Musapur, Nazarpur, Nilakhya, Paikar Char, Palashtali, Paratali, Roypura, Sreenagar in 2001. The overall NDVI values increased in 2021 throughout the Narsingdi district and the lowest values (0.075-0.360) shrinkage within twelve units - Alokbali, Chandpur, Char Dighaldi, Char Madhua, Char Subuddi, Karimpur, Maheshpur, Musapur, Nazarpur, Nilakhya, Paikar Char, Roypura, and Sreenagar. The rest of the local government units represented healthy vegetation coverage with better NDVI values ranging between 0.361-0.740 (Figure 6).

Land Surface Temperature

**Table 8.** Land Surface Temperature (LST) at the Upazila level in Narsingdi district in 2001 and 2021 in Bangladesh.

| Upazila name | LST-2001 (°C) | | | | LST-2021 (°C) | | | |
|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | STD | Min | Max | Mean | STD |
| Belabo | 26.67 | 27.83 | 27.28 | 0.24 | 27.16 | 28.27 | 27.61 | 0.22 |
| Manohardi | 26.35 | 27.62 | 26.98 | 0.22 | 27.06 | 28.16 | 27.76 | 0.19 |
| Narsingdi Sadar | 25.26 | 28.18 | 26.87 | 0.67 | 26.18 | 30.87 | 28.01 | 0.86 |
| Palash | 25.75 | 27.40 | 26.82 | 0.39 | 26.46 | 29.00 | 27.70 | 0.48 |
| Roypura | 25.40 | 27.86 | 26.73 | 0.47 | 26.28 | 28.53 | 27.33 | 0.40 |
| Shibpur | 26.17 | 27.70 | 27.06 | 0.30 | 26.83 | 29.13 | 27.61 | 0.35 |

The mean values of LST were calculated for all the Upazilas and local government units of the Narsingdi district. Among all the Upazilas, the highest mean value was calculated in Belabo (27.28±0.24) in 2001 and in Narsingdi Sadar (28.01±0.86) in 2021. In 2001, the maximum temperature was recorded in Narsingdi Sadar (28.18°C**)** and the minimum was 25.26°C whereas, in 2021, the maximum (30.87°C) and minimum (26.18°C) temperature were estimated in Narsingdi Sadar (Table 8). Comparing all the local government units in 2001, the highest mean temperature (27.69±0.4) was recorded in Narsingdi Paurashava and the lowest (26.11±0.38) in Chandpur. In 2021, the highest mean value (29.58±0.65) was found in Madhabdi Paurashava and the lowest (26.85±0.3) in Chandpur (Table 9).

The land surface temperature increased throughout the areas of the Narsingdi district. In 2001, no heat island was observed in the district. However, in 2021, the Narsingdi Sadar Upazila was found as the heat island among all the Upazilas (Figure 7). In 2001, the minimum temperature (25.26°C) was recorded in Char Dighaldi and the maximum temperature (28.18°C) in Narsingdi Paurashava. In 2021, the minimum temperature (26.18°C) was found in Nazarpur, and the maximum (30.87°C) in Mahishasura (Figure 8). Figure 7 and Figure 8 depicted a significant temperature increase from 2001 to 2021. During the twenty years of time-lapse, the lowest temperature value increased by 0.92°C, and the highest value increased by 2.69°C.

**Table 9.** Land Surface Temperature (LST) at the smallest local government unit level in Narsingdi district in 2001 and 2021 in Bangladesh.

| Local government Unit ID | | LST-2001 ($^oC$) | | | | LST-2021 ($^oC$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Name of the Local Government Unit | Min | Max | Mean | STD | Min | Max | Mean | STD |
| 1 | Adiabad | 26.87 | 27.22 | 27.01 | 0.10 | 27.36 | 27.91 | 27.69 | 0.17 |
| 2 | Alipura | 26.72 | 27.16 | 26.99 | 0.13 | 27.26 | 27.72 | 27.55 | 0.16 |
| 3 | Alokbali | 25.31 | 26.89 | 26.13 | 0.47 | 26.31 | 27.83 | 27.17 | 0.38 |
| 4 | Amdia | 26.46 | 27.38 | 26.92 | 0.27 | 27.72 | 29.03 | 28.30 | 0.37 |
| 5 | Amirganj | 26.55 | 27.52 | 27.20 | 0.22 | 27.33 | 28.05 | 27.79 | 0.19 |
| 6 | Amlaba | 26.91 | 27.40 | 27.13 | 0.13 | 27.21 | 28.02 | 27.52 | 0.19 |
| 7 | Ayubpur | 27.18 | 27.56 | 27.40 | 0.11 | 27.37 | 29.13 | 27.98 | 0.32 |
| 8 | Baghaba | 26.79 | 27.70 | 27.34 | 0.22 | 27.25 | 28.09 | 27.74 | 0.24 |
| 9 | Bajnaba | 26.89 | 27.16 | 27.01 | 0.09 | 27.18 | 27.68 | 27.44 | 0.17 |
| 10 | Banshgari | 25.70 | 27.13 | 26.53 | 0.43 | 26.40 | 27.58 | 27.14 | 0.32 |
| 11 | Bara Chapa | 27.00 | 27.62 | 27.23 | 0.16 | 27.42 | 28.01 | 27.74 | 0.17 |
| 12 | Belabo | 26.90 | 27.40 | 27.19 | 0.15 | 27.34 | 27.91 | 27.64 | 0.14 |
| 13 | Binyabaid | 26.97 | 27.74 | 27.30 | 0.20 | 27.41 | 27.96 | 27.70 | 0.11 |
| 14 | Chak Radha | 26.59 | 27.18 | 26.95 | 0.14 | 27.06 | 27.95 | 27.60 | 0.21 |
| 15 | Chalak Char | 26.82 | 27.19 | 27.03 | 0.09 | 27.75 | 28.09 | 27.88 | 0.09 |
| 16 | Chandanbari | 26.70 | 27.23 | 26.97 | 0.16 | 27.63 | 28.10 | 27.90 | 0.15 |
| 17 | Chanderkandi | 26.59 | 27.23 | 27.01 | 0.18 | 26.87 | 27.67 | 27.26 | 0.22 |
| 18 | Chandpur | 25.46 | 26.93 | 26.11 | 0.38 | 26.33 | 27.45 | 26.85 | 0.30 |
| 19 | Char Aralia | 26.08 | 27.27 | 26.54 | 0.41 | 27.16 | 27.86 | 27.48 | 0.24 |
| 20 | Char Dighaldi | 25.26 | 27.15 | 26.33 | 0.55 | 26.42 | 28.06 | 27.26 | 0.47 |
| 21 | Char Madhua | 25.40 | 27.02 | 26.19 | 0.48 | 26.48 | 27.60 | 27.11 | 0.36 |
| 22 | Char Mandalia | 26.84 | 27.39 | 27.09 | 0.15 | 27.51 | 27.98 | 27.73 | 0.16 |
| 23 | Char Sindur | 26.02 | 27.10 | 26.64 | 0.25 | 27.06 | 28.01 | 27.46 | 0.24 |
| 24 | Char Subuddi | 26.49 | 26.93 | 26.67 | 0.15 | 26.83 | 27.62 | 27.25 | 0.26 |
| 25 | Char Ujilaba | 27.00 | 27.27 | 27.16 | 0.09 | 27.44 | 28.08 | 27.69 | 0.20 |
| 26 | Chinishpur | 26.93 | 27.58 | 27.38 | 0.22 | 27.83 | 29.18 | 28.68 | 0.46 |
| 27 | Danga | 26.73 | 27.33 | 27.05 | 0.16 | 27.75 | 28.82 | 28.14 | 0.25 |
| 28 | Daukar Char | 27.16 | 27.40 | 27.26 | 0.10 | 27.79 | 28.09 | 27.92 | 0.11 |
| 29 | Daulatpur | 26.35 | 27.17 | 26.73 | 0.24 | 27.06 | 27.57 | 27.39 | 0.15 |
| 30 | Dulalpur | 26.21 | 26.82 | 26.58 | 0.14 | 26.83 | 27.41 | 27.23 | 0.15 |
| 31 | Ekduaria | 26.73 | 27.35 | 27.04 | 0.17 | 27.44 | 27.93 | 27.70 | 0.12 |
| 32 | Gazaria | 26.92 | 27.38 | 27.19 | 0.13 | 27.57 | 28.13 | 27.90 | 0.16 |
| 33 | Ghorashal Paurashava | 25.87 | 27.40 | 26.85 | 0.38 | 26.61 | 29.00 | 27.84 | 0.49 |
| 34 | Gotashia | 26.47 | 27.02 | 26.71 | 0.17 | 27.45 | 28.09 | 27.85 | 0.18 |
| 35 | Hairmara | 26.90 | 27.22 | 27.08 | 0.11 | 27.59 | 27.87 | 27.76 | 0.09 |
| 36 | Hajipur | 27.07 | 27.88 | 27.33 | 0.26 | 28.03 | 29.83 | 28.61 | 0.58 |
| 37 | Jinardi | 25.75 | 27.27 | 26.53 | 0.42 | 26.46 | 28.05 | 27.28 | 0.45 |
| 38 | Josar | 26.77 | 27.56 | 27.11 | 0.20 | 27.15 | 27.84 | 27.52 | 0.14 |

*Continued*

| Local government Unit ID | | LST-2001 (°C) | | | | LST-2021 (°C) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Name of the Local Government Unit | Min | Max | Mean | STD | Min | Max | Mean | STD |
| 39 | Joynagar | 26.80 | 27.30 | 27.04 | 0.11 | 27.27 | 28.02 | 27.57 | 0.19 |
| 40 | Kanchikata | 26.70 | 27.40 | 27.11 | 0.19 | 27.63 | 28.02 | 27.79 | 0.10 |
| 41 | Kanthalia | 27.20 | 27.79 | 27.48 | 0.21 | 28.10 | 28.57 | 28.24 | 0.12 |
| 42 | Karimpur | 25.32 | 27.24 | 26.24 | 0.49 | 26.31 | 27.92 | 27.13 | 0.48 |
| 43 | Khidirpur | 26.70 | 27.31 | 26.92 | 0.14 | 27.57 | 28.02 | 27.77 | 0.12 |
| 44 | Lebutala | 26.76 | 27.51 | 27.02 | 0.16 | 27.69 | 28.08 | 27.87 | 0.10 |
| 45 | Madhabdi Paurashava | 27.32 | 27.92 | 27.58 | 0.18 | 28.54 | 30.62 | 29.58 | 0.65 |
| 46 | Maheshpur | 25.91 | 26.83 | 26.45 | 0.30 | 26.66 | 27.14 | 26.95 | 0.17 |
| 47 | Mahishasura | 26.27 | 27.81 | 27.30 | 0.41 | 27.41 | 30.87 | 28.73 | 0.91 |
| 48 | Manohardi Paurashava | 26.74 | 26.96 | 26.84 | 0.08 | 27.62 | 28.16 | 27.85 | 0.18 |
| 49 | Marjal | 26.83 | 27.31 | 27.11 | 0.15 | 27.38 | 27.81 | 27.61 | 0.12 |
| 50 | Masimpur | 26.57 | 27.19 | 26.84 | 0.19 | 27.07 | 27.86 | 27.39 | 0.24 |
| 51 | Meher Para | 26.89 | 27.55 | 27.17 | 0.18 | 28.02 | 28.93 | 28.42 | 0.25 |
| 52 | Mirzanagar | 26.88 | 27.31 | 27.10 | 0.13 | 27.26 | 27.83 | 27.63 | 0.18 |
| 53 | Mirzapur | 27.00 | 27.62 | 27.16 | 0.19 | 27.05 | 28.02 | 27.49 | 0.28 |
| 54 | Mirzar Char | 25.76 | 26.68 | 26.29 | 0.30 | 26.82 | 27.46 | 27.13 | 0.21 |
| 55 | Musapur | 25.88 | 27.11 | 26.68 | 0.39 | 26.37 | 27.58 | 27.08 | 0.33 |
| 56 | Narayanpur | 26.97 | 27.55 | 27.25 | 0.13 | 27.44 | 28.09 | 27.70 | 0.17 |
| 57 | Narsingdi Paurashava | 26.81 | 28.18 | 27.69 | 0.40 | 27.59 | 29.58 | 29.02 | 0.55 |
| 58 | Nazarpur | 25.36 | 27.41 | 26.34 | 0.57 | 26.18 | 28.76 | 27.39 | 0.62 |
| 59 | Nilakhya | 25.72 | 27.86 | 26.79 | 0.51 | 26.90 | 28.53 | 27.63 | 0.40 |
| 60 | Nuralla Pur U/C | 27.13 | 27.85 | 27.47 | 0.24 | 28.18 | 29.17 | 28.73 | 0.35 |
| 61 | Paikar Char | 25.91 | 27.68 | 27.05 | 0.49 | 26.93 | 29.09 | 28.08 | 0.53 |
| 62 | Palashtali | 26.28 | 27.23 | 26.86 | 0.22 | 26.66 | 27.61 | 27.30 | 0.26 |
| 63 | Panchdona | 27.00 | 27.45 | 27.20 | 0.12 | 27.73 | 28.89 | 28.13 | 0.27 |
| 64 | Paratali | 25.87 | 27.40 | 26.80 | 0.44 | 26.72 | 27.94 | 27.47 | 0.33 |
| 65 | Patuli | 26.67 | 27.83 | 27.43 | 0.32 | 27.16 | 27.64 | 27.40 | 0.12 |
| 66 | Putia | 27.09 | 27.53 | 27.35 | 0.12 | 27.25 | 28.59 | 28.08 | 0.41 |
| 67 | Radhanagar | 26.83 | 27.08 | 26.95 | 0.09 | 27.27 | 27.81 | 27.61 | 0.16 |
| 68 | Roypura | 25.80 | 27.13 | 26.61 | 0.42 | 26.53 | 27.09 | 26.87 | 0.16 |
| 69 | Roypura Paurashava | 26.38 | 27.13 | 26.79 | 0.31 | 27.01 | 27.20 | 27.08 | 0.07 |
| 70 | Sadhar Char | 26.17 | 27.33 | 26.96 | 0.31 | 26.86 | 28.07 | 27.54 | 0.36 |
| 71 | Sallabad | 27.36 | 27.76 | 27.53 | 0.13 | 27.43 | 28.27 | 27.84 | 0.20 |
| 72 | Shibpur Paurashava | 27.00 | 27.19 | 27.11 | 0.06 | 27.22 | 27.71 | 27.50 | 0.15 |
| 73 | Shukundi | 26.61 | 27.05 | 26.87 | 0.12 | 27.39 | 27.78 | 27.65 | 0.12 |
| 74 | Silmandi | 27.24 | 27.71 | 27.41 | 0.14 | 28.22 | 29.92 | 28.66 | 0.42 |
| 75 | Sreenagar | 25.63 | 27.44 | 26.39 | 0.44 | 26.28 | 27.86 | 27.04 | 0.35 |
| 76 | Uttar Bakharnagar | 26.81 | 27.21 | 27.03 | 0.13 | 27.37 | 27.73 | 27.58 | 0.10 |

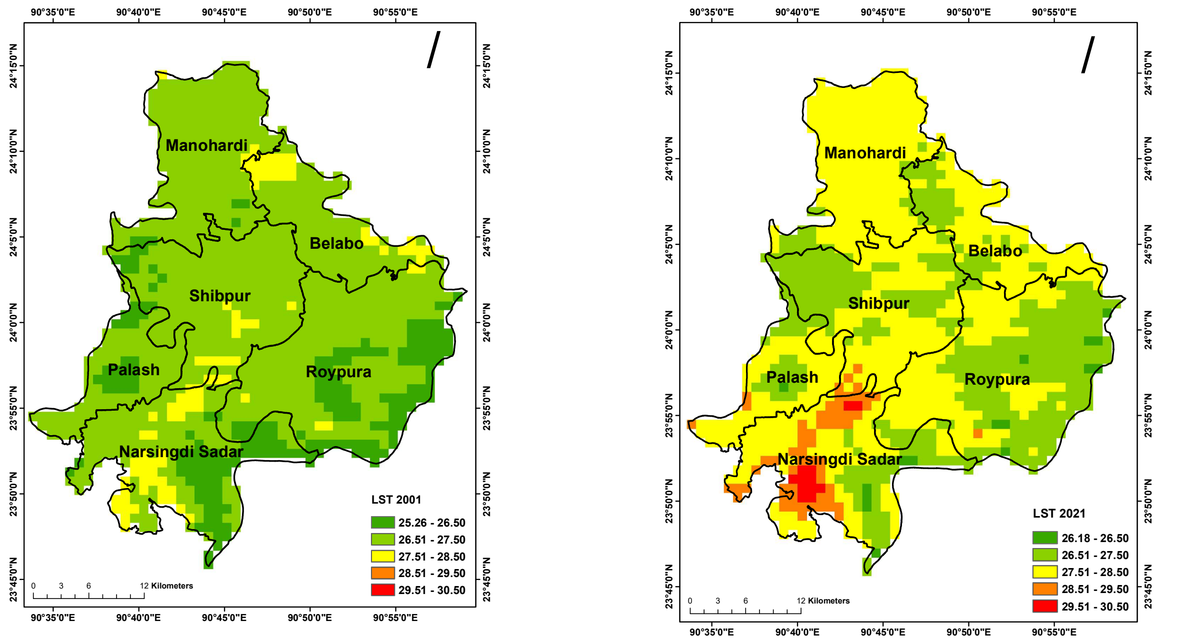



**Figure 7.** Land Surface Temperature (Degree Celsius) at the Upazila in Narsingdi district in 2001 and 2021 in Bangladesh.

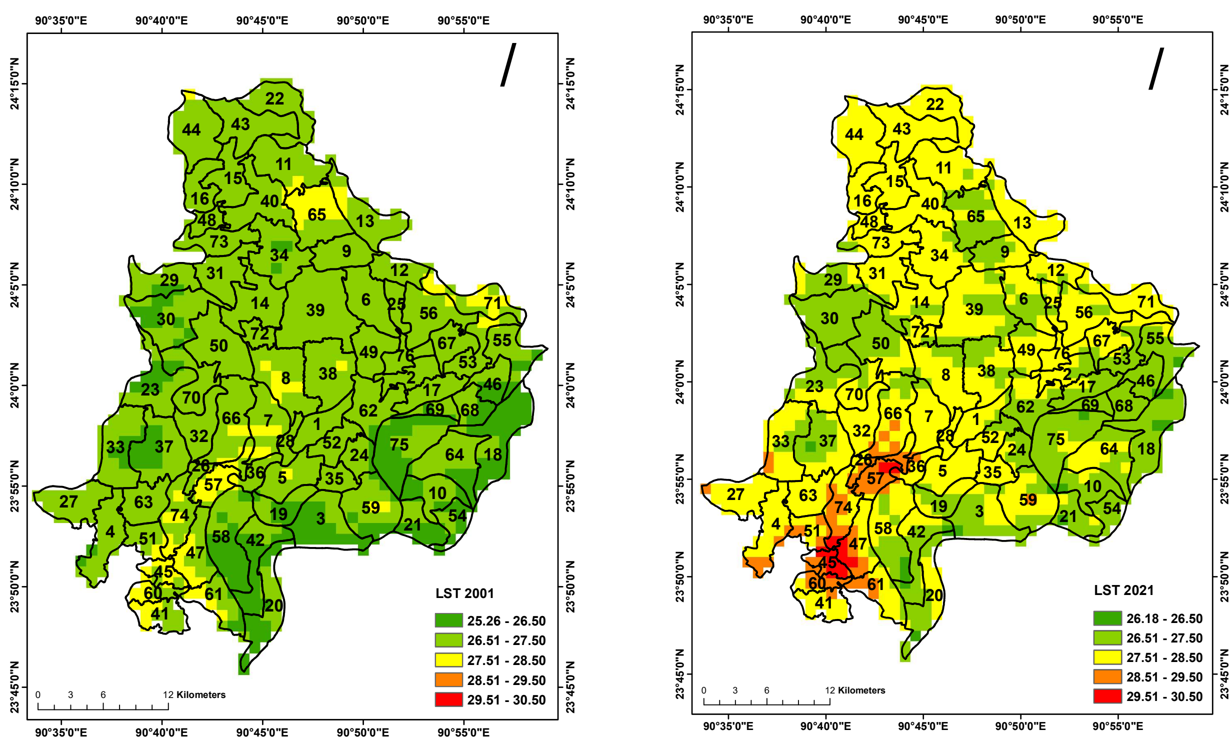



**Figure 8.** Land Surface Temperature (Degree Celsius) at the smallest local government unit in Narsingdi district in 2001 and 2021 in Bangladesh.

**Correlation Between LST and NDVI**

In 2001, the correlation between LST and NDVI was 0.71, and in 2021, it was 0.21. Both the relationship was positive. However, in 2021 the correlation was very low. Generally, with the increase of vegetation coverage, NDVI increases, and LST decreases. However, in recent days, global warming has played an essential role in global temperature increase. It seems the climate change trend has affected the LST and NDVI in 2021. For this reason, vegetation coverage increased but the temperature increased instead of decreasing (Figure 9).

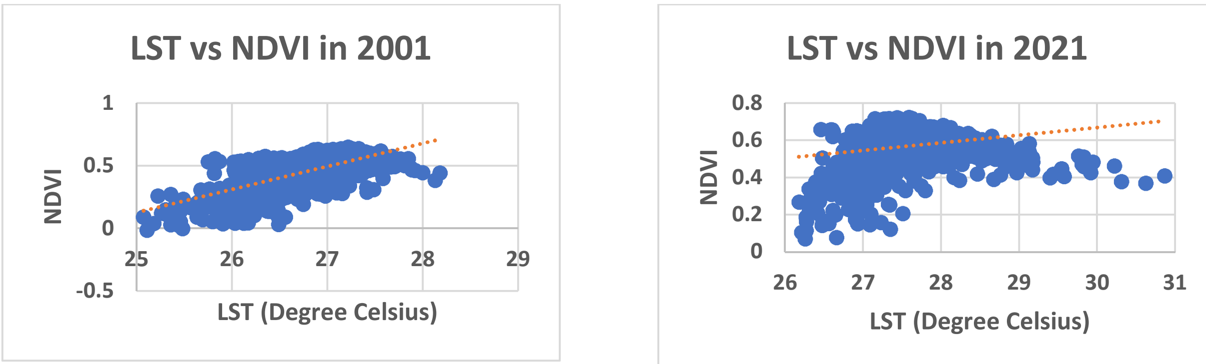
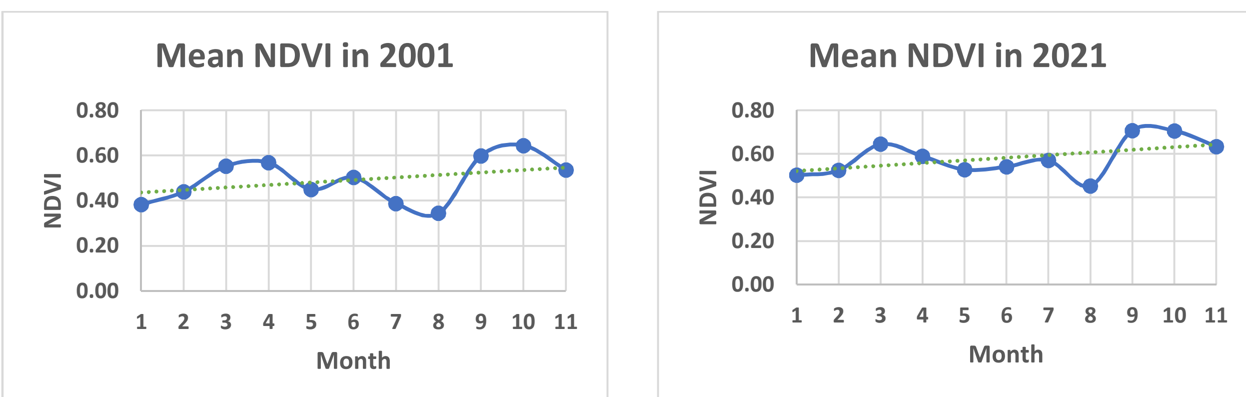



**Figure 9.** Correlation between LST and NDVI in 2001 and 2021 in Narsingdi district of Bangladesh.

Monthly Mean NDVI

Considering the monthly mean NDVI in 2001, the minimum NDVI was 0.34 in August and the maximum was 0.64 in October. Those were 0.45 in August, the minimum, and 0.71 in September, the maximum in 2021 (Figure 10). An overall increase in NDVI value was observed between 2001 and 2021.

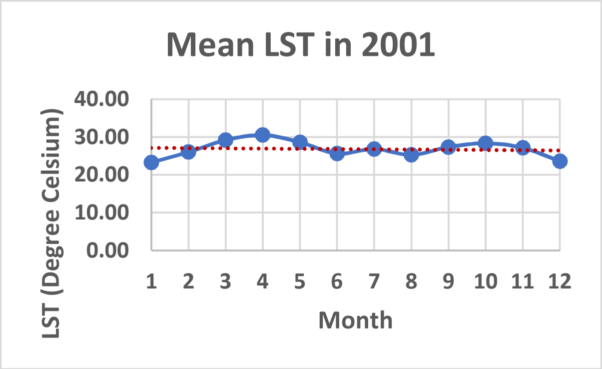


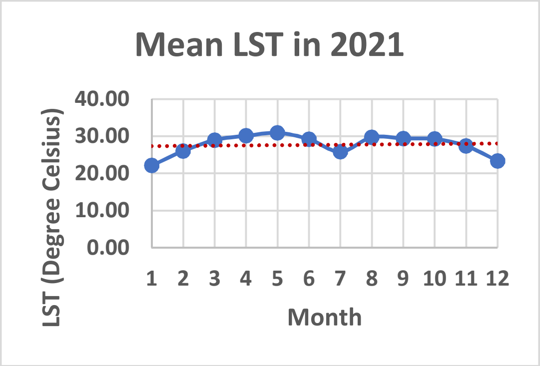

**Notes: 1=Jan, 2=Feb, 3=Mar, 4=Apr, 5=May, 6=June, 7=July, 8=Aug, 9=Sep, 10=Oct, 11=Nov**

**Figure 10.** Monthly mean NDVI in 2001 and 2021 in Narsingdi district of Bangladesh.

Monthly Mean LST

In the change of two decades, a gradual change in land surface temperature is observed. Considering the monthly mean LST in 2001, the minimum LST was 23.30°C in January, and the maximum was 30.55°C in April. Those were 22.14°C in January, the minimum, and 30.89°C in May, the maximum in 2021 (Figure 11). The lowest value of temperature decreased, and the highest value increased slightly. With the increase of mean NDVI, the upward shift of land surface temperature is proof of gradual climate change and global warming worldwide.




**Notes: 1=Jan, 2=Feb, 3=Mar, 4=Apr, 5=May, 6=June, 7=July, 8=Aug, 9=Sep, 10=Oct, 11=Nov, 12= Dec**

**Figure 11.** Monthly mean LST in 2001 and 2021 in Narsingdi district of Bangladesh.

Yearly Mean NDVI

A steady upward change in NDVI value and land surface temperature was recorded from 2001 to 2021. Considering the yearly mean of the NDVI from 2001 to 2021, the highest value, 0.58, was found in 2021. While the lowest value, 0.46, was found in 2004 (Figure 12). The trend of NDVI from 2001 to 2021 is increasing.

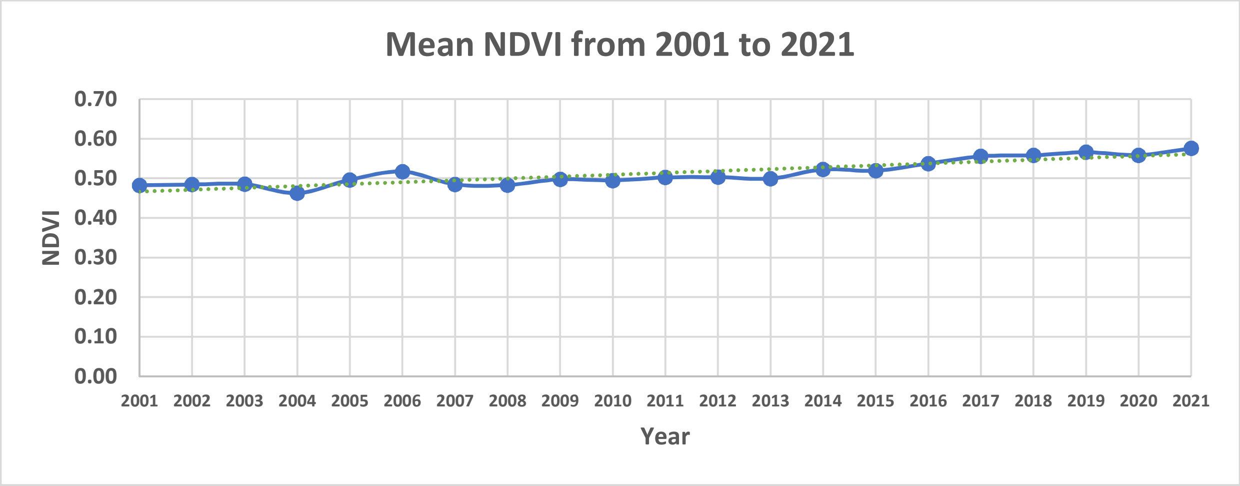



**Figure 12.** Yearly mean NDVI from 2001 to 2021 in Narsingdi district of Bangladesh.

Yearly Mean LST

The trend of LST from 2001 to 2021 is increasing. Considering the yearly mean of the LST from 2001 to 2021, the highest value, 27.98°C, was found in 2021. While the lowesc t value, 26.35°C, was found in 2003 (Figure 13).

**Discussion**

In the present study, the land use land cover changes were analyzed in the Narsingdi district from 2001 to 2021 and found a sharp decrease in agricultural land and a severe increase in a built-up area. At the same time, a gradual decrease in the water body and a moderate increase in forest vegetation coverage was also observed. Comparing the average results presented in Table 3, it is found that the agricultural land decreased from 64.39% to 53.31%, and the water body reduced from 9.94% to 7.47% from 2001 to 2021. In contrast, forest vegetation coverage increased from 22.31% to 26.05%, and the built-up area raised from 3.37% to 13.17% during the same time. Among all the changes, the increase in a built-up area and decreased agricultural land were found to be more significant. These findings are similar to those of

(Hussain *et al.,* 2022), where Pakistan's built-up area increased by 4.5% from 2001 to 2021. The results are also in the same line of the research, which showed that the built-up area increased in Saudi Arabia by 2.6% from 2001 to 2021 (Chouari 2022). Kiran *et al.,* (2022) represented the same changes in India. Rajshahi observed a remarkable increase in built-up area by 11.71% and a decrease in agricultural land by 12.40% (Kafy *et al.,* 2021a) in Rajshahi from 1999 to 2019. Ashwathappa *et al.,* (2022) reported a decrease in the water bodies in India from 2001 to 2021. An increase in built-up area and a decrease in agricultural land are also mentioned by Agoha *et al.,* (2021) in their research. In the present study, rapid urbanization found as the primary cause behind the changes, also similar to the reports of Kafy *et al.,* (2021a), Ashwathappa *et al.,* (2022), Agoha *et al.,* (2021), and Tasin *et al.,* (2022).

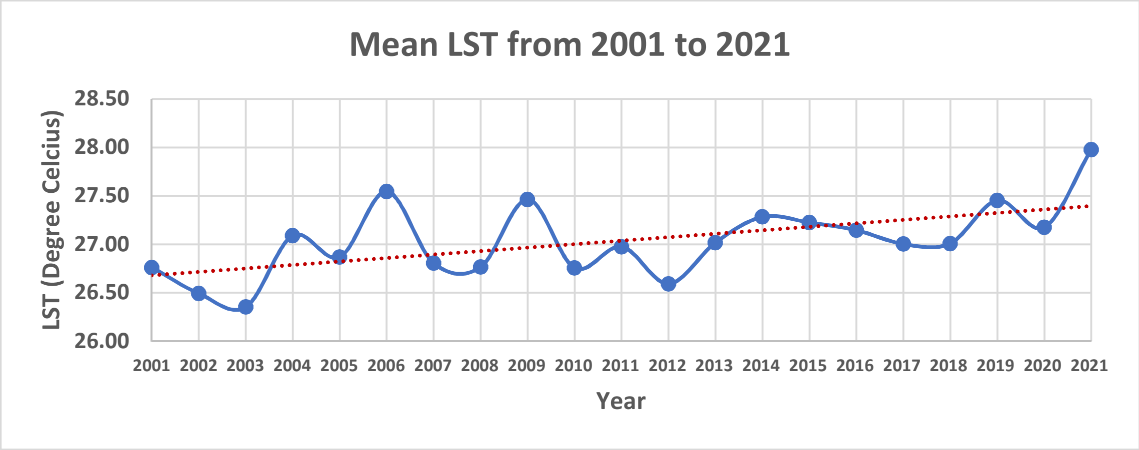



**Figure 13.** Yearly mean LST from 2001 to 2021 in Narsingdi district of Bangladesh.

Results of the present study exposed that the NDVI value increased over the last two decades in different areas of the Narsingdi district. This finding is in line with the results by Das *et al.,* (2022) revealed that an NDVI value increase of 0.11 from 2001 to 2021 is almost similar to this study (0.10). Similar reports are also found in China, where the NDVI value gradually increased from 2000 to 2015 (Wang *et al.,* 2021). An overall increasing trend of NDVI is also reported by Xu *et al.,* (2021) from 2001 to 2017. An increased rate of NDVI value (0.001/year) was calculated from 2001-2016 by Lou *et al.,* (2021). After the field visit, it was observed that urbanization and industrialization increased massively, and the educated city dweller also became aware of the necessity of green vegetation and engaged their open space and roof for growing plants.

Moreover, some places have been deforested during the last two decades due to urbanization and industrialization. Everyone knows, when the large tree exist, the germination rate and survival capacity of undergrowth reduced as they are less competitive for the open sunlight. But, when the large trees are cut down, the bushes and other lianas get open sun and an appropriate environment for germination and rapid growth. Thus, through the field visit, it is found some places that if though there are no large mature trees in practical but represented a high NDVI value because of the well growth of bushes and lianas. The gradual growth of temperature also acted here as a favourable external factor for quick increase of the seed germination rate and survivality.

The land surface temperature increased in the Narsingdi district during the last twenty years. The findings are similar to the results provided by Ibraheem and Al-hadithi (2022), who showed that the total temperature increased in Baghdad by 5°C from 2001 to 2021. Das *et al.,* (2022) stated that an increase in LST ranged from 2.97 to 8.34°C from 2001 to 2021. The temperature and even the NDVI increase are remarkable evidence of climate change and global warming. Besides, the rapid growth of impermeable concrete layer in the urban area, population growth, and release of heat and greenhouses gases (GHGs) from the increased industries and vehicles are responsible for the increasing land surface temperature.

Based on the land use and land cover changes in different Upazilas of the Narsingdi district, Belabo is found as more vulnerable to agricultural land conversion to other land uses. Built-up areas increased significantly in Narsingdi Sadar Upazila than in any other Upazilas. There is under 20% forest vegetation coverage in two Upazilas – Narsingdi Sadar and Roypura. In Roypura, forest vegetation coverage increased from 10.47% to 16.09% in the last two decades but decreased in Narsingdi Sadar from 11.11% to 8.91%. Water bodies decreased throughout the Upazilas except for Palash, and a noticeable decrease was observed in Narsingdi Sadar by 4.66% and Roypura by 7.62%.

The mean value of the normalized difference vegetation index increased in all Upazilas, and in Roypura, the increase was remarkable from 0.41 to 0.54 during the last twenty years. The mean value of NDVI improved more in Roypura than in Narsingdi Sadar. The overall land surface temperature also increased with the time lapse, and a significant increase was detected in Narsingdi Sadar, where the mean temperature increased by 1.14$^{o}$C from 2001 to 2021. Considering existing green space, NDVI and LST, it is clear that the Narsingdi Sadar Upazila is found as a more critical area, followed by Roypura.

## Conclusions

In the Narsingdi district, the land use and land cover change, normalized difference vegetation index, and land surface temperature of six different Upazilas and seventy-six unions were detected by using satellite imageries from 2001 to 2021. Land use and land cover changes observed severe in two adjacent Upazilas – Narsingdi Sadar and Roypura. In Narsingdi Sadar, agricultural land, forest cover, and water body are decreased by 6.67%, 2.2%, and 4.66%, and built-up areas increased by 13.53%, respectively, during the last two decades. At the same time, in Roypura, agricultural land and water body decreased by 10.94% and 7.62%. In contrast, built-up area and forest vegetation coverage increased by 12.94% and 5.62%, respectively. Mean NDVI values increased in all the Upazilas but significantly increased in Roypura by 0.13. In Narsingdi Sadar Upazila, the forest coverage decreased, and total forest vegetation coverage is less than half of the required forest cover of plain land. The land surface temperature increased in Narsingdi Sadar Upazila evidently by 1.14$^{o}$C during the last twenty years. The visual changes indicate that Narsingdi Sadar Upazila is a critical area in the Narsingdi district. The adjacent Upazila, Roypura, has also become vulnerable nowadays. Rapid urbanization and industrialization, the rapid growth of city dwellers and traffic, the release of excessive heat from the impervious concrete layers and industries, production of greenhouse gases from the industries and vehicles, climate change, and global warming are detected as the driving factors of green spaces loss and land surface temperature rise.

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## Statement of author's credit

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