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Research article

Exploring the Role of Population Dynamics in Surface Urban Heat Island Hotspots in Peri-Urban Dhaka

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Abstract

This study investigates the hotspots of surface urban heat island (SUHI) in the peri-urban areas of Dhaka based on the nexus of population dynamics, urban expansion, and land surface temperature. The respective land use land cover (LULC) classification and land surface temperature (LST) estimation were derived for 2000 and 2022 using images from Landsat-5 and Landsat-8, respectively, by applying established equations. Urban growth and its relation to LST were estimated using the classification based on the random forest and normalised difference built-up index (NDBI). The latter are directly associated with economic activities. The results indicated increased LST over time with urban sprawl and population increase, and hotspots were typical in high male-dominated migration rates and highly dense industrial activity. This study gives insight into the sustainable approach to urban planning and managing populations through clarity on the prevailing relationships among population growth and urbanisation with changing temperature.

Keywords: Land surface temperature; Land use land cover; population dynamics; Surface urban heat island; Urban expansion.

1. Introduction

Growth in Dhaka Megacity was explosive from 1 million in 1972 to over 17 million in 2015. It ranks 8th among the most populous cities and 7th among the densest cities in the world, growing at an annual growth rate of 3.48% (UNFPA, 2016). This has been a very unplanned trend in nature, contributing to habitat transformation (Asgarian *et al.,* 2014), ecosystem degradation (Su *et al.,* 2012), and loss of agricultural lands (Lambin *et al,* 2011), besides disturbing the hydrologic cycle (Brown *et al.,* 2011). Rapid growth of urbanisation with an imbalanced pattern has put Dhaka into a critical situation, placing the eco-sensitive environment and land resource at risk. For instance, the natural waterbodies and wetlands within the periphery of Dhaka are undergoing severe transformation into built-up areas through landfilling and multi-storeyed concrete establishments in different modalities, especially the real estate developments (Hassan *et al.,* 2017). So, the expansion of Dhaka megacity is occurring at the expense of critical environmental, ecology and natural land resources by adding impervious surfaces such as rooftops, buildings, and paving. Thus, urban sprawl has substituted natural waterbodies and wetlands with built-up areas with low albedo and high heat storage. It changes energy balance of the entire existing environment by altering the transfer and storage of energy due to urbanisation (Streutker, 2017). Also, urban activities like vehicular traffic, fossil fuel burning, energy generation, etc. generate heat as a by-product which becomes a cause of heat pollution and a responsible factor of SUHI (Haashemi *et al.* 2016). So, the crowding in the city centre would, in all likelihood, lead to the intensification of the SUHI, in areas of dense urban development (Shah and Ghauri, 2015). Haashemi *et al.* (2016) support the finding that the core city gets considerably hotter compared to its peri-urban surroundings through amplification by heat generation from urban activities.

While there is no evidence yet to connect these changes with spatiotemporal phenomena, the rate of increase has been growing enormously. Worldwide many studies concentrated about the surface urban heat island (SUHI) on different cities (Li *et al.,* 2020; Manoli *et al.,* 2019; Raj *et al.,* 2020; Shastri *et al.,* 2017; Zhou *et al.,* 2017; Yao *et al.,* 2017; Hu *et al.,* 2019; Chun & Guldmann, 2018; Huang *et al.,* 2016). Despite rapid urban expansion with high population growth and their impacts on the environment of Dhaka, the volume of scientific research linking urbanisation with other spatio-temporal phenomena is still nominal and yet to yield a conclusion. Most of the prior studies on Bangladesh cities focuses on the urban land use land cover (LULC), land surface temperature (LST) and the urban heat island (UHI) separately (Kant *et al.,* 2018; Roy *et al.,* 2016; Uddin *et al.,* 2022; Tabassum *et al.,* 2024) or to assess LULC linking with LST (Roy *et al.,* 2016; Ahmed *et al.,* 2013; Xiong *et al.,* 2012). Also, some limited studies have been conducted about the SUHI (Itzhak-Ben-Shalom *et al.,* 2017; Kant *et al.,* 2018; Roy *et al.,* 2016; Dewan *et al.,* 2021a; Dewan *et al.,* 2021b), but the peri-urban areas of Dhaka city are still unseen.

However, this study extends its objective compared to the earlier works. It aims to identify SUHI hotspots in a peri-urban area of Dhaka mega urban region linking both LULC change, and commensurate population dynamics triggered by urbanisation. It is important for health risk mitigation due to SUHI and sustainable urban development. Therefore, such a study potentially benefits in foreseeing and identifying the potential location of SUHI hotspots and their physical direction in response to the population dynamics evolved by socio-economic factors. This would serve the needs of the city planners and the authorities in managing SUHI and thus encouraging the people towards sustainable growth.

2. Material and Method

2.1. Study Area

This area falls into the polycentric zone connecting Dhaka with the neighbouring cities and periphery areas according to RAJUK's Structure Plan for Dhaka 2016-2035 and updated Dhaka (Figure 1). Metropolitan Development Plan (DMDP). The area in short comprises the Dhaka Metropolitan Area (DMA) and the extra eight municipalities and 51 unions falling within central Bangladesh (Rajuk, 2006). It belongs to hot and humid tropical climate classes (Rabbani *et al.,* 2019). According to estimation, many researchers rank Dhaka city as one of the fastest-growing cities in the world.

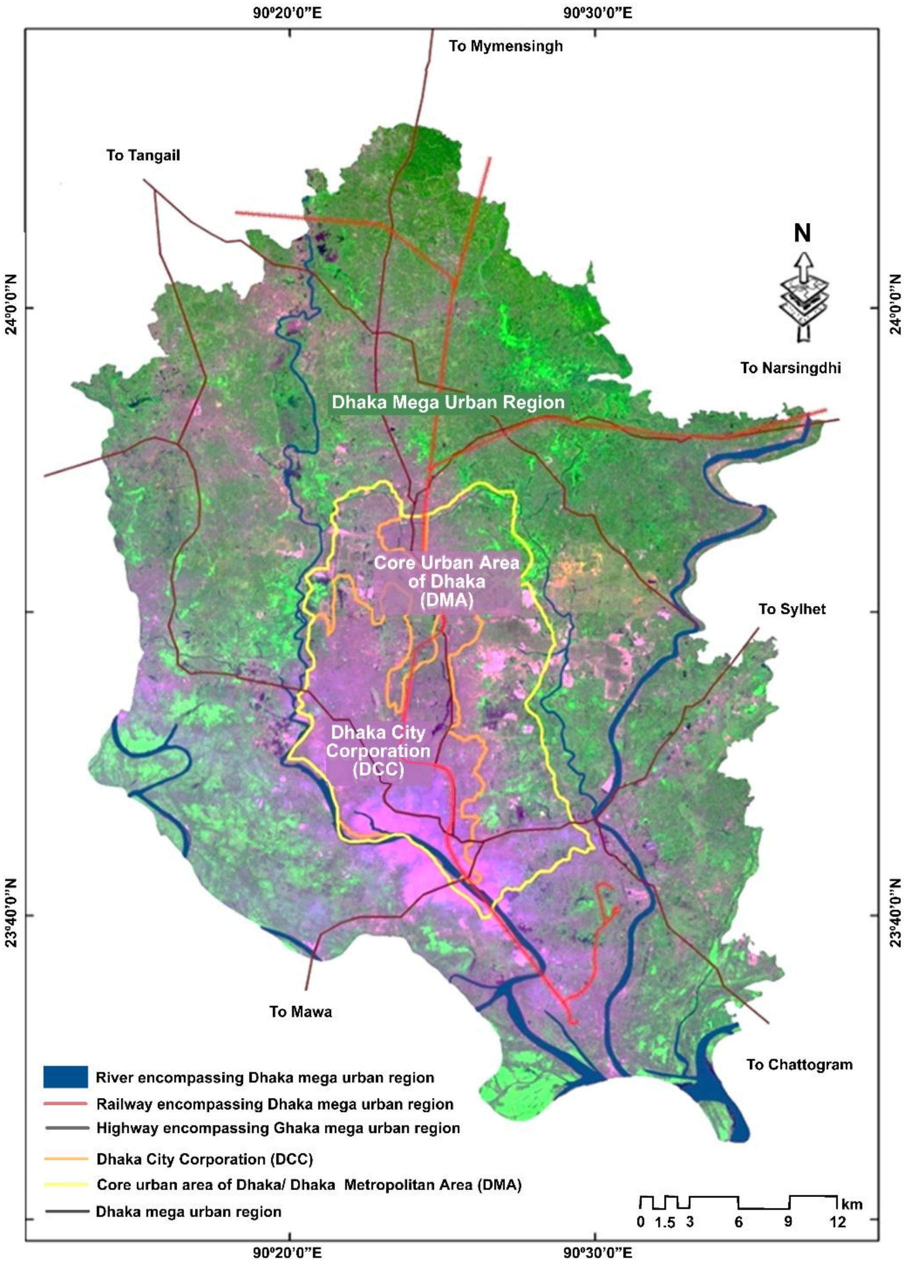

Figure 1. The Study Area of The Dhaka Mega Urban Region.

Geomorphologically, it features alluvial terraces and low-lying areas near the Meghna and Shitalakkhya rivers (Hassan and Southworth, 2017). The area benefits from extensive regional and national highways, enhancing its connectivity and attractiveness for investment and labour (Hassan and Southworth, 2015). The tropical monsoon climate results in heavy rains from May to September, with summer temperatures exceeding 30°C and January being the driest month.

2.2. Data Requirement and Preparation

This study utilised multi-temporal Landsat images, census data, GIS databases, and field data. Four cloud-free post-monsoon Landsat scenes from USGS (http://earthexplorer.usgs.gov/) were analysed, including Landsat-5 TM and Landsat-8 OLI, both geometrically corrected to UTM projection. Focusing on the dry season for minimal cloud interference, we applied the FLAASH atmospheric correction method in ENVI 5.3 for high accuracy (Matthew *et al.,* 2002). Digital numbers were converted to top-of-atmosphere (TOA) radiance and then to surface reflectance. GIS data on administrative boundaries, road networks, and other features were sourced from the Urban Development Directorate, Dhaka City Corporation, and RAJUK. Additionally, LULC maps from the Survey of Bangladesh were used for classification accuracy assessment.

Table 1. Data Sources of the Satellite Images.

Temporal Year	Date	Sensor	Path/ Row	Spatial Resolution	Spectral resolution	Cloud cover (%)
2020	2022-02-11	LANDSAT 8 OLI/TIRS	137/43	30 m	RGB and NIR bands (30 m) and Thermal infrared bands (100 m resampled to 30 m)	0
	2022-02-11		137/44	30 m		0
2000	2000-02-20	LANDSAT 5 TM	137/43	30 m	RGB and infrared bands (30 m) and Thermal infrared band (120 m resampled to 30 m)	0
	2000-02-20		137/44	30 m		0

2.3. LST Calculation and SUHI Identification

To assess the impact of urban growth on SUHI, this study analysed variations in Land Surface Temperature (LST), which are influenced by Earth's energy balance, surface properties, sunlight exposure, and cloud cover (Ahmed *et al.,* 2013). We extracted LST from Landsat images, comparing different periods and contrasting Dhaka's core urban area with its surroundings. Atmospheric temperatures for these dates were sourced from NOAA, WMO, and BMD.

LST calculations involved first deriving the Normalized Difference Vegetation Index (NDVI) from near-infrared and red band reflectance (Roy *et al.,* 2016). Land surface emissivity, crucial for accurate LST calculation, was estimated using a modified NDVI threshold method (Sobrino *et al.,* 2004) based on vegetation proportion (PV) with threshold values set accordingly (Sobrino and Raissouni, 2004) (see Table 2).

Table 2. NDVI Threshold Values for Different Surface Characteristics.

Surface characteristics	NDVI threshold	Estimation of emissivity
Bare land, impervious surface	0 < NDVI <0.2	ε = ai ρred + bi (Roy *et al.,* 2016) ρred is the red band's reflectivity
Vegetation	NDVI >0.5	εv + Ci, Ci is cavity effect by the surface roughness of mixed surface area (Sobrino *et al.,* 2004)
Mixed of bare land and vegetation	0.2 ≤ NDVI ≤0.5	ε = m PV + n (Sobrino *et al.,* 2004) PV is vegetation proportion.

Finally, LST calculation was done from Landsat-5 TM for the year 2000 by the well-established single-channel method used and explained in detail in several studies (Roy *et al.,* 2016). For Landsat-8 TIRS images for the year of 2022, LST was calculated using the split-window algorithm used in several studies (Roy *et al.,* 2016). Generally, temperature increases from rural to urban areas, indicating a positive linear relationship (Schatz and Kucharik, 2015). SUHI is determined by comparing surface temperatures between a city's core and its surrounding area (Voogt and Oke, 2003). SUHI was calculated for Dhaka's core (Dhaka Metropolitan Area) versus its peri-urban areas for 2000 and 2022 using this approach (Equation 1).

$$SUHI = (avg.LST)\ urban\ core\ area - (avg.LST)\ surrounding\ area \quad (1)$$

2.4. LULC Change Detection

Development of SUHI due to increased LST is a key effect of LULC changes in urban areas. Urban areas with built-up surfaces show higher LST (Mondol *et al.,* 2018), while vegetation and water bodies lower LST through cooling and evapotranspiration (Sun *et al.,* 2012). In Dhaka, landfill areas with high reflectivity contribute to increased LST (Hassan *et al.,* 2017).

LULC classifications (Table 3), based on recent Dhaka studies (Parvin and Abudu, 2017), were validated with field data. Due to mixed pixel issues in Landsat images (Weng, 2012), a hybrid classification method was used. This included atmospheric correction, unsupervised classification into 180 classes, and random forest classification with 100 spectral signatures for accurate LULC mapping for 2000 and 2022 (Ishtiaque *et al.,* 2017).

Table 3. LULC Classes Defined in This Study.

Classes	Descriptions
Barren Land	Landfills of both earth and sand, developed land, construction sites.
Built-up Areas	Infrastructure of all kinds—residential, industrial, commercial, mixed use , villages, pavements, settlements, road network and anthropogenic structures
Vegetation	Natural vegetation, trees, forest (mixed), grasslands, parks and gardens, playgrounds, and agricultural lands.
Water-bodies	Rivers, canals, open water (permanent), lakes, ponds, wetlands (permanent/seasonal), low lands and swamps

Accuracy was assessed using an error matrix and Kappa values (Roy and Mahmood, 2016), comparing 200 randomly selected reference pixels for each time-period with land use maps (Shastri *et al.,* 2017) (Table 3). Field surveys in February 2020 provided data for the current year, while Google Earth imagery and a topographical map of 2000 from the Urban Development Directorate served as references for 2000. The accuracy of the land cover maps is approximately 90%, with Kappa values of 0.85 for 2000 and 0.89 for 2022, assessed using Cohen's Kappa Coefficient.

Table 4. Accuracy Assessment of LULC Classification of The Study.

	Percentage			
Year	**2022**		**2000**	
LULC	**Producer Accuracy**	**User Accuracy**	**Producer Accuracy**	**User Accuracy**
Water-bodies	87.50	94.23	91.03	93.42
Vegetation	90.91	92.59	89.23	85.29
Built-up Area	98.53	90.54	93.33	89.36
Potential Built-up Area	85.00	89.47	63.64	87.50
Overall		92.04		89.55
Kappa		0.89		0.85

2.5. Extraction of Physical Index

Since built up area or impervious surface is the major spatial feature of urban area (BBS, 2012), NDBI (Normalized Difference Built-Up Index) was used due to its ability to reveal pixels that represent impervious surfaces. The value range of NDBI is between -1 to +1, negative value representing water-bodies and positive value representing other types of land uses including built up areas or impervious surfaces. The value range of the latter is 0 to 0.2. NDBI was calculated from the surface reflectance of mid infrared and near infrared band using a well-established equation described in several studies (Roy *et al.,* 2016; Zha *et al.,* 2003).

2.6. Population Dynamics Analysis

Population data were collected from the population census and the sample census questionnaire, respectively, conducted by the Bangladesh Bureau of Statistics (BBS). Population data is available in Bangladesh at the Union level. Dhaka's mega-urban region comprises the Dhaka Metropolitan Area, eight municipalities, and 51 Unions. Based on this administration, population data of 60 administrative units (1 DMA+8 municipalities+51 Unions) were collected from the last census of Bangladesh (BBS, 2012). This study used projected population data for 2022 using a modified version of the Malthusian growth model. The malthusian growth model has been expressed in previous studies in detail (Mondol *et al.,* 2018).

2.7. Methodological Framework

Initially, the study identified the intensity of the Surface Urban Heat Island (SUHI) effect by comparing Land Surface Temperature (LST) between the Dhaka Metropolitan Area (DMA) and its surrounding areas. To examine whether Land Use and Land Cover (LULC) changes in DMA contribute to increased LST, bivariate analyses were performed at the Thana level for 2000 and 2022, revealing significant correlations. Regression analyses were then conducted to assess the relationship between mean LST changes (dependent variable) and changes in each LULC class (independent variables) for both years, mitigating multicollinearity effects.

The results indicated a positive correlation between LST and both barren land and built-up areas within DMA. Since SUHI is an urban phenomenon, only the core urban area (DMA) was analysed for its relationship with LULC and LST. Additionally, regression analyses were performed to investigate the impact of urban expansion and population dynamics on SUHI, correlating urban land expansion (dependent variable) with net population change (independent variable). Barren land was considered part of the built-up area in this analysis due to its role in land reclamation and construction projects.

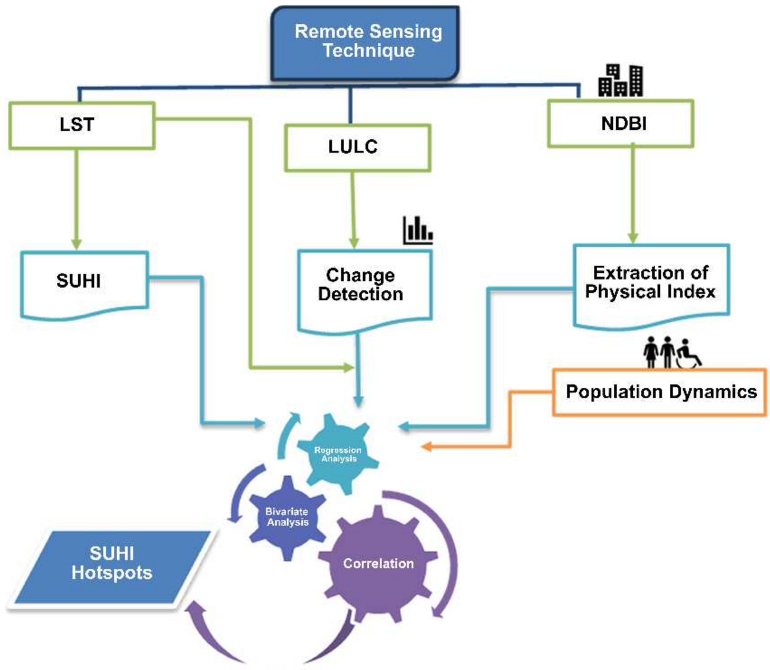

Figure 2. Methodological Framework for Assessing SUHI Hotspots.

In the subsequent phase, SUHI hotspots in peri-urban areas were identified by analysing the relationships between urban expansion, net population change, and LST. Significant positive correlations between these factors and LST were used to determine the intensity of SUHI. Risk ratings for SUHI hotspots were assigned based on three criteria: normalised LST, increase in built-up land (NDBI), and net population change per square kilometre. These criteria were standardised to a common range and weighted equally in a risk assessment model, classifying areas from very low to very high risk. Administrative units with over 50% high to very high-risk areas were designated as SUHI hotspots (Figure 2).

Qualitative validation involved stakeholder feedback from policymakers, experts, and residents and in-depth observations of SUHI hotspots. Attributes such as highway presence, road density, sex ratio, and population density were analysed to understand their roles in urban expansion and SUHI intensity. Historical causes of urban growth were also investigated through discussions with residents to corroborate the findings.

3. Results

3.1. Spatio-temporal Pattern of LST

In 2000, the land surface temperature (LST) across the Dhaka mega-urban region ranged from 11.9°C to 23.7°C. The central portion of the study area predominantly exhibited LST values around 20°C. By 2022, the LST across the region had increased significantly, ranging from 17°C to 32.6°C. Much of the area now experiences a mean LST exceeding 20°C. In the urban core, particularly within the Dhaka Metropolitan Area (DMA), the mean LST has risen to approximately 25°C, with some eastern regions reaching temperatures of 28°C and above. This increase is attributed to the rapid industrial expansion and extensive barren sandy lands created for development projects (Figure 3). The LST change map was calculated based on the normalised LST (NLST) of 2000 and 2022, which was increased by 0.70, Figure 4.

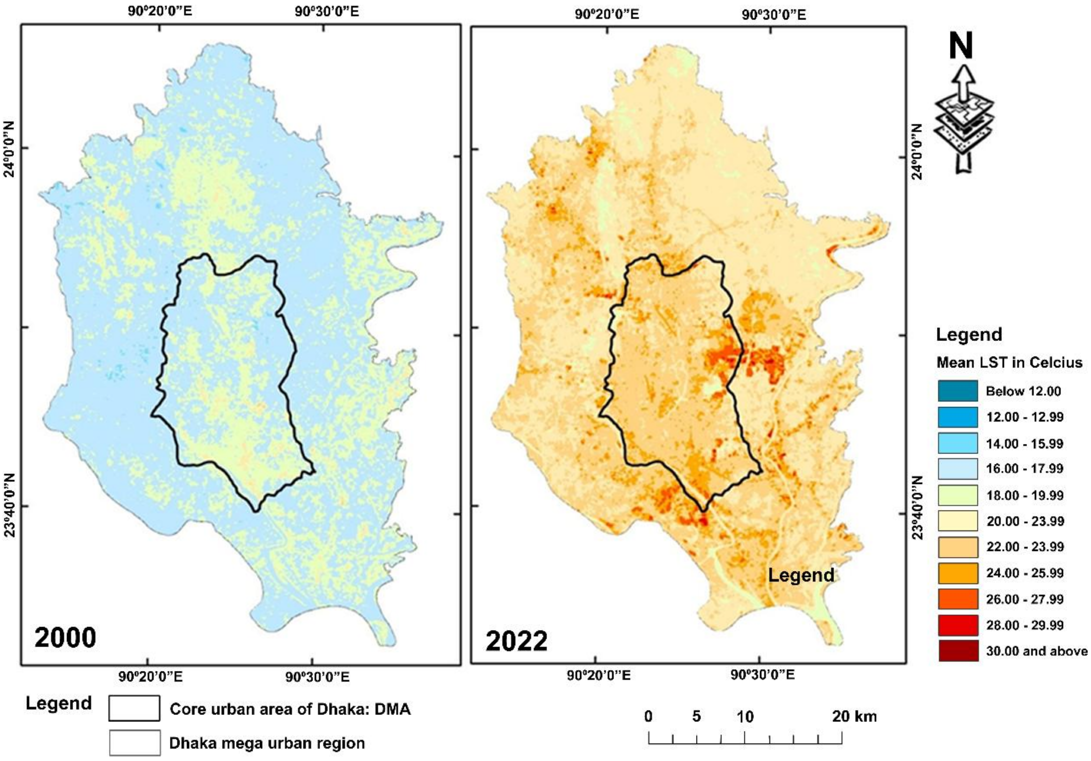

Figure 3. Mean Land Surface Temperature (LST) Scenario in Dhaka Mega Urban Region In 2000-2020.

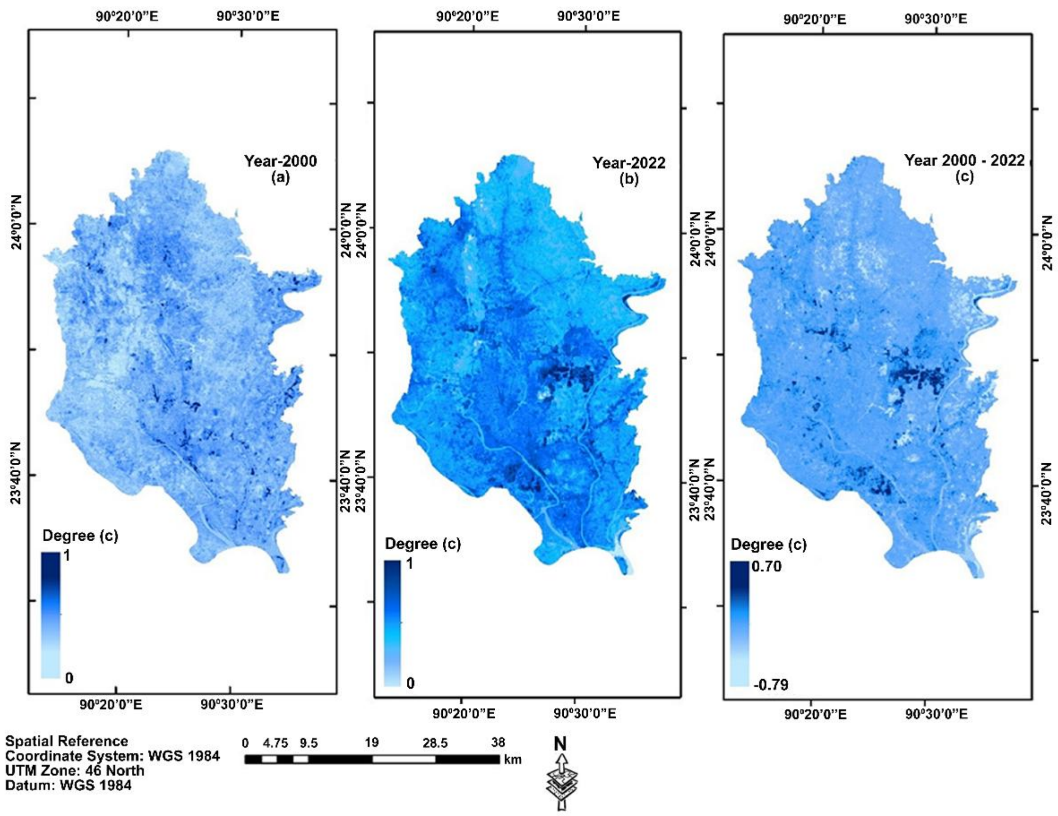

Figure 4. Spatial distribution of changes in calculated normalised LST in 2000-2022 period in study area.

3.2 SUHI identification within Dhaka Mega Urban Region

Dhaka Metropolitan Area (DMA) is historically and administratively the urban core area, whereas the rest of the study area is mainly the peri-urban area. From Table 5, it is evident that DMA acted as a surface urban heat island (SUHI) in 2000, and its intensity increased about 0.49 OC in the 2000-2022 time periods. The LST of both DMA (urban core area) and the rest of the study area (peri-urban area) increased to near about 5 ^{O}C in the last 22 years.

Table 5. SUHI Scenario in DAP of Mega-Urban Region of Dhaka in 2000-2020.

Year	Mean LST (°C)		
	Urban core area	Rest of the study area	SUHI Intensity
2000	18.07	17.84	0.23
2022	22.97	22.25	0.72
Temporal Difference (2022-2000)	4.41	4.9	0.49

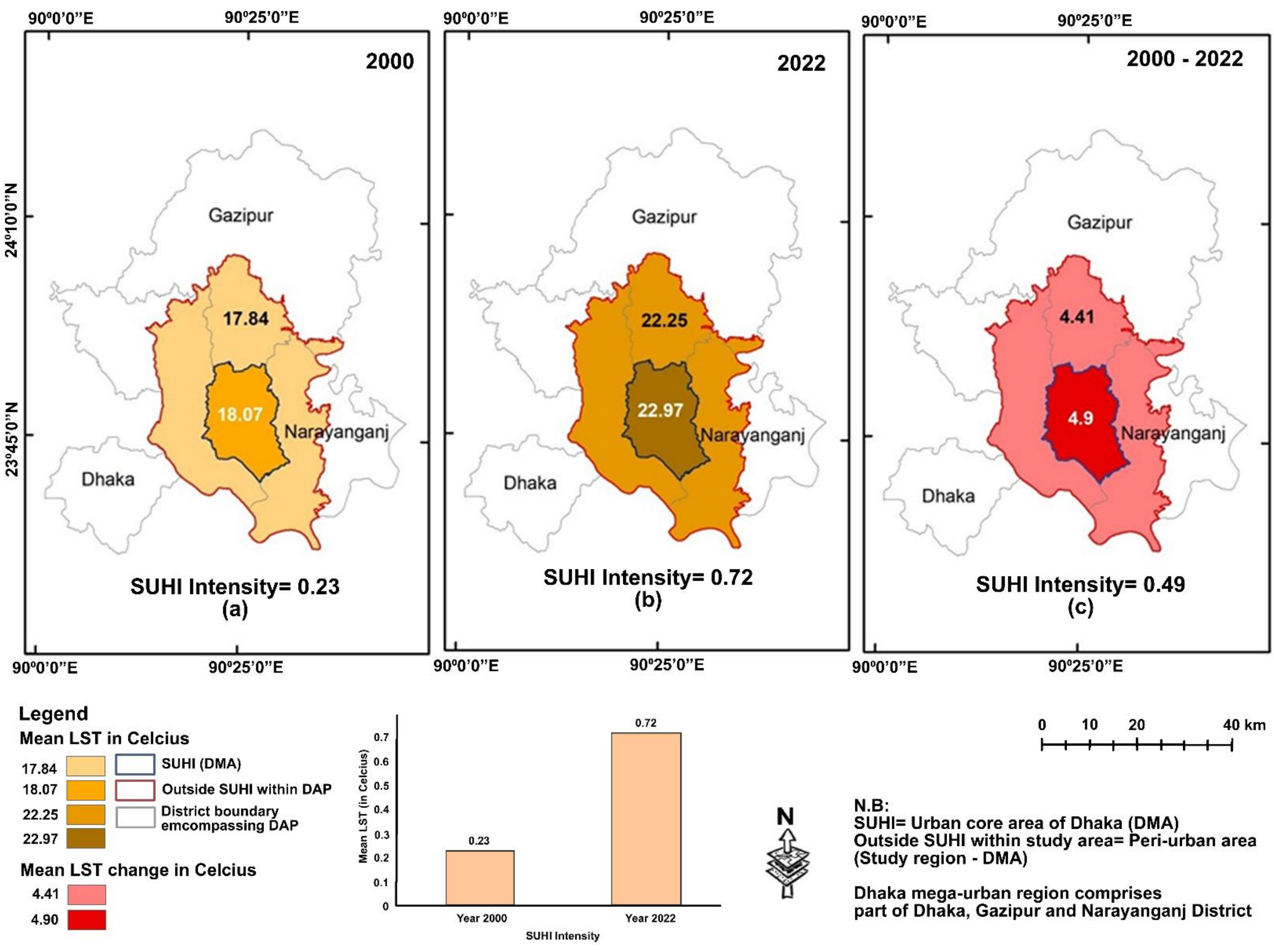

Figure 5. SUHI Scenario in Dhaka Mega-Urban Region in 2000-2022.

3.3. Spatio-temporal Pattern of LULC Change

Spatial arrangement of LULC of the study region portrays that built-up area as well as barren land increased rapidly in the last 22 years, whereas vegetation and water bodies decreased subsequently. More precisely, built-up area and barren land increased by 135% and 110% respectively in the last 22 years (Table 6 and Figure 6). The conversion pattern among LULC classes suggests that other LULC classes, i.e. vegetation, water and barren land, are the primary contributors to built-up area expansion, whereas barren land has been forming with the cost of losing water bodies and vegetation (Table 7).

Table 6. LULC Changes within Dhaka of Mega-Urban Region in 2000-2022.

LULC Class	Area (in sq. km)			% of the total study area		
	2000	2022	2000-2022	2000	2022	2000-2022
Waterbodies	351.33	194.65	-156.68	22.91	12.69	-44.60
Vegetation	954.40	817.46	-136.94	62.24	53.30	-14.35
Built-up area	170.17	400.50	230.33	11.10	26.11	135.35
Barren land	57.52	121.23	63.71	3.75	7.90	110.77

Table 7. Conversion Matrix Among LULC Classes of Dhaka Mega Urban Region in 2000-2022.

	2022					
	Class Name	Water	Vegetation	Built Up	Barren land	Total
2000	Water-bodies		79.17	44.52	32.99	156.68
	Vegetation	-79.17		175.04	41.07	136.94
	Built-up area	-44.52	-175.04		-10.81	-230.33
	Barren land	-32.99	-41.07	10.81		-63.71
	Total	-156.68	-136.94	230.33	63.71	0

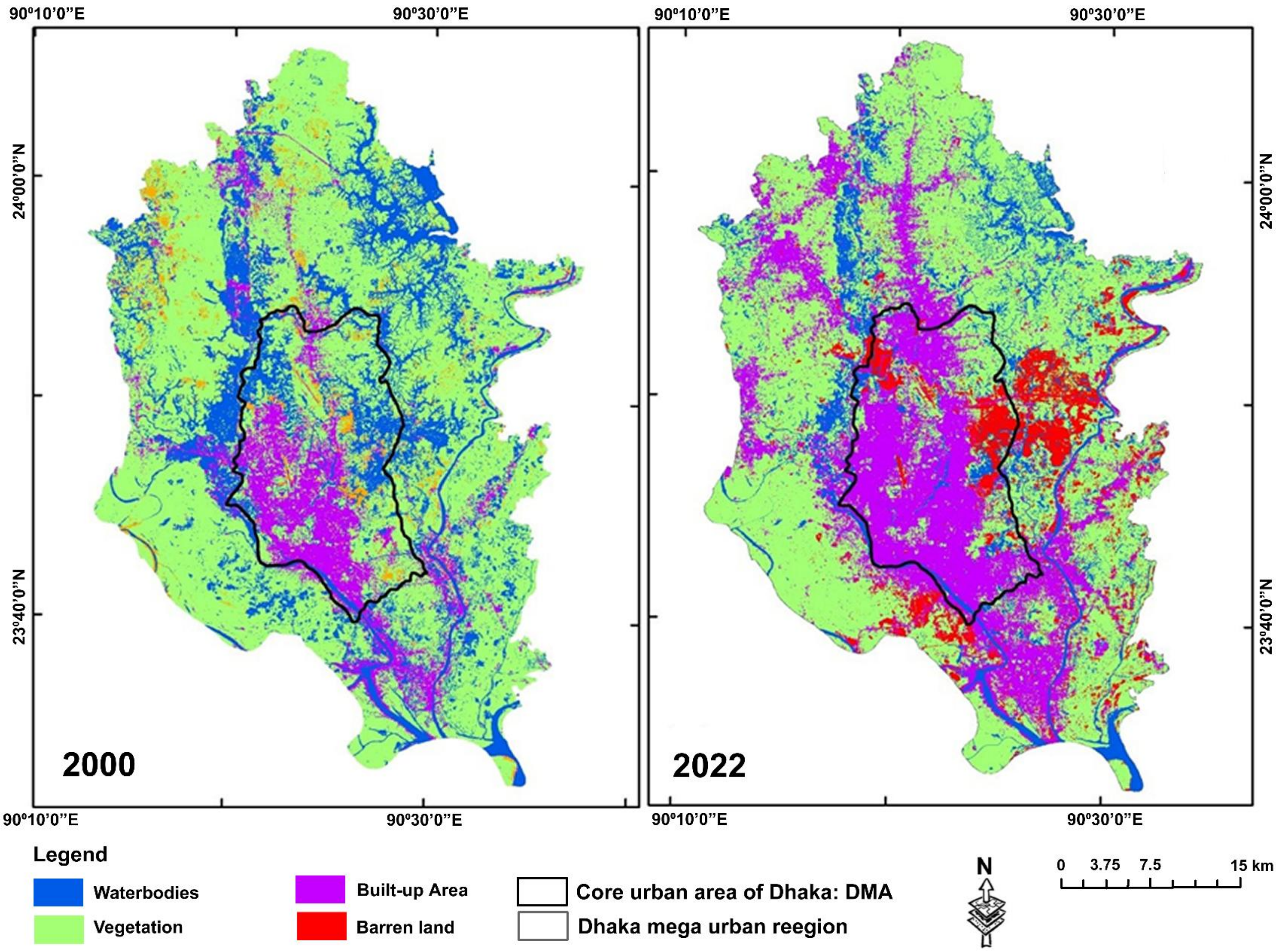

Figure 6. LULC Change in Dhaka Mega Urban Region in 2000-2022.

Figure 6 shows that in the last twenty years, an increasing trend of built-up area has been observed towards the north, northwest, and southeastern parts of the region. Barren land, which was mostly found in the northern part of the region in 2000, shifted towards the central east just near the city in 2022. Barren land in 2000 has already become a built-up area in 2022.

3.4. Linking LST with LULC and Population Dynamics in SUHI Scenario

3.4.1. Urban Built-Up Land Expansion as a Contributing Factor of Increasing LST in SUHI

From the above discussion, it has been observed that the Dhaka mega urban region has been experiencing an increasing trend both in mean LST and built-up land expansion over the last 22 years. Mean LST of all LULC classes was below 19ºC in 2000, which increased to around 23°C in 2022. Figure 7 shows the increase of mean LST by LULC classes in 2000-2022 where built-up area shows highest increase of mean LST (4.69°C) because of the compactness of the surface along with build infrastructures compared to other LULC classes i.e. vegetation and water bodies supporting the hypothesis of rapid urbanization being responsible for the increase of land surface temperature. A noticeable fact addressed that all land cover types experienced an increase in LST over the periods (e.g., even for vegetation).

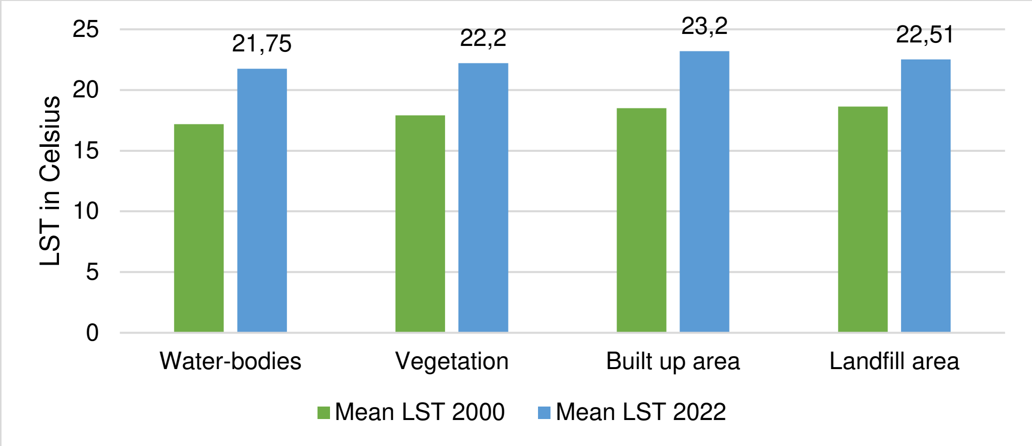

Figure 7. Mean LST Change (2000-2022) by LULC Classes in Dhaka Mega Urban Region.

Since DMA was identified as a surface urban heat island (SUHI) within the Dhaka mega urban region, DMA was chosen as the focus area for exploring the relationship of LST and urban built-up land expansion. In the Dhaka mega urban region, all barren land in 2000 was converted to built-up area in 2022, and new barren land was formed in the expanse of water bodies and vegetation, LULC classes (see Figure 7 and Table 7). So, both built-up area and barren land LULC class have been acting as indicators of urban expansion.

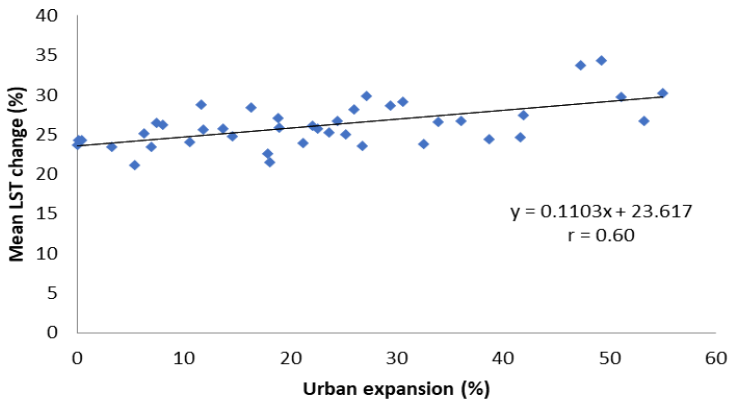

Figure 8. Scatter plot representing linear relationship between mean LST changes with an urban expansion in 2000-2022 period.

Since both built-up area and barren land LULC classes have been acting as indicators of urban expansion, regression analysis between mean LST change and urban expansion (considering both built-up area and barren land) suggests that urban expansion has a positive relationship with LST ($r \geq 0.50$) in SUHI, i.e. DMA Figure 8 during the study period.

Also, regression analysis of normalised LST and NDBI index of each year represents a similar result. Normalised LST was used to minimize seasonal effects commonly attributed to temporal variation of satellite images. As shown in Figure 9, the NDBI is positively correlated with normalised LST throughout the study period, providing evidence of increasing built-up land in a core urban area (i.e. DMA) being an important factor in aiding LST increase. The regression analysis of normalised LST and NDBI clarifies a significant improvement of the relationship from 2000 (r=0.67) to 2022 (r=0.72) (Figure 9). This result points out the growing influence of urbanisation on land surface temperature. In 2000, the relationship between NDBI and normalized LST was moderate, where the stronger correlation can be observed in 2022, reflecting the rapid urban development contributed to elevated surface temperatures.

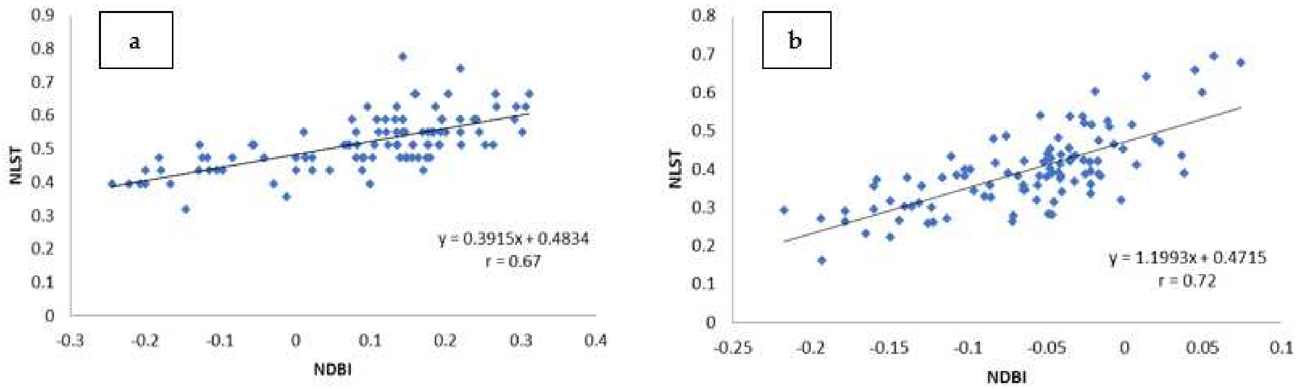

Figure 9. Linear Relationship Between Normalised LST And Physical Indicator NDBI In 2000 (A) And 2022 (B).

3.4.2. Net Population Increase as A Contributing Factor of Urban Built Up Land Expansion in SUHI and Its Surrounding Peri-Urban Area

It is already evident from Figure 8 and 9 that the increase of mean LST of DMA in 2000-2022 is due to subsequent growth of urban built-up land. Regression analysis between urban expansion and net population change at Thana level within SUHI (i.e. DMA) represents strong positive correlation (79.0%), Figure 10a, evidence that population dynamics in SUHI (i.e. DMA) has been contributing significantly to expansion of urban built-up land as well as to increase LST over the study period.

To explore the contribution of population dynamics to urban expansion in the Dhaka mega-urban region (i.e., including DMA and peri-urban area within the study area), regression analysis was also done within the study region, as shown in Figure 10b. This figure depicts urban build-up land expansion having a strong positive correlation with net population change (R=96.0%).

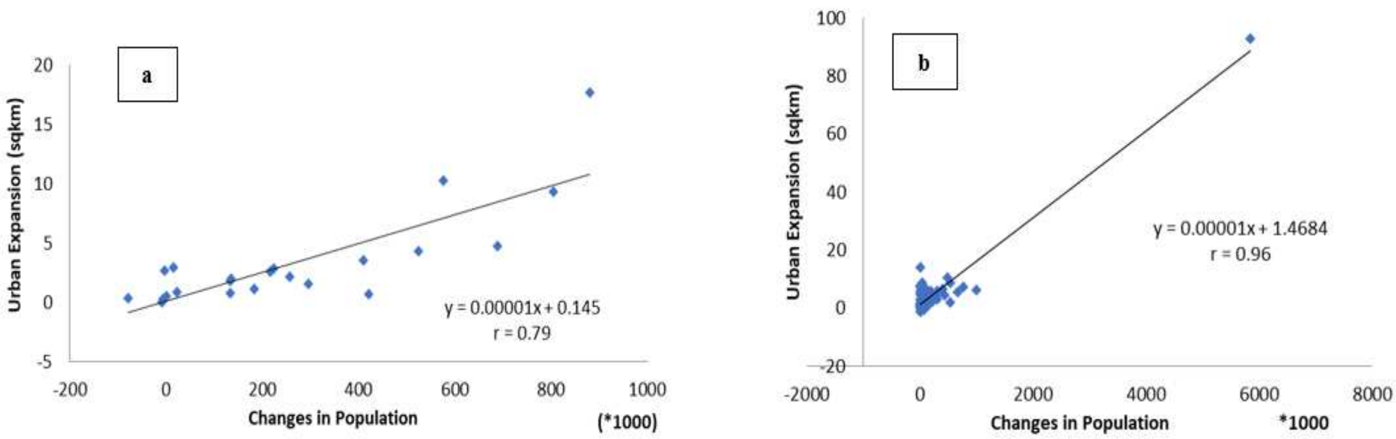

Figure 10. Scatter Plot Representing Linear Relationship of Urban Expansion and Net Population Change in (A) SUHI (DMA) and (B) Outside SUHI (Dhaka Mega Urban Region I.E. DMA and Peri Urban Area Within Study Area).

3.5. Identifying SUHI Hotspots in Peri Urban Area of Dhaka Mega Urban Region Based on Spatial Risk Assessment

It has been evident from the analysis and discussion done for this study that population dynamics is the major factor contributing to urban expansion and land surface temperature. So, urban expansion is considered to be the primary driver of SUHI, which is further influenced by the increasing trend of population dynamics, which is considered to be the secondary driver.

As shown in Figures 11 and 12, urban expansion and net population change have been experiencing an increasing trend over the study period, not only in SUHI (DMA), but also in its surrounding peri-urban area (Study region - DMA). The population growth rate outside SUHI in a peri-urban area of the Dhaka mega urban region is almost double that of in the SUHI. Figure 13 resembles the potentiality of forming new SUHI hotspot in peri-urban area and/or expansion of present SUHI (i.e. DMA) outward within the Dhaka mega urban region.

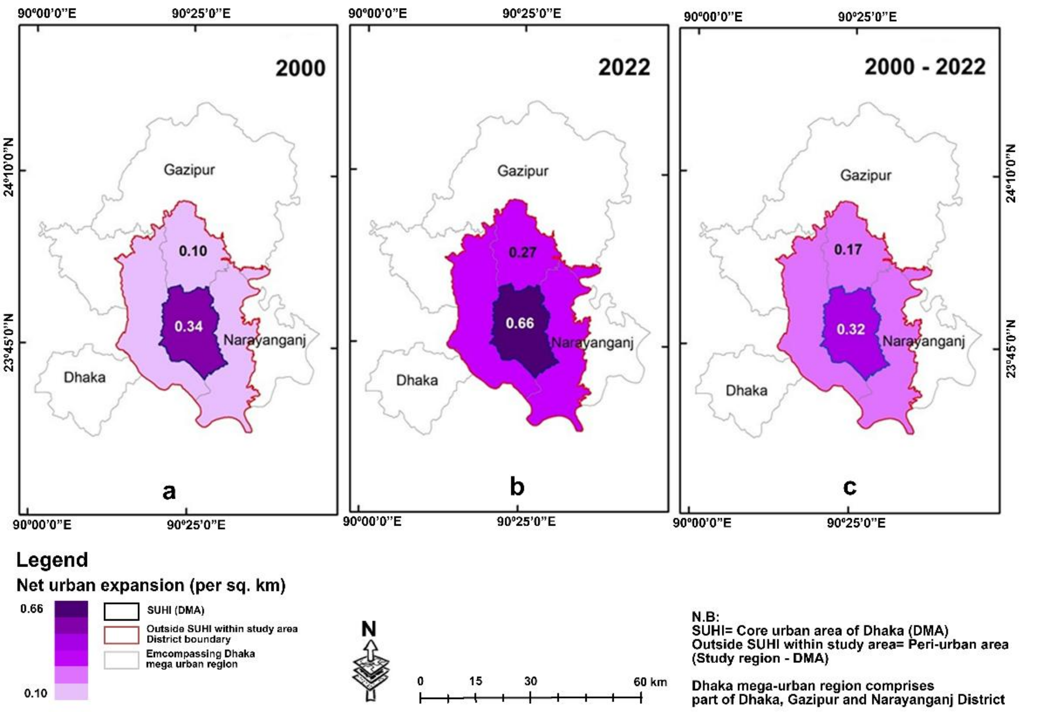

Figure 11. Net urban expansion (per sq. km) in SUHI and outside SUHI within the Dhaka mega urban region in 2000-2022.

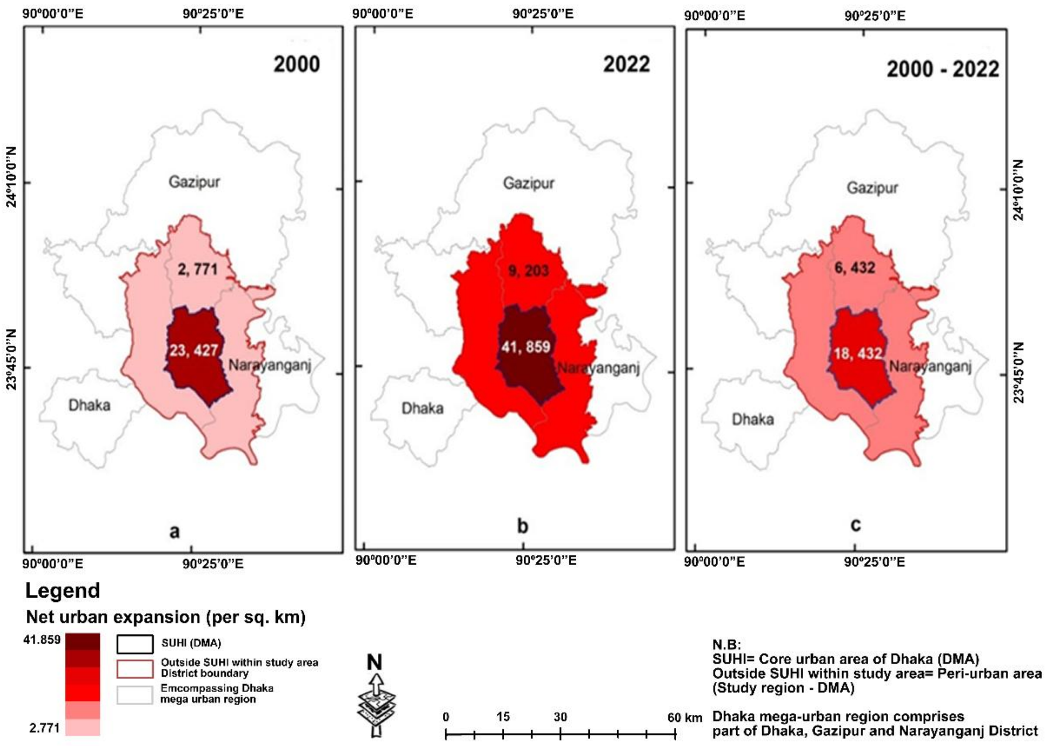

Figure 12. Net Population Increase (Km^2) in SUHI And Outside SUHI Within the Dhaka Mega Urban Region in 2000-2022.

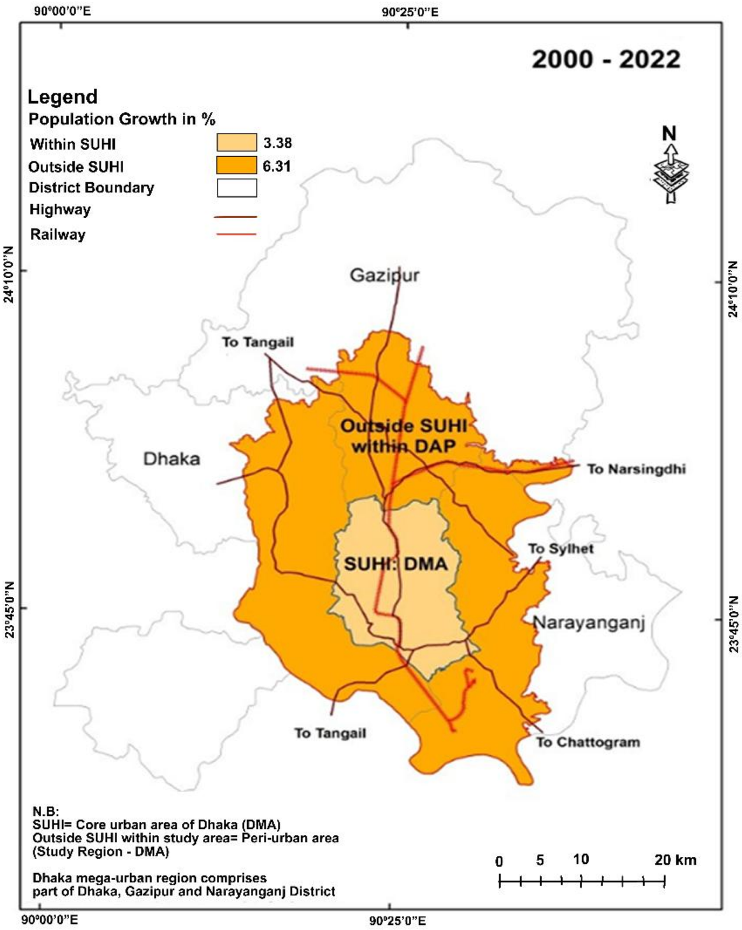

Figure 13. Net Population Growth in 2000-2022 in SUHI and Outside SUHI Within Dhaka Mega Urban Region.

The overall risk of the Dhaka mega urban region to SUHI effect is depicted spatially in Figure 14a and b presents that there are 13 unions located in a peri-urban area, which are in very high to highly risk to be SUHI hotspots, Table 8. As shown in Figure 14b, the top four unions identified as SUHI hotspots are located to the south of DMA in Narayanganj Sadar and Keranigang Upazila. The rest of SUHI hotspots are located east of DMA in Savar Upazila, only a few (two unions; Konabari and Tetuljhora) to the north in Gazipur Sadar Upazila.

Table 8. Percentage of the Total Area of Identified SUHI Hotspots Falls into Different Risk Categories.

SI	Union	% of total area					% of Area to be potential SUHI hotspots
		Very Low	Low	Moder-ate	High	Very High	
1	Kashipur	0.00	0.02	5.23	54.16	40.58	94.74
2	Fatullah	0.00	0.37	7.11	44.79	47.72	92.51
3	Subhadya	0.00	0.81	21.97	60.49	16.74	77.23
4	Siddirganj Mun.	0.00	2.93	20.22	53.78	23.08	76.86
5	Tetuljhora	0.00	2.01	23.88	60.50	13.61	74.11
6	Kutubpur	0.00	2.91	23.27	56.27	17.55	73.81
7	Savar Mun.	0.00	3.51	23.52	57.83	15.15	72.98
8	Kalindi	0.00	1.01	28.17	70.82	0.00	70.82
9	Aminbazar	0.00	3.19	32.18	64.63	0.00	64.63
10	Dhamsana	0.00	3.57	33.25	48.07	15.12	63.19
11	Tongi Mun.	0.00	12.81	33.74	46.64	6.81	53.45
12	Ashulia	0.00	14.74	31.83	47.20	6.23	53.43
13	Konabari	0.00	7.03	41.40	41.52	10.07	51.59

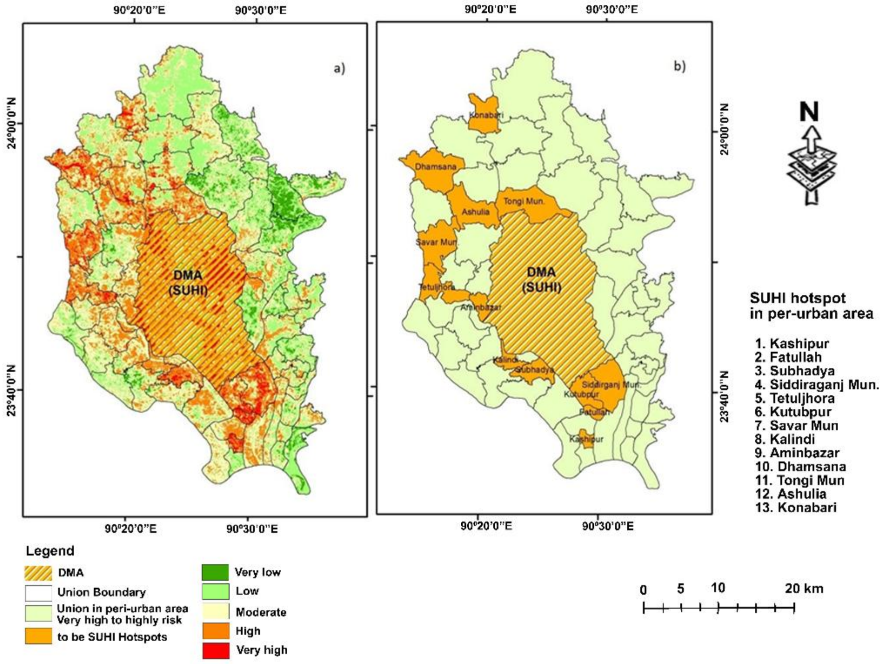

Figure 14. Spatial Risk Map of Dhaka Mega Urban Region to SUHI Effect.

3.6. Validation of identified SUHI hotspots

The result of in-depth personal observation by identifying specific attributes of identified SUHI hotspots from the census and map and verifying the population dynamics-urban expansion-land surface temperature nexus as shown in Table 9 represents that high road density, sex ratio and population density makes area fallen into very high to highly risk to be SUHI hotspots (R=84.2%). This scenario represents that accessibility and connectivity (i.e. presence of highway and high road density) attracts investors to set up industry and business which further promotes in migration of male labours to that area (identified by high sex ratio <100) and subsequent increase of urban population and activity (i.e. population density), so as formation of SUHI.

Table 9. Validation of Identified SUHI Hotspots by Identifying Specific Attributes and Verifying the Population Dynamics-Urban Expansion-Land Surface Temperature Nexus.

S1	SUHI hotspots (Union)	% of area to be potential SUHI (pSUHI	Changing Population Density (PD)	Sex Ratio (SR)	Road Density (km/sq.km) (RD)	Highway encompassing the Union	Regression analysis between pSUHI (as dependent variable) and PD1 , SR2 , RD3 (as independent variable)
			As a proxy of	As a proxy of	As a proxy of		
			Changing urbanization (UNFPA, 2016)	Male dominant in-migration (UNFPA, 2016)	Accessibility and connectivity (UNFPA, 2016)		
1	Kashipur	94.74	54431	108.33	1.74	Yes	
2	Fatullah	92.51	78980	111.16	2.29	Yes	
3	Subhadya	77.23	26688	118.75	2.16	Yes	
4	Siddirganj Mun.	76.86	24328	106.96	1.50	Yes	184.2%
5	Tetuljhora	74.11	12374	119.50	0.95	Yes	Overall level of significance= 0.9%
6	Kutubpur	73.81	32993	110.92	1.08	Yes	Individual level of significance:
7	Savar Mun.	72.98	29098	109.30	0.59	Yes	PD= 6.3%
8	Kalindi	70.82	7755	109.64	2.42	Yes	SR= 3.7%
9	Aminbazar	64.63	6108	119.26	1.60	Yes	RD= 10.0%
10	Dhamsana	63.19	31698	111.48	0.75	Yes	
11	Tongi Mun.	53.45	22653	115.43	1.08	Yes	Standardized coefficient
12	Ashulia	53.43	16255	119.28	0.71	yes	PD=40.8% SR=45.7%
13	Konabari	51.59	32125	131.43	1.32	Yes	RD=34.4%

Note : PD = Population Density (per Km^2)

SR = Sex Ratio (Male-Female)

RD = Road in km per Km^2 area

4. Discussion

The Dhaka mega-urban region is anticipated to surpass the growth rates of cities such as Shanghai, Beijing, and Mexico City by 2030 (Hassan and Southworth, 2017; UN-Habitat, 2016). As the nation's administrative, financial, and cultural hub, Dhaka has experienced continual urban expansion. Given the rapid growth in Dhaka, it is crucial to assess the potential impacts of this expansion on the peri-urban areas. Whereas studies about the consequence of LULC change on land surface temperature are prodigious, which includes Roy *et al.* (2016); Omran (2012), here, the study focuses on demarcating the SUHI hotspots in the periphery of Dhaka city. This identification depends upon the interaction among population dynamics, urban expansion, and LST. In contrast, Ren *et al.* (2007) also agree with the phenomenon of increase in the intensity in SUHI in both the core urban area-DMA, and its outskirt fringe. The maximum values in the observations of LST fall in the built-up areas and in barren lands, which reflects the influence of newly developed residential areas on the urban climate as confirmed by Weng and Yang (2004). On the contrary, within the same period of two decades, the losers were vegetation, water bodies, and barren lands as built-up areas increased by about 136%. This agrees with Tewolde's (2011) and Ahmed et al. (2013) findings. This expansion has resulted in more areas experiencing higher temperatures, highlighting the warming effects of urban microclimates (Ren *et al.,* 2007).

The positive correlation between LST and urban expansion, and between urban expansion and net population increase (Hassan & Nazem, 2015) underscores the impact of population dynamics on urban and peri-urban microclimates. Urban population growth in Dhaka is primarily driven by rural-to-urban migration, as the natural increase rates and reclassification of rural areas are less relevant due to similar total fertility rates in urban and rural areas (DHS, 2014). The influx of rural migrants is identified as a major driver of population change, aligning with Hassan and Southworth's findings (2017) and UNFPA (2016) findings regarding LULC changes and their impact on LST.

The rapid increase in population density due to migration is facilitated by high road density, as shown in Figure 12, with urban expansion occurring along major highways such as Dhaka-Mymensingh and Dhaka-Narayanganj. This expansion has led to significant industrial growth, attracting more people and increasing population density (UNFPA, 2016). Within SUHI hotspots in the peri-urban area, over 90% of the population is engaged in non-agricultural activities due to the concentration of textile and garment industries (BBS, 2012; BBS, 2017). This shift has resulted in land use and cover changes, leading to increased LST (Roy *et al.,* 2016; Ahmed *et al.,* 2013). This is instantiated by the core economic growth factors: the contribution of Dhaka's one-third to GDP (UNFPA, 2016); on the other hand, the industry sector also accounts for 28.77% share during 2015-16 (BBS, 2017). This has been contextualized by the dominant male migration pattern for economic opportunities in the textile and garment industries (Uddin, *et al.,* 2022; Hossain, 2015).

This paper makes the case for urgent targeted interventions in growth management of the urban population and mitigation of the SUHI effect for sustainable development within the mega-urban region of Dhaka, given the recent convergence of Dhaka with nearby cities like Narayanganj and Gazipur (UNFPA, 2016; Hassan *et al.,* 2017).

5. Conclusion

The result of this study found a significant relationship between urban expansion, population dynamics and the land surface temperature increase in peri-urban Dhaka. The expansion of urban areas, influx of rural migrants and concentration of textile and garment industries in SUHI hotspots leads to changes in land use and increased temperatures. The association between normalised LST and NDBI shows a stronger correlation in 2022 than in 2000. This is indicative of the growing influence of urban development on thermal dynamics and the concentration of surface urban heat island (SUHI) hotspots in the core urban area (DMA). Furthermore, the research indicates the spatial distribution of surface urban heat island (SUHI) hotspots, which are primarily located within the core urban area (DMA).

These study results point to more research gaps aside from establishing the relationships between LST increase and either urban expansion or high population density. Areas that require further research involve other causative factors of LST, including topographic attributes such as slope and elevation. Other areas include seasonal changes in LST and how they might affect the SUHI effect.

The future research also relates to the interaction of SUHI with other drivers of urban growth: biophysical, socio-economic, and institutional aspects. Besides, advanced tools, such as Google Earth Engine, may be used to monitor and analyse urban growth and microclimate in urban areas. This approach will be useful for the researcher, the urban planner, and the policy maker in managing urban development in a sustainable way to advance the cause of the SDGs. This study suggests promoting the sustainable urban planning to manage urban growth and mitigate the SUHI effect. As the city grows faster in this region, the increase of green spaces and vegetation in urban areas can help to reduce the temperature.

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Conceptualization: Mahmood, R., Hassan, F. & Kulsum, U.; **methodology**: Mahmood, R.; **investigation**: Mahmood, R., Hassan, F. & Kulsum, U.; **writing—original draft preparation**: Mahmood, R., & Hassan, F.; **writing—review and editing**: Mahmood, R., Hassan, F, Kulsum, U.; **visualization**: Mahmood, R., & Hassan, F. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

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