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Identifying and Mitigating Heat Islands in Dhaka: A Study on Urban Vulnerability and Climate Resilience

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Abstract

Heatwaves pose a significant threat to cities globally, and Dhaka, with its high population density, unplanned urbanization, and heavy traffic, stands out as one of the most vulnerable urban centres to the effects of global climate change, notably heatwaves. To tackle this issue, a study aimed to identify the most vulnerable areas termed potential heat islands (HIs), within Dhaka City, including both Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). Analysis of secondary weather data highlighted April to June as the hottest months annually. Leveraging Landsat 8 satellite imagery from 2015 to 2022 and employing QGIS software, the study identified seven potential heat islands: Mirpur HI, Tejgaon HI, Badda HI, Bashundhara HI, Uttara HI, Old Dhaka HI, and Konapara HI. Of these, the first five were within DNCC, covering 37.16% of the area, while the remaining two were in DSCC, covering 39.77%. Analysis of land use and land cover (LULC) indicated that these heat islands were predominantly composed of built-up areas, with Mirpur, Badda, Tejgaon, and Old Dhaka heat islands consisting of over 70% built-up areas each, and Konapara and Uttara heat islands containing more than 50%. Notably, green and blue spaces were limited, with blue spaces constituting less than 10% and green spaces following a similar trend. The study emphasized the role of increased built-up areas in reducing albedo rates and elevating temperatures, while the lack of green and blue spaces hindered natural cooling processes, exacerbating heat issues. Urgent actions are needed to enhance green and blue spaces in Dhaka City, particularly within heat island zones, to mitigate the urban heat island effect and enhance resilience to heat waves, thereby fostering a healthier and more sustainable urban environment.

Keywords: *Heatwave, Climate Change, RS-GIS, Remote Sensing, Heat Island.*

Introduction

Our modern world is witnessing rapid industrialization and urban development, primarily concentrated in urban areas, where over half of the global population resides, contributing to approximately 80% of the world's GDP (Bank, 2022). Cities have emerged as pivotal drivers of global economic growth and advancement. However, alongside their prominence, cities also harbour detrimental aspects, with the swift and sometimes unplanned expansion being a primary driver of pollution and environmental degradation. Responsible for up to 75% of total greenhouse gas emissions, cities face heightened environmental challenges due to their dense population, infrastructure, and pollution levels (Forum, 2022; UNEP, 2022). Among these challenges, extreme temperatures pose a significant threat, especially in cities like Dhaka,

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known for excessive pollution and inadequate urban planning (Hasan, 2021). Extreme heat adversely affects human health, particularly impacting vulnerable groups like the elderly and males in Bangladesh (Tan et al., 2010).

A heatwave, characterized by high temperatures and elevated humidity levels over an extended period, is a global meteorological phenomenon influenced by various factors such as atmospheric conditions and high-pressure systems (NOAA, 2022). During a heatwave, temperatures rise significantly above normal averages, persisting for days or weeks, impacting the environment, infrastructure, agriculture, and human health.

Urban heat islands, where temperatures in metropolitan areas are notably higher than surrounding rural areas, result from a combination of natural and human-induced factors (Taha, 2004; Xie, Wang, & Feng, 2015). These factors include insufficient green and blue spaces, low-albedo urban materials, increased energy consumption, transportation activities, and urban planning and infrastructure deficiencies. Understanding these causes is vital for implementing effective mitigation strategies and enhancing urban resilience to extreme heat events. This study aims to identify potential heat islands within Dhaka city, pinpointing areas most vulnerable during heatwaves and assessing the underlying causes contributing to this vulnerability.

Study Area

Our research focused on Dhaka city, located within the Dhaka district of Bangladesh, spanning coordinates from 23.896 N to 23.668 N and from 90.330 E to 90.511 E. Dhaka city is divided into two distinct metropolitans: the southern part, known as Dhaka South City Corporation (DSCC), and the northern part, referred to as Dhaka North City Corporation (DNCC). DSCC covers an area of 99.7 km^2, while DNCC spans 200.7 km^2. With a population exceeding 23 million and a growth rate of 3.25% (Review, 2023), Dhaka city represents a significant urban centre in Bangladesh. Figure 1 illustrates a detailed map of our study area.

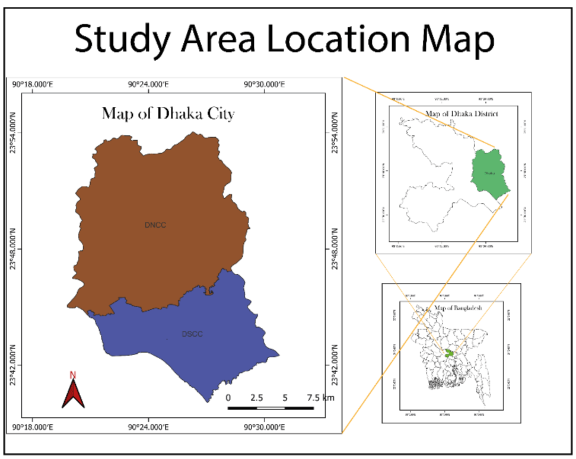

Figure 1: Location map of the study area.

Method

In our study to identify heat islands in Dhaka city, we employed a quantitative approach. Initially, we analyzed Dhaka's temperature and weather data from the past 10 to 15 years to determine the hottest months of the year. Data from 'weatherspark.com' (2022) were utilized, considering factors such as average temperature, rainfall, cloud cover, and average hourly temperature. This analysis aimed to identify the most suitable months for observing the heat island effect, leading us to conclude that April to June is optimal.

Next, we utilized a remote sensing and geographic information system (RS-GIS) methodology to detect heat islands in Dhaka city. Landsat 8 satellite imagery was employed to create temperature maps of Dhaka at specific times and identify heated zones. Quantum GIS software, version 3.18.3, served as our operational tool. Bands 10 and 11 of Landsat 8 imagery were utilized for the analysis. All imagery was sourced from https://earthexplorer.usgs.gov/. The Semi-automated Classification Plugin within QGIS 3.18.3 was used to prepare temperature maps from Landsat 8 band 10 and 11 imagery.

Five distinct sets of imagery from April to June, spanning from 2015 to 2022, were utilised to create temperature maps. Imageries with minimal cloud cover (less than 10%) were selected to minimize errors resulting from cloud coverage (Cheng et al., 2012). The imageries of 2016, 2017, and 2020 did not fulfil the condition expressed before. The dates of the satellite imagery utilized are detailed in Table 1.

Table 1: Date of the capture of the satellite imagery from 2015 to 2022 with their name.

Name of file	Year	Date
LC08_L1TP_137044_20150418_20200909_02_T1	2015	April 4th
LC08_L1TP_137044_20180528_20200901_02_T1	2018	May 28th
LC08_L1TP_137044_20190515_20200828_02_T1	2019	May 15th
LC08_L1TP_137044_20210418_20210424_02_T1	2021	April 18th
LC08_L1TP_137044_20220523_20220525_02_T1	2022	May 23rd

In Landsat 8 Level-1 satellite imagery, two types of data are produced by the sensor: Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). For detecting land surface temperature (LST), only TIRS data is necessary. TIRS sensor generates two bands: Band 10 and Band 11. Band 11 often exhibits higher noise issues, while Band 10 provides more accurate outcomes (Missions, 2019). Therefore, in our study, Band 10 was selected for determining LST.

Microwave radiation travelling upward from the atmosphere to the satellite, represented in Landsat Level-1 data or digital numbers (DN), can be converted to the top of atmosphere (TOA) brightness temperature using thermal constants provided in the metadata file. The process of determining the land surface temperature of the raster data is outlined in the Landsat 8 user handbook (Zanter, 2016). The first step involves converting the DN value into radiance by applying the following formula: $L\lambda = ML * Qcal + AL$ (1)

Where,

Lλ = Spectral radiance (W/(m2 * sr * µm))
ML = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_10 from the metadata)
AL = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_10 from the metadata)
Qcal = Level 1 pixel value in DN

Then the spectral radiance data (in equation 1) can be converted to brightness temperature which is the effective temperature by applying the following formula (Zanter, 2016),

$$T_c = \frac{k2}{\ln\left(\frac{k1}{L\lambda}+1\right)} - 273.15 \qquad (2)$$

Where,
T = Top of atmosphere brightness temperature in Celsius
where:
Lλ = TOA spectral radiance (Watts/(m2 * srad * µm))
K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_10, where 10 is the thermal band number)
K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_10, where 10 is the thermal band number)

This process was done by the QGIS 3.22 software by using the semi-automated classification plugin. Five different files were produced representing the land surface temperature of different timelines.

Potential Heat Island identification

After determining the LST, the next step was to identify the highest heated spot in the city from the LST maps. Heated zones were identified from each map, and those were combined to create an accumulated heat island map from the year 2015 to 2022 in April to June by using the QGIS software. To separate the zones as potential heat islands, temperatures greater than 2 degrees centigrades from the average temperature of Dhaka were considered. Then the common areas from each map were intersected with the QGIS by using a geoprocessing tool.

Land use classification map

After that, to evaluate the heat island land use and land cover scenario, a supervised classification map was prepared for the DNCC, and another supervised classification map from Rahman and Islam (2022) was used for the DSCC. To prepare the DNCC classification map, 10 m resolution Sentinal-2B high-resolution imagery (1st January 2022) from the Copernicus Open Access Hub website (https://scihub.copernicus.eu/dhus/) has been used in the study. The details about the satellite imagery are given in Table 2. The timeline of the imagery was selected for 1st January 2022 as January is one of the driest months in Bangladesh and the sky remains comparatively clear.

Though the identification of potential heat islands was based on the condition of LST from April to June, the huge cloud coverage in the imageries in these periods made it difficult and error-prone to construct a land use classification map. Besides, some anomalies could form in the calculations of water bodies and green areas due to the pre-monsoon rain that usually happens in the study area. That's why to get a standard and less anomaly-free land use classification, January was selected.

Table 2: Band set data of sentinel 2B (System, 2015).

Data Acquired	Used Band name	Sensor	Band number	Sentinel-2B		Resolution (meters)	WRS Path and Row	Cloud Coverage
				Central wavelength (nm) $^{-2}$	Bandwidth (nm) $^{-2}$			
1st January 2022	Blue	MSI	2	492.1	65	10	137/44	<10%
	Green	MSI	3	559	35	10	137/44	<10%
	Red	MSI	4	665	30	10	137/44	<10%
	Vegetation Red Edge	MSI	5	703.8	15	20	137/44	<10%
	Vegetation Red Edge	MSI	6	739.1	15	20	137/44	<10%
	Vegetation Red Edge	MSI	7	779.7	20	20	137/44	<10%
	NIR	MSI	8	833	115	10	137/44	<10%
	SWIR – Cirrus	MSI	11	1376.9	30	60	137/44	<10%
	SWIR	MSI	12	1610.4	90	20	137/44	<10%

In QGIS 3.22, a semi-automatic classification plugin (Congedo, 2021) has been used with the "minimum distance" algorithm in the supervised classification of Sentinel-2B imagery. The minimum distance algorithm is a well-known method used for land use classification (Ukrainski, 2017). The band sets 2 to 12 were used except for 9 and 10 in the process. Different virtual band sets were used to distinguish various land features; e.g., band sets 2, 3, and 8 were used to identify the vegetation area, reflecting the near-infrared light more than others. Then the region of interest (ROI) polygons for each category were taken based on NDVI values (System, 2019). The land use categories and their NDVI value ranges are given in Table 3.

Table 3: Categories of land use classification, NDVI range, and description.

Categories	NDVI Range	Description
Waterbodies	< 0.06	Physiographic units hold water in them. Like; ponds, rivers, lakes, and wetlands.
Built-up area	0.14-0.21	These are the areas occupied by human-made structures, like, buildings, roads, monuments, and bridges.
Sparse vegetation	0.22-0.46	Very low vegetation cover only 10 to 50% of their surface area, e.g., herbs, shrubs, scattered trees.
Dense vegetation	0.47-0.99	Very high vegetation, especially, large trees that cover more than 50% of their surface area, e.g., parks, forests.
Bare soil	0.061-0.14	Surface areas are mainly bare soil without any other physiographic units.

Accuracy assessment

The accuracy assessment of the classified image was conducted using the semi-automatic classification (SCP) plugin in QGIS 3.22. To compare the classified image with the real world, Google satellite imagery was utilized as the reference map, providing high-resolution images of the actual terrain.

A simple random sampling method was employed to randomly select regions of interest (ROIs) from the classified map, following the approach outlined by Congalton (2001). A total of 565 points were collected within the QGIS software. Each point was then compared with the corresponding location on the Google satellite image to determine classification accuracy. Accuracy metrics including overall accuracy, user accuracy, producer accuracy, and the kappa coefficient were calculated to assess the classification performance. The overall accuracy was found to be 82.6743%, indicating the proportion of correctly classified pixels among all pixels. Additionally, the kappa coefficient, a measure of agreement beyond chance, was determined to be 0.7966, suggesting a substantial level of agreement between the classified image and the reference data. A summary of the methodology is depicted in Figure 2.

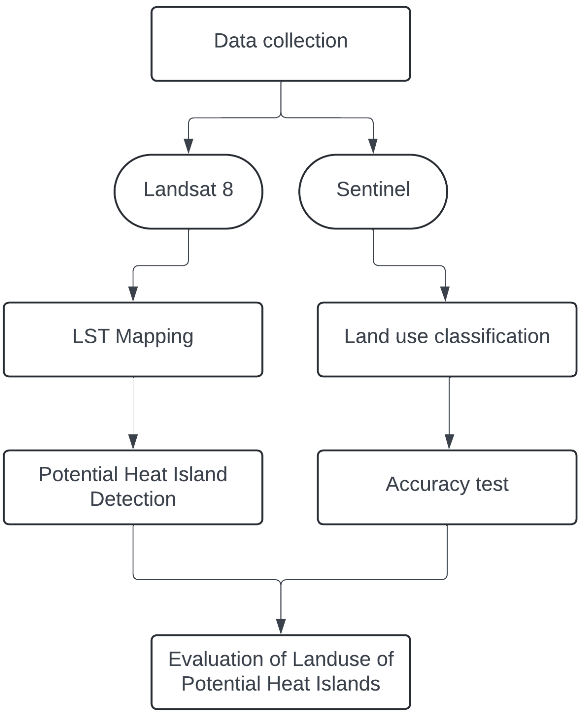

Figure 2: Methodology flow chart of the study.

Results and Discussion

After completion of the series of analyses, we have got the results that are being discussed as follows.

Land Surface Temperature Scenario

The TIRS data from Landsat 8 Level-1 imagery were utilized to collect land surface temperature (LST) data. The land surface temperature maps, depicted in Figure 3, illustrate the variance in land surface temperature across Dhaka city for different years. These images were captured at 10 am local time.

The data highlights the variability in land surface temperature over the years. The years 2015, 2019, and 2021 contained a higher overall land surface temperature as the red surface is more prominent in these years. Besides, 2018 and 2022 depicted a lower overall temperature all over Dhaka city. This could be an effect of the El Nino and La Nina cycle, where La Nina was taking place in 2018 and 2022 (Przyborski, 2022). However, it also identifies consistent areas across each map where temperatures are notably higher than surrounding areas. These regions are indicative of zones that are most vulnerable to heat waves.

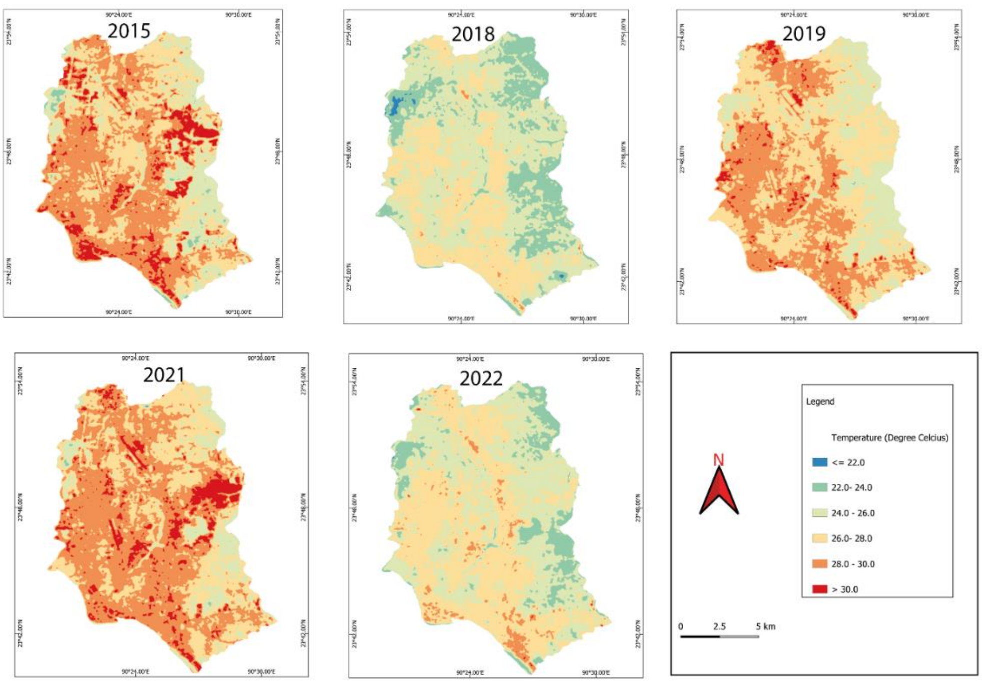

Figure 3: Land surface temperature Map of Dhaka city for different years.

Potential Heat Islands

As discussed previously, the land surface temperature distribution in Dhaka city is not uniform, with certain areas exhibiting higher temperatures than others. By analyzing the patterns of these hotter zones across the heat maps of Dhaka city from Figure 3, we have identified specific zones that can be classified as potential heat islands. These zones are illustrated in Figure 4.

A total of 7 distinct zones have been identified as potential heat islands in Dhaka city, historically experiencing higher temperatures compared to their surroundings. Among these, five zones are located within Dhaka North City Corporation (DNCC), covering a combined area of 74.577 km^2, which represents 37.16% of the total DNCC area. The remaining two heat islands are situated within Dhaka South City Corporation (DSCC), encompassing an area of 39.492 km2, equivalent to 39.77% of DSCC.

Identifying these heat islands is crucial for understanding the areas most susceptible to extreme heat events and implementing targeted mitigation strategies to alleviate their impact on urban residents and infrastructure.

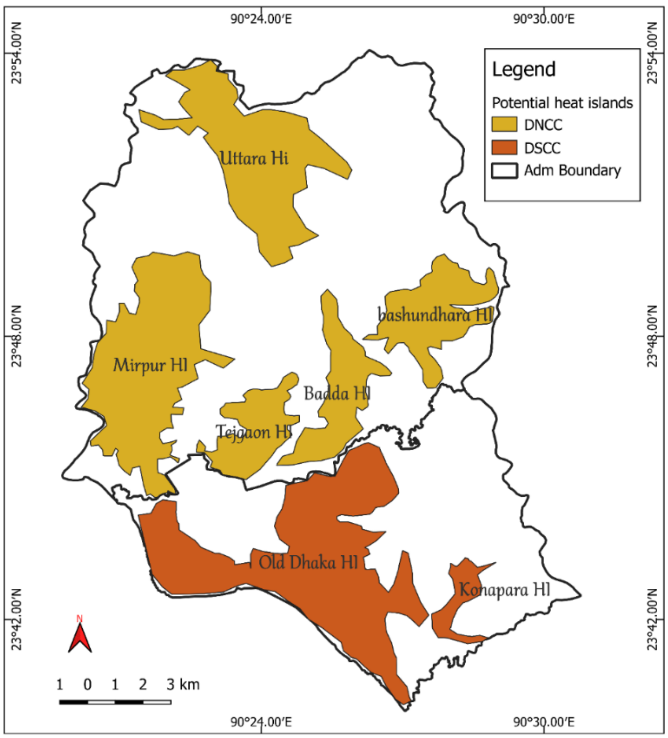

Figure 4: Potential heat islands in Dhaka city.

Table 4: Estimated land area of the heat islands

id	City	Name of the HI	Area in Sq Km
1	DNCC	Mirpur HI	26.112
2	DNCC	Tejgaon HI	7.211
3	DNCC	Badda HI	8.801
4	DNCC	bashundhara HI	10.786
5	DNCC	Uttara Hi	21.667
6	DSCC	Old Dhaka HI	36.707
7	DSCC	Konapara HI	2.785

Evaluation of Land use land cover of potential heat islands

We have divided the potential heat islands of Dhaka city into seven different zones. The evaluations of these zones are given as follows:

Mirpur Heat Island

This zone is located in the western part of DNCC. This zone covers the area of Mohammadpur, Gabtoli, and the majority of Mirpur. The land use map is shown in Figure 5 and quantities of the land use type are given in Table 5.

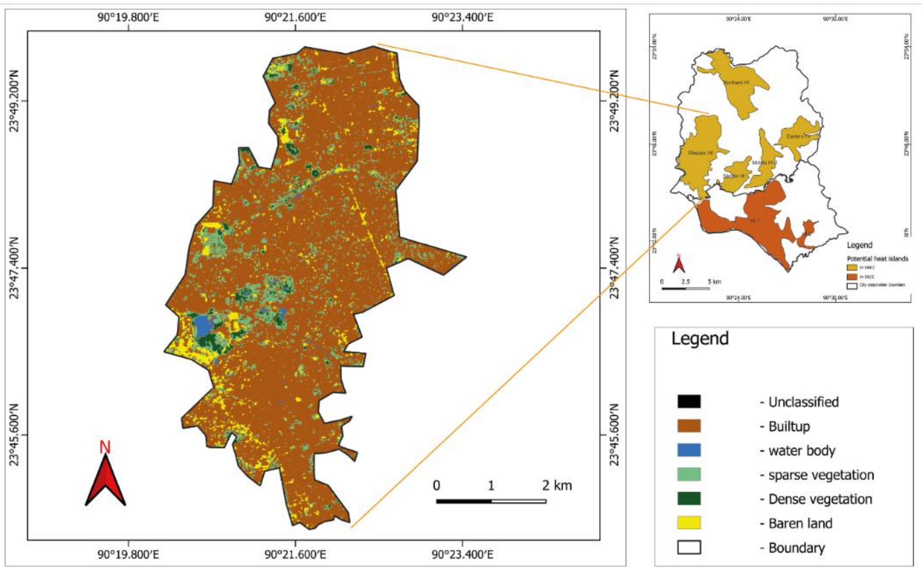

Figure 5: Land use classification map of Mirpur heat island of DNCC

Table 5: Types of land use and their quantities in Mirpur Heat Island in DNCC

No.	Class	Percentage %	Area [in sq Km]
1	Builtup area	80.026	20.9178
2	Waterbody	0.778	0.2035
3	Sparse vegetation	11.244	2.9390
4	Dense vegetation	2.056	0.5374
5	Bare land	5.896	1.5411

Uttara Heat Island

Northern heat island is located in the northern part of DNCC. It contains the area of Uttara and Hazrat Shahjalal International Airport area, where the airport area is a specialized area. It contains both baren and built-up areas within its structure as well as some green zones. The details about the land use and land cover are given in Figure 6 and Table 6.

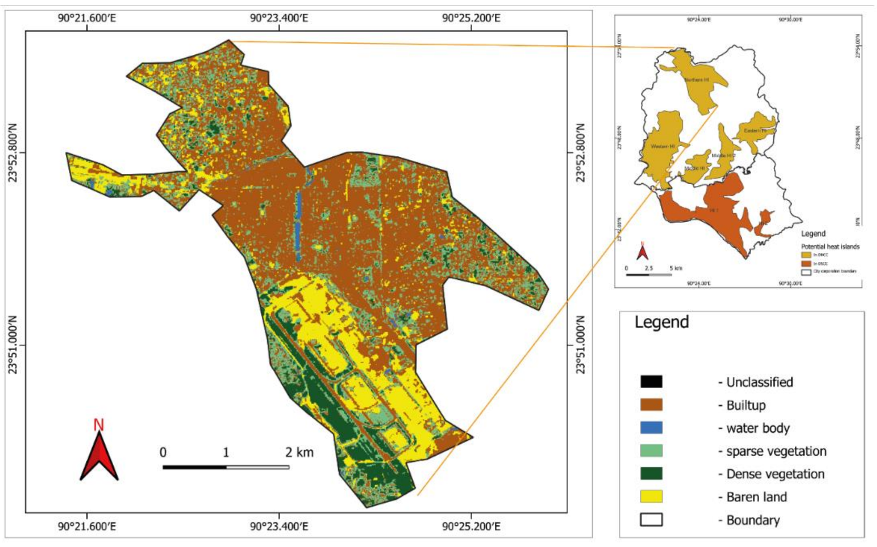

Figure 6: Land use classification map of Uttara heat island of DNCC

Table 6: Types of land use and their quantities in Uttara Heat Island in DNCC

No.	Class	Percentage %	Area [in sq Km]
1	Builtup area	53.979	11.7127
2	Waterbody	0.645	0.1400
3	Sparse vegetation	19.255	4.1781
4	Dense vegetation	8.897	1.9306
5	Bare land	17.224	3.7373

Tejgaon Heat Island

Middle heat island (1) situated in the midzone of Dhaka city, it lies under the DNCC. It consists of areas like Farmgate, Tejgaon, and Mohakhali. The land use land cover scenario is illustrated in Figure 7 and details are given in Table 7.

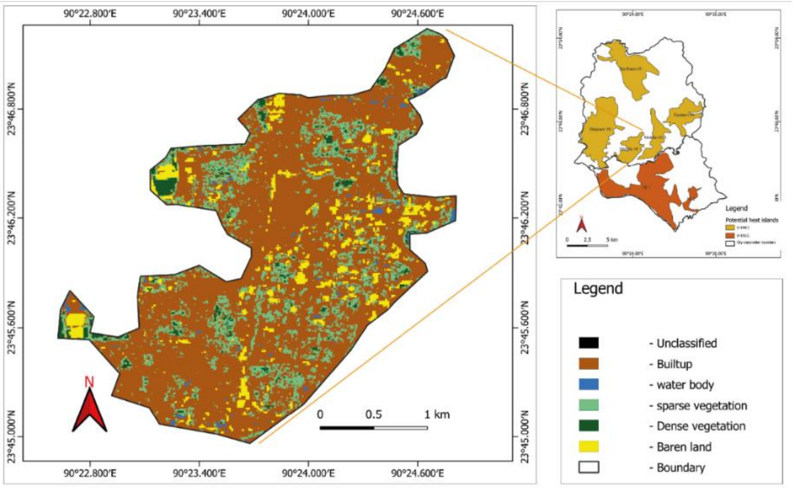

Figure 7: Land use classification map of Tejgaon heat island of DNCC

Table 7: Types of land use and their quantities in Tejgaon Heat Island in DNCC

No.	Class	Percentage %	Area [in sq Km]
1	Builtup area	71.905	5.1903
2	Water body	0.925	0.0668
3	Sparse vegetation	17.124	1.2361
4	Dense vegetation	2.710	0.1956
5	Bare land	7.336	0.5295

Badda Heat Island

This heat island begins from Rampura, covers the Badda, Nurer Chala, and stretches to the Notun Bazar area. In Figure 8 the land use classification of this area has been illustrated and details are given in Table 8.

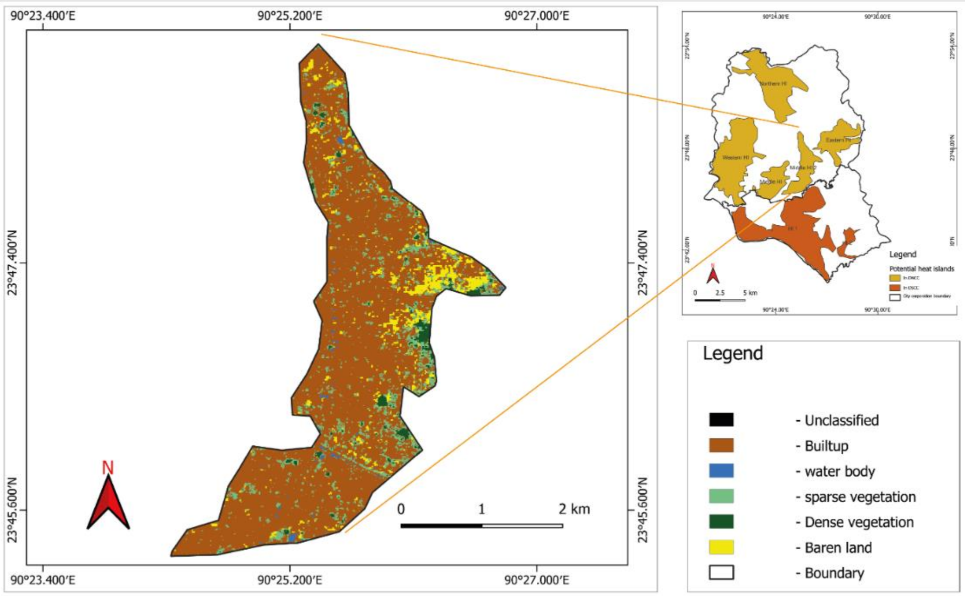

Figure 8: Land use classification map of Badda Heat Island of DNCC

Table 8: Types of land use and their quantities in Badda Heat Island in DNCC

No.	Class	Percentage %	Area [in sq Km]
1	Builtup area	80.412	7.0857
2	Waterbody	0.571	0.0503
3	Sparse vegetation	10.786	0.9504
4	Dense vegetation	2.157	0.1901
5	Bare land	6.074	0.5352

Bashundhara Heat Island

This is the easternmost heat island in DNCC. This area carries some portions of Bashundhara and Aftab Nagar. The detailed classification map and amounts of the land types are given in Figure 9 and Table 9.

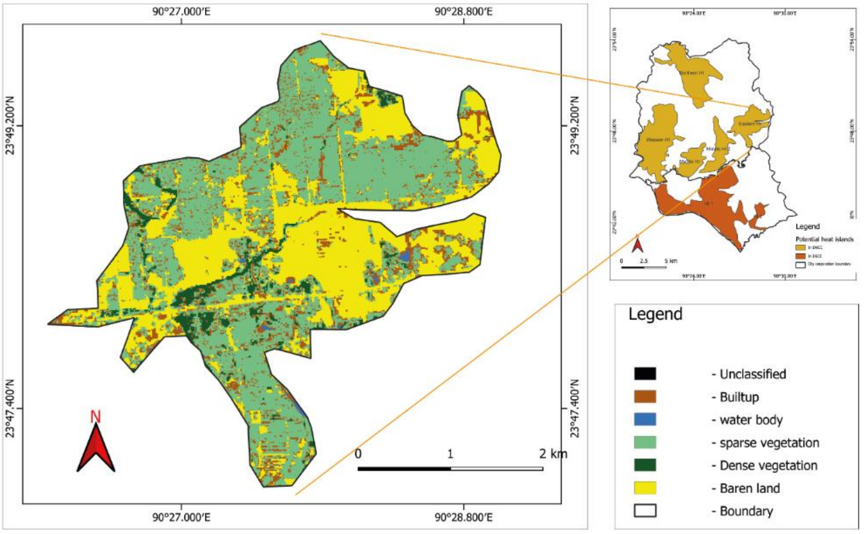

Figure 9: Land use classification map of Bashundhara HI of DNCC

Table 9: Types of land use and their quantities in Bashundhara HI in DNCC

No	Class	Percentage %	Area [in sq Km]
1	Builtup area	12.364	1.3344
2	Waterbody	0.278	0.0300
3	Sparse vegetation	47.309	5.1059
4	Dense vegetation	4.390	0.4738
5	Bare land	35.659	3.8485

Heat Islands of DSCC

Two significant heat island zones can be identified in the DSCC part. One of them is Heat Island 1 which consists of areas like Kamrangir Char, Matijhil, and Jatrabari and stretches to the Pagla sewage plan. Besides Heat Island 2 consists of areas like Matuail and Konapara. The land use classification map is illustrated in Figure 10 and details are given in Tables 10 and 11.

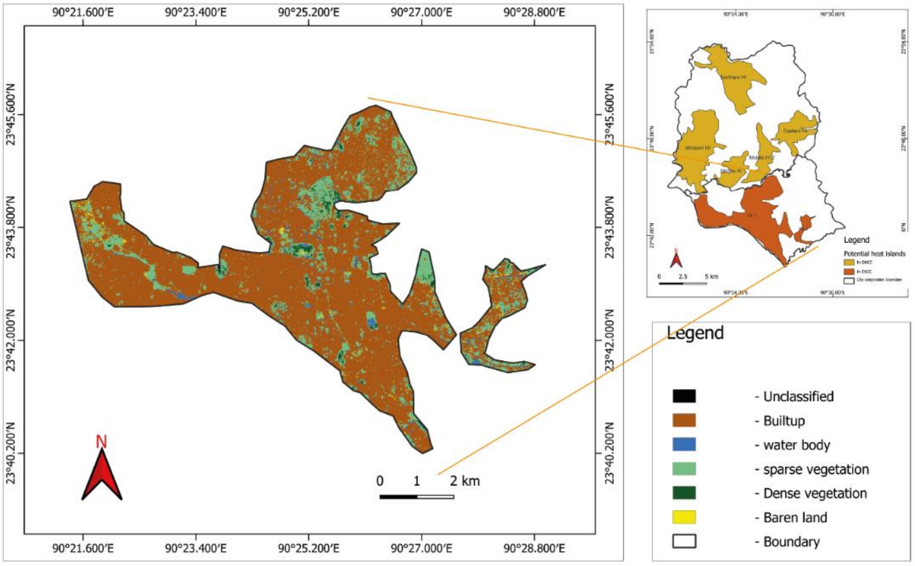

Figure 10: Land use classification map of Old Dhaka HI and Konapara HI of DSCC

Table 10: Types of land use and their quantities in Old Dhaka HI in DSCC

No.	Class	Percentage %	Area [in sq Km]
1	Builtup area	78.461	28.8348
2	Waterbody	3.155	1.1594
3	Sparse vegetation	15.538	5.7104
4	Dense vegetation	1.557	0.5723
5	Bare land	1.289	0.4736

Table 11: Types of land use and their quantities in Konapara HI in DSCC

No.	Class	Percentage %	Area [in sq Km]
1	Builtup area	56.735	1.5807
2	Waterbody	7.893	0.2199
3	Sparse vegetation	29.672	0.8267
4	Dense vegetation	1.859	0.0518
5	Bare land	3.841	0.1070

Discussion

Based on the analyzed data and its findings, it is evident that Dhaka City faces a significant deficit in both green and blue spaces. Regarding green spaces, the majority of vegetation in Dhaka comprises sparse vegetation, predominantly consisting of scattered trees, shrubs, and herbs. However, dense and deep vegetation, which plays a crucial role in regulating temperature and moisture in the microenvironment, is lacking in the city.

Among the identified 7 heat islands, only the northern heat island possesses more than 8% dense vegetation. In contrast, the remaining heat islands exhibit less than 5% dense vegetation coverage relative to their total area (refer to Figure 11). This deficiency in dense vegetation exacerbates the heat island effect in Dhaka City, contributing to elevated temperatures and reduced environmental resilience. Addressing this shortage of green space, particularly by promoting the establishment of dense vegetation, is essential for mitigating the impacts of heat waves and enhancing the overall urban environment. Implementing strategies to increase greenery and biodiversity within the city can contribute to temperature regulation, air quality improvement, and overall livability for Dhaka's residents.

Similarly, a critical situation is observed with water bodies, or blue spaces, within the heat islands. These areas contain a minimal amount of water bodies relative to their total area. Most heat islands exhibit less than 1% coverage of water bodies, except heat islands 1 and 2, which contain approximately 3.15% and 7.89% water bodies, respectively (refer to Figure 12). This scarcity of water bodies within the heat islands exacerbates their vulnerability to extreme heat conditions. Water bodies have a higher latent heat capacity compared to terrestrial surfaces, meaning they heat up and cool down more slowly. When water bodies are scarce or absent, the surrounding areas experience rapid temperature fluctuations and extreme heat conditions.

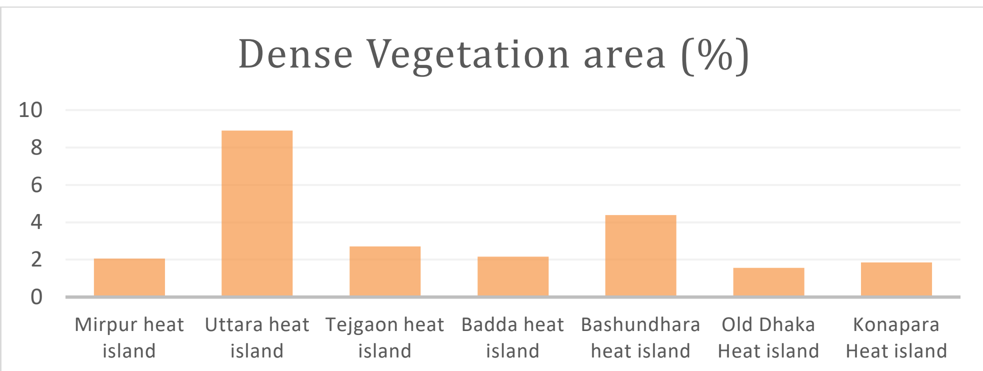

Figure 11: Total dense vegetation amount in different HI's.

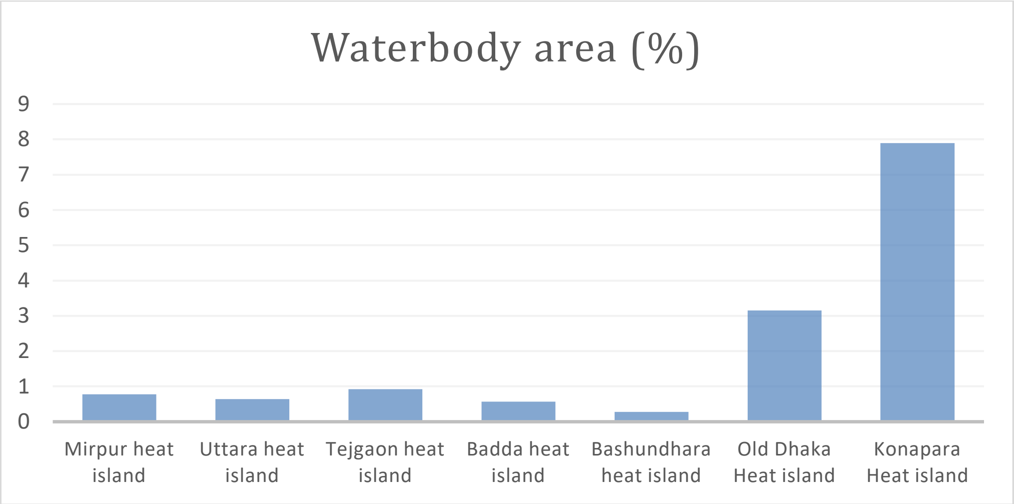

Figure 12: Total blue space amount in different HI's.

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Cities of temperate regions, like Dhaka, shows a significant synergic effect between the heatwaves and urban heat islands (Zhao et al., 2018). Addressing this issue is crucial for mitigating the impacts of heat waves in Dhaka City. Increasing the presence of water bodies and dense vegetation within heat island zones can help regulate temperatures, provide natural cooling, and enhance the overall resilience of these areas to extreme heat events (Gunawardena, 2017). Implementing strategies to protect and enhance existing water bodies, as well as creating new water features, can contribute to creating a more sustainable and resilient urban environment in Dhaka.

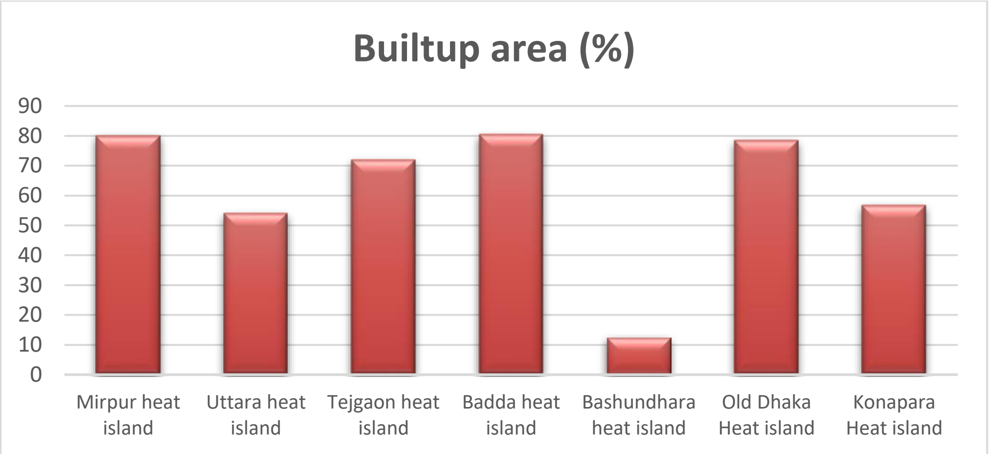

Figure 13: Total built-up area amount in different HI's

Conclusion

Indeed, Dhaka stands as one of the most densely populated and heavily polluted cities globally, presenting significant challenges in maintaining a sustainable environment. However, these circumstances do not grant us the license to engage in unplanned and unsustainable development practices. It is imperative to recognize that it is never too late to enact positive change. Therefore, swift and decisive action is necessary to enhance green and blue spaces in Dhaka city, particularly within the identified heat island zones. By implementing quick plans and programs aimed at increasing these areas, we can mitigate the severity of heat waves and improve the overall urban environment.

Furthermore, it is essential to prioritize the mitigation of heat impacts in potential heat islands, as these areas are particularly vulnerable to the adverse effects of extreme heat events. By providing extra attention and resources to these zones, we can effectively address the challenges posed by heat waves and create a safer and more resilient urban environment for all residents.

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