Research Article

Urban Heat Vulnerability and Health Impact in Bangladesh: A Comparative Scenario of Satkhira and Bagerhat Municipalities

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ABSTRACT

Urban areas of Bangladesh are experiencing heat stress due to climate change. This heat stress poses significant risks to human health in urban areas. The study was conducted in the Satkhira and Bagerhat municipalities to explore the impact of urban heat stress on human health and the comparative scenario of health vulnerability in both areas. The study adopted multidisciplinary methods, including secondary literature review, historical time series analysis of temperature and heat waves, Urban Heat Island (UHI) identification, and health vulnerability assessment. The experimental knowledge and experience of urban citizens were collected through a household survey, focus group discussions, and key informant interviews. The study reveals that health problems are increasing with the increasing trend of heat stress and the formation of heat islands. In Bagerhat Municipality, health problems are comparatively low because of the lower number of heat island formations. There needs to be integration of heat stress management into spatial planning, which may entail limiting new development in the municipal areas. Alleviation of the urban heat-island effect by greening areas, providing shade by using green coverage, and restoration of urban forests and water bodies.

Keywords: Climate Change; Heat Stress, Heat Island, Health, Satkhira, Bagerhat

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Introduction

Bangladesh, which ranks among the most populous nations in the world, has experienced rapid population growth over the past century, though it has recently moderated somewhat [1]. The country is going to witness a rapid spread of urbanization over the next decade. According to an estimate, by 2050, nearly every other man, woman, and child will live in an urban area [2]. Along with the population, the urban climate is also rapidly changing in Bangladesh. Urbanization in Bangladesh has also led to environmental degradation, including air and water pollution, deforestation, and loss of green spaces. An increasing frequency of extreme weather events is one of the most concerning effects of climate change on urban systems. Urban life is at risk due to an increase in the frequency and severity of heat waves [3]. Heat waves can cause an increase in heat stress and mortality, especially in susceptible groups, including the elderly and people with underlying medical issues [4].

Furthermore, the urban heat island effect is intensified by climate change, leading to higher temperatures in urban areas compared to their rural surroundings, which negatively affects public health [5].

Methods

The study made triangulation of qualitative information for understanding the temperature and heatwave trends, vulnerability in the study areas, and their impacts on urban health. The study collected relevant information and literature from the Bangladesh Meteorological Department (BMD), the Department of Disaster Management (DDM), Satkhira and Bagerhat Municipalities, and other relevant organizations. The study also reviewed the Bangladesh Climate Change Strategy and Action Plan (BCCSAP), Satkhira Master Plan 2023–2043, National Plan for Disaster Management (NPDM, 2021 to 2025), District Disaster Management Plan (DDMP), BDRCS Urban Resilient Strategy, Standing Order on Disaster – 2019, policies and acts, World Bank's Enhancing Coastal Resilience in a Changing Climate, Nationwide Climate Vulnerability Assessment of Bangladesh 2023, etc. Primary data were collected from various stakeholders, ranging from the ward level to the municipal level, through Household Surveys, Focus Group Discussions (FGDs), and Key Informant Interviews (KIIs). A total of 1,800 Household Surveys (900 in each municipality), 24 Focus Group Discussions (12 in each municipality) with local communities, and 34 Key Informant Interviews were conducted with the municipality, government agencies, and academicians. Statistical downscaling methods were used to develop historical trends of local temperature and heat waves. The existing land use, land cover, and urban system mapping were exercised in the municipality through remote sensing and GIS applications with a 10m spatial resolution and a 5-day revisit frequency. Sentinel-2 L2A satellite imagery was processed and facilitated by Google Earth Engine (GEE). The multi-spectral optical data exploitation approach from LANDSAT 8 ETM+ (Enhanced Thematic Mapper) was used to map surface states. Land Surface Temperature (LST) was analyzed to identify potential heat island zones in the municipality.

Urban Heat Island (UHI) and Land Surface Temperature (LST) were measured by analyzing Landsat 8 Thermal Infrared Sensor (TIRS) using Google Earth Engine (a cloud-based platform for geospatial analysis). To validate the UHI and LST, NDVI was applied to calculate the proportion of vegetation and emissivity of the urban area. The Normalized Difference Vegetation Index (NDVI) was used to find the vegetation index in terms of the presence and health of vegetation, based on the reflectance of visible and near-infrared light, using the following formula:

$$NDVI=(NIR+Red)/(NIR-Red)$$

Where NIR (Near-Infrared) is the reflectance in the near-infrared part of the electromagnetic spectrum (typically Landsat band 5 or similar). Red is the reflectance in the red part of the spectrum (typically Landsat band 4 or similar). The minimum and maximum NDVI values of the Normalized Difference Vegetation Index (NDVI) were used to calculate the proportion of vegetation cover (PV) in the region of interest. Again, the proportion of vegetation (PV) and emissivity (EM) were calculated using the following formula:

Proportion of Vegetation (PV) = (NDVI — NDVI_min) / (NDVI_max — NDVI_min)

Where:
NDVI represents the pixel's NDVI value.
NDVI_min is the minimum NDVI value specified.
NDVI_max is the maximum NDVI value specified.

Formula:
((NDVI - NDVI_min) / (NDVI_max - NDVI_min))^2

The Proportion of Vegetation (PV) is a metric used to quantify the relative abundance of vegetation within a specified area by analyzing Normalized Difference Vegetation Index (NDVI) values. Emissivity (EM) is computed as a function of PV, reflecting how efficiently a surface emits thermal radiation. EM values near 1.0 are typical for natural surfaces like soil and vegetation, while lower values are often associated with water bodies or urban areas. Both PV and EM play essential roles in remote sensing and environmental studies, contributing to a more comprehensive understanding of land characteristics and thermal behavior.

Emissivity Calculation - Formula: $0.004 \times PV + 0.986$

Land Surface Temperature (LST) was estimated by the selection of a Thermal Band in the urban area as Band 10 using the following Formula:

$(TB / (1 + (\lambda \times (TB / 1.438)) \times \ln(em))) - 273.15$ [6].

Urban Heat Island (UHI) is specified and quantified by using the following formula:

$UHI = T - Tm/Tsd$ [7].

Where T is LST, Tm is the LST mean, and Tsd is the standard deviation of LST.

Study area

The Satkhira Municipality, which covers an area of 27.84 km², is located in the southwestern coastal region (Figure 1). The municipality is situated on the bank of the Arpangachhia River, near the border with West Bengal, India. The geographical coordinates of Satkhira Municipality are between 88º54' E and 89º20' E and between 21º36' and 22º54' N [8]. Bagerhat Municipality is one of the coastal towns in the southern part of Bangladesh, in the Bagerhat district, which lies beside the Bhairab River (Figure 1). The Bagerhat Municipality is located in the impact zone of the Sundarbans, the largest mangrove forest in the world.

Study Results

Land use of the municipalities

Both municipalities have a diverse landscape with various land cover and land use. In Satkhira Municipality, vegetation coverage is approximately 1,412.29 hectares, comprising lush greenery and indigenous flora, highlighting the region's ecological richness. Open spaces, totaling 33.59 hectares, provide recreational areas and potential sites for future development within the urban landscape. Agricultural land spans 1,297.70 hectares, emphasizing the area's reliance on farming for sustenance and economic activity. With 280.65 hectares designated as built-up areas, the municipality exhibits significant urbanization and infrastructure development. Sandy lands cover 12.62 hectares, featuring terrain characterized by sandy soils and unique ecological niches. Water bodies, covering 240.73 hectares, sustain local ecosystems and livelihoods, while lowlands, spanning 16.73 hectares, contribute to the region's hydrological dynamics (Figure 2, Table 1).

The land use and land cover of Bagerhat Municipality delineate various categories. The largest portion of land, encompassing 433.66 hectares, is designated as vegetation, indicating areas primarily covered by natural flora and greenery. Open space contributes 7.44 hectares, representing areas with minimal development.

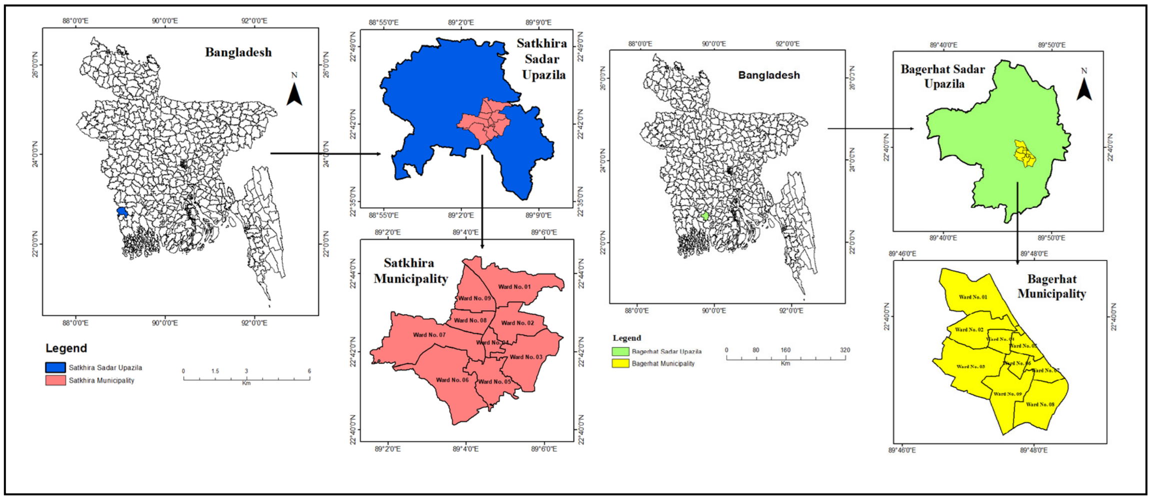


Figure 1: Study area

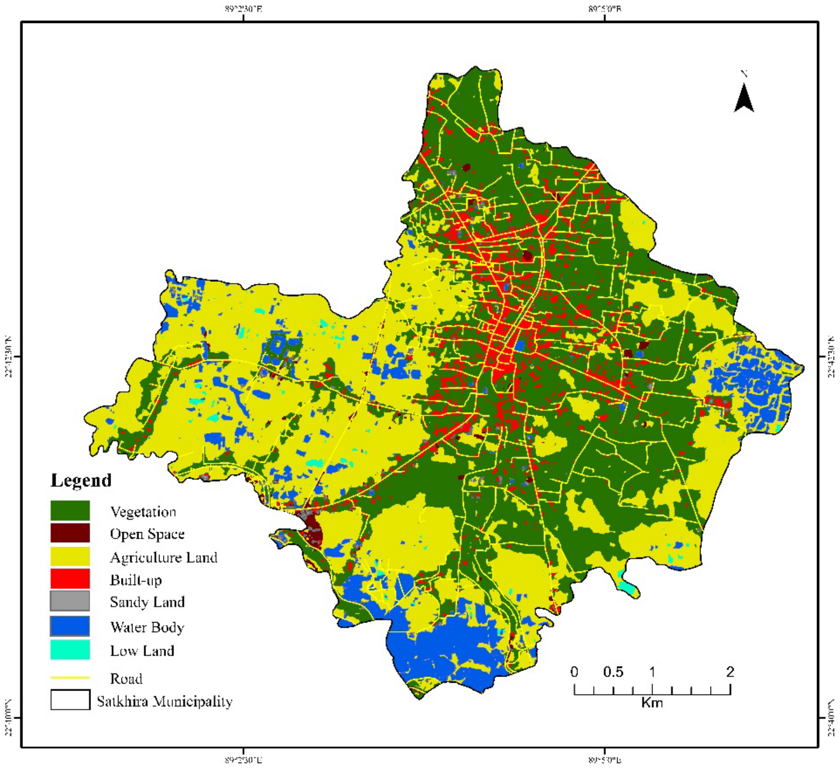


Figure 2: Land Use and Land Cover of the Satkhira Municipality

Table 1: Land use of the Satkhira and Bagerhat Municipality

Land Classification	Satkhira		Bagerhat	
	Area/hectare	% of total land	Area/hectare	% of total land
Vegetation	1412.29	42.87	433.66	67.55
Open space	33.59	1.02	7.44	1.16
Agricultural land	1297.70	39.39	53.98	8.41
Build-up area	280.65	8.52	127.67	19.89
Sandy lands	12.62	0.38	2.69	0.42
Waterbody	240.73	7.31	16.27	2.53
Lowlands	16.73	0.51	0.31	0.05
Total	3294.31	100.00	642.02	100.00

Agricultural land covers 53.98 hectares, reflecting areas utilized for farming activities such as crop cultivation and livestock rearing. Built-up areas, totaling 127.67 hectares, represent developed regions with infrastructure like buildings, roads, and other man-made structures. Sandy lands, occupying 2.69 hectares, denote areas characterized by sandy soil composition. Water bodies, covering 16.27 hectares, include canals, ponds, rivers, and other aquatic features within the municipality. Lowlands, with a minimal area of 0.31 hectares, refer to areas situated at lower elevations relative to the built-up area (Figure 3, Table 1).

Vaidyanathan et al. (2016) provided a heat wave (HW) definition considering four core variables: the heat metric (viz., maximum/minimum/mean temperature, diurnal temperature difference, etc.), duration, threshold type, and threshold intensity. According to BMD classification, a Mild Heat Wave is defined as a maximum temperature that lies between 36°C and 38°C. A Moderate Heat Wave occurs when the maximum temperature lies between 38°C and 40°C. If the maximum temperature exceeds 40°C, it is classified as a Severe Heat Wave [9]. As the annual average temperature is increasing, the yearly number of heat wave days is also rising at

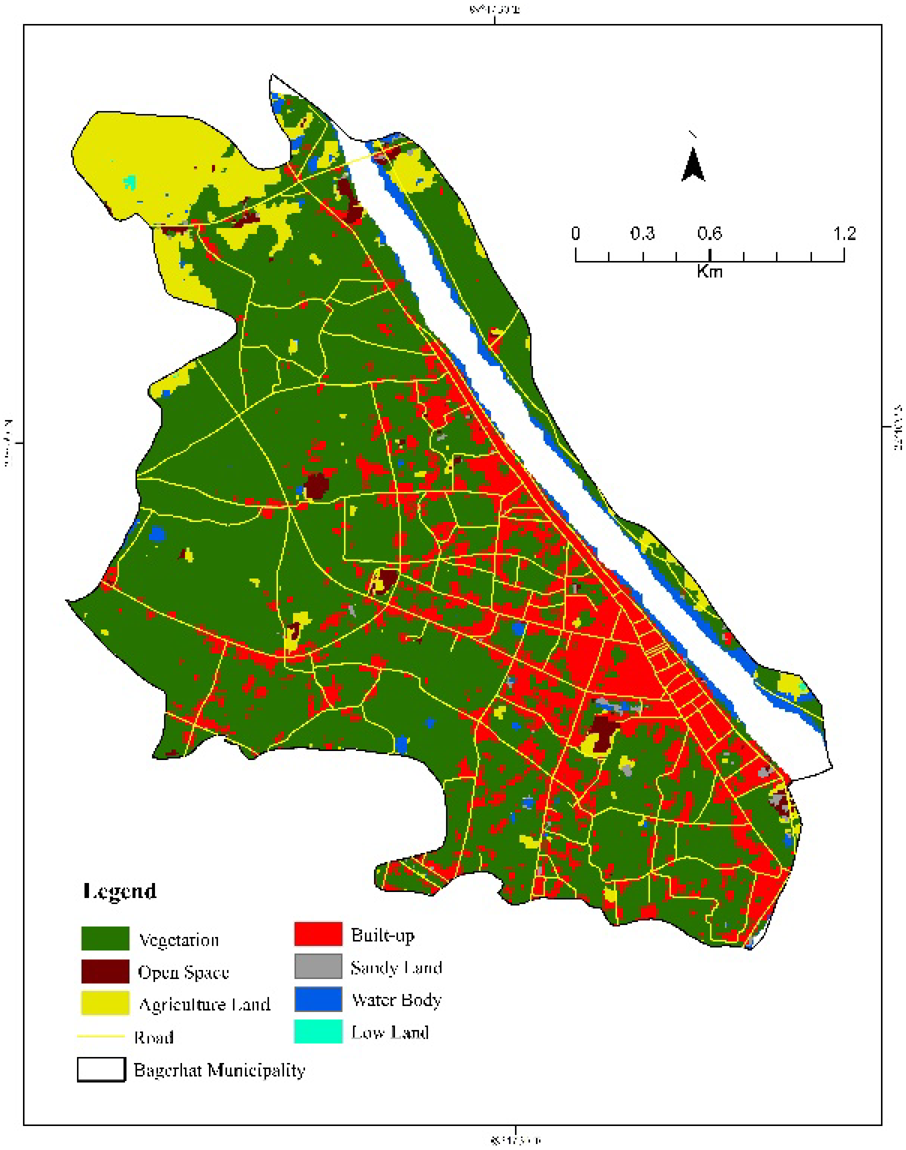


Figure 3: Land Use and Land Cover of the Bagerhat Municipality

an alarming rate in both municipalities. Within 30 years (1992–2022), the minimum and maximum heat wave days recorded in Satkhira were 39 and 87 days in 2001 and 2010, respectively. Additionally, the highest number of heat wave days recorded in Satkhira was 91 days in 2010 (Figure 5).

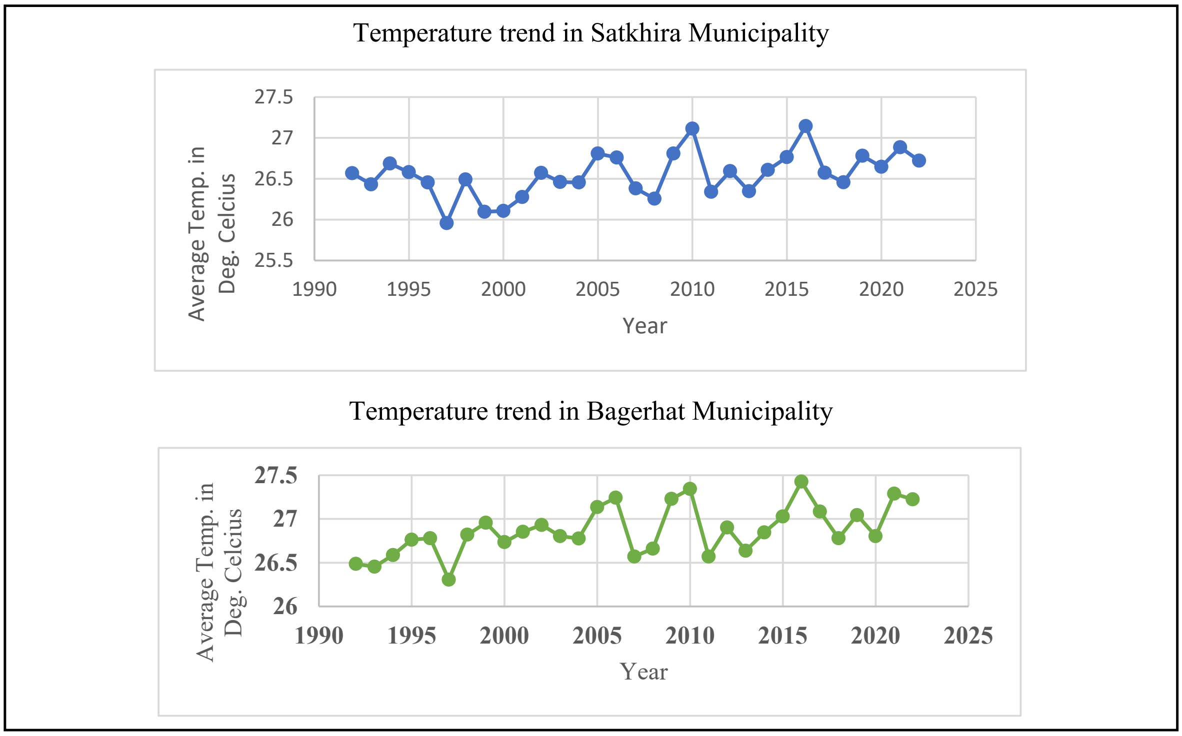
The Land Surface Temperature (LST) of Satkhira Municipality varies from 48°C to 32°C, and in Bagerhat, it varies from 41°C to 29°C. The average temperature of Satkhira Municipality is 38.90°C, while in Bagerhat Municipality it is 34.71°C. Wards No. 9, 8, 7, and 4 have experienced the highest temperatures compared to other wards (Figures 6 and 7).

The stack profile represents the temperature variation between urban, suburban, and rural areas. The urban areas of Satkhira and Bagerhat Municipalities have higher temperatures than the surrounding areas. In Satkhira Municipality, the urban maximum intensity is 26.76°C and the minimum intensity is 10.02°C. Wards No. 9, 8, and part of 7 have the highest urban heat island formation (Figure 8).

In Bagerhat Municipality, the urban maximum intensity is 21.55°C and the minimum intensity is 9.27°C. Wards No. 8, 7, 6, and 5 have the highest urban heat island formation (Figure 9).

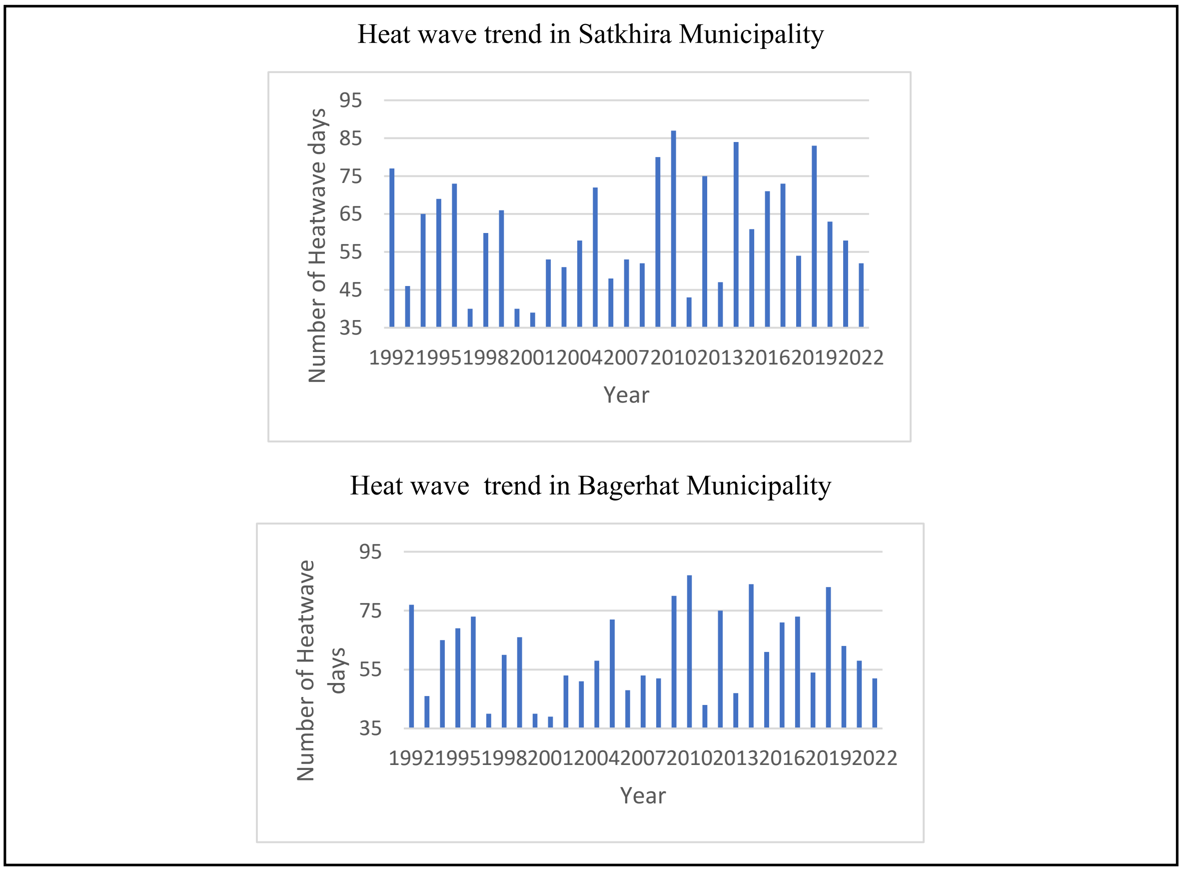
Heat-related health problems

In both municipalities, heat stress is common. Due to the formation of heat islands and the increasing trend of land surface temperature, urban residents are experiencing heat-related health problems. Although heat-related health problems are present in both



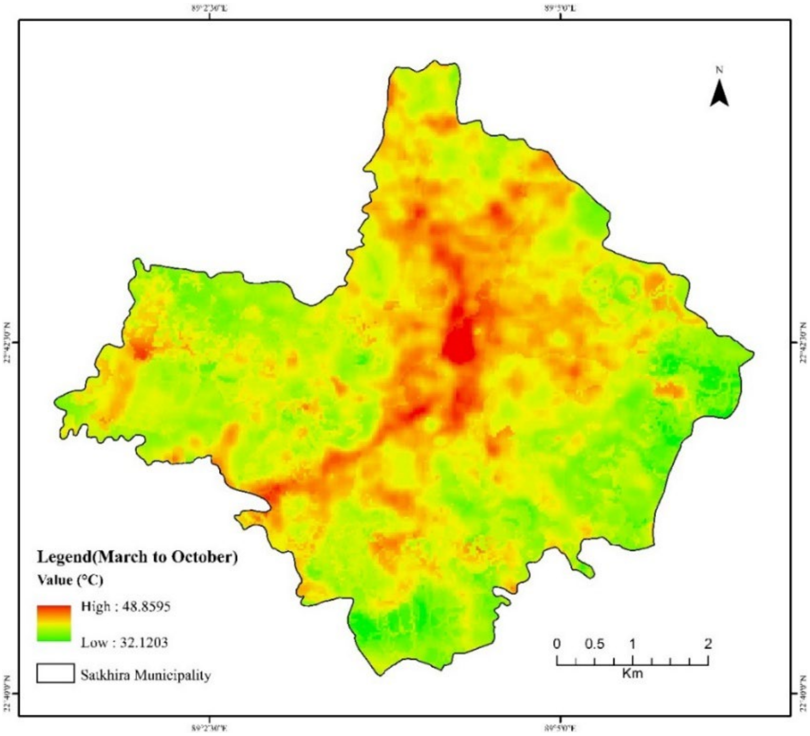
Source: BMD, 2024

Figure 4: Trends of yearly average temperature in Satkhira and Bagerhat Municipalities



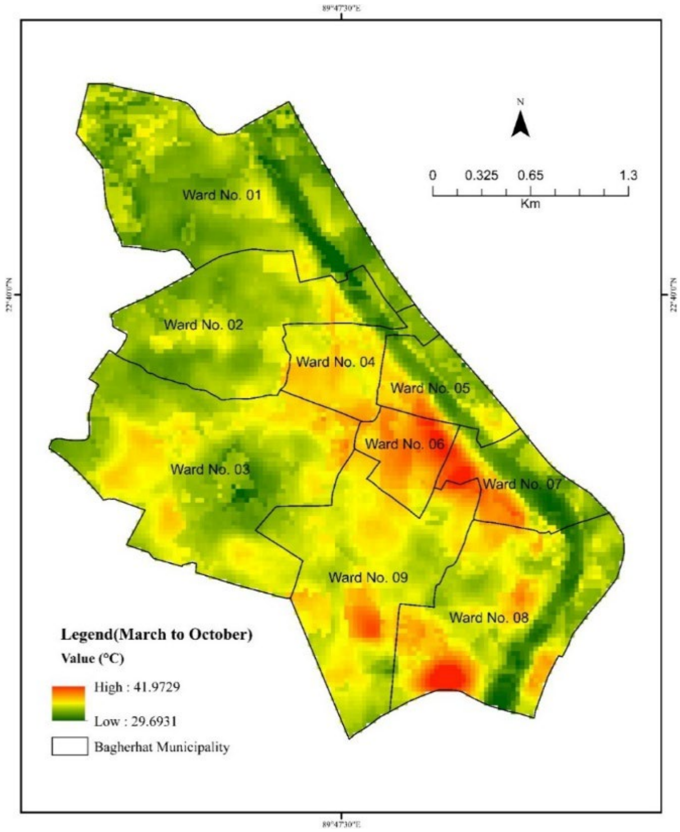
Source: BMD, 2024

Figure 5: Trend of heat waves in Satkhira and Bagerhat Municipalities



Source: Landsat 8, 2023

Figure 6: Land surface temperature in Satkhira Municipality



Source: Landsat 8, 2023

Figure 7: Land surface temperature in Bagerhat Municipality

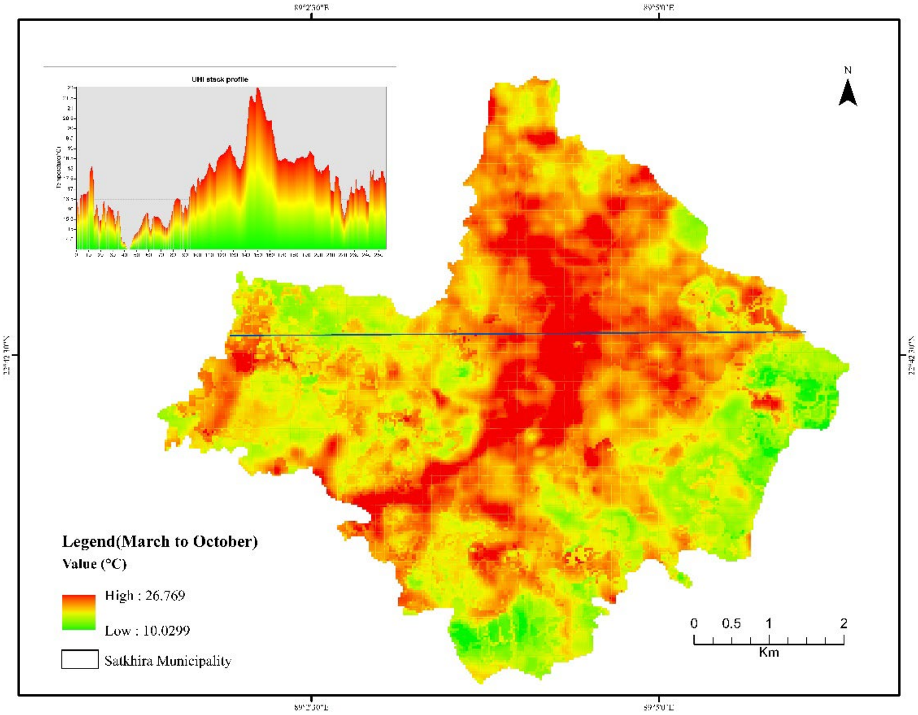


Figure 8: Urban Heat Island in Satkhira Municipality

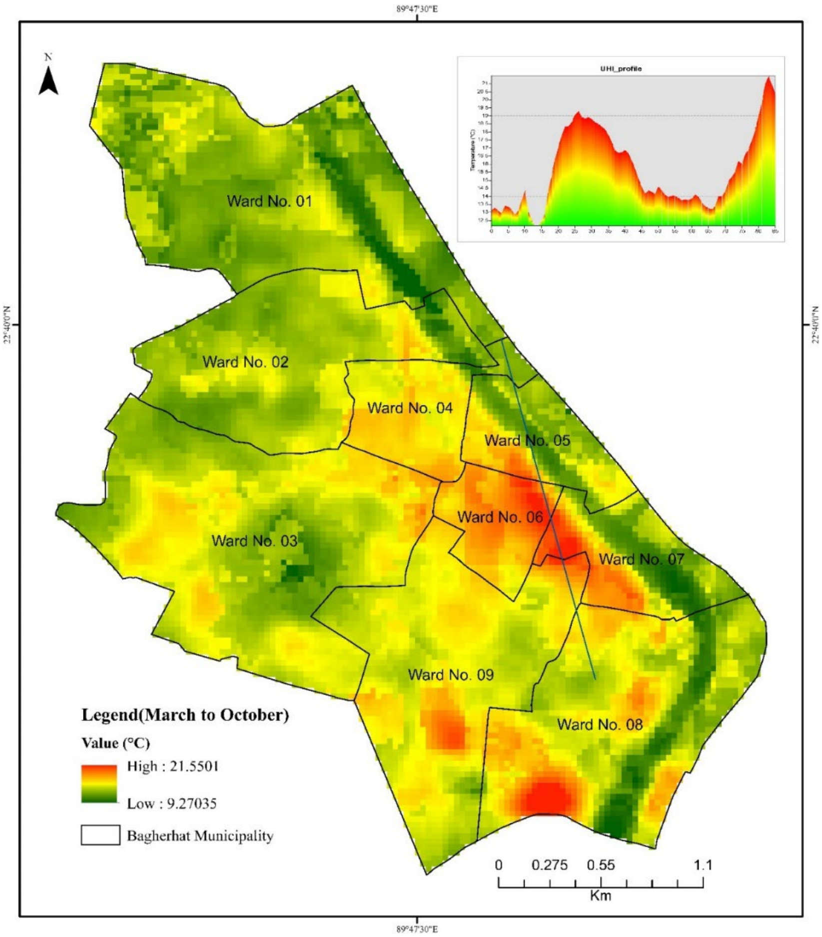


Figure 9: Urban Heat Island in Bagerhat Municipality

municipalities, the incidence is comparatively lower in Bagerhat Municipality. Figure 10 depicts the percentage of individuals affected by heat-related health issues in Satkhira and Bagerhat. Satkhira has a comparatively higher rate of affected individuals, at 83.50%, indicating a more severe heat issue in that area. In contrast, Bagerhat has a lower rate of 69.80%.

All age groups are vulnerable to heat-related health problems; however, the elderly and infants are more vulnerable than other age groups. Figure 12 illustrates the heat-related health problems across different age groups. Infants and the elderly were reported to be heavily affected by heat-related health problems in both municipalities. In Satkhira, 90.80% of elderly individuals and 82.50% of infants suffer from heat-related health problems. In Bagerhat, the rates are 72.60% for the elderly and 67.80% for infants, indicating high vulnerability to excessive heat. Conversely, adult individuals are the least affected age group, with 32% in Satkhira and 18.90% in Bagerhat.

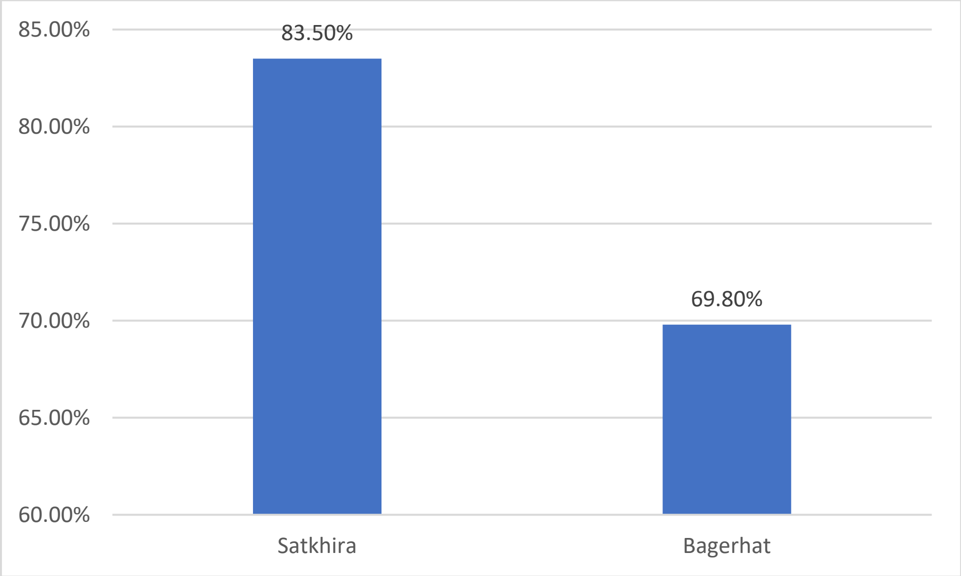


Figure 10: Victim of heat-related health problems

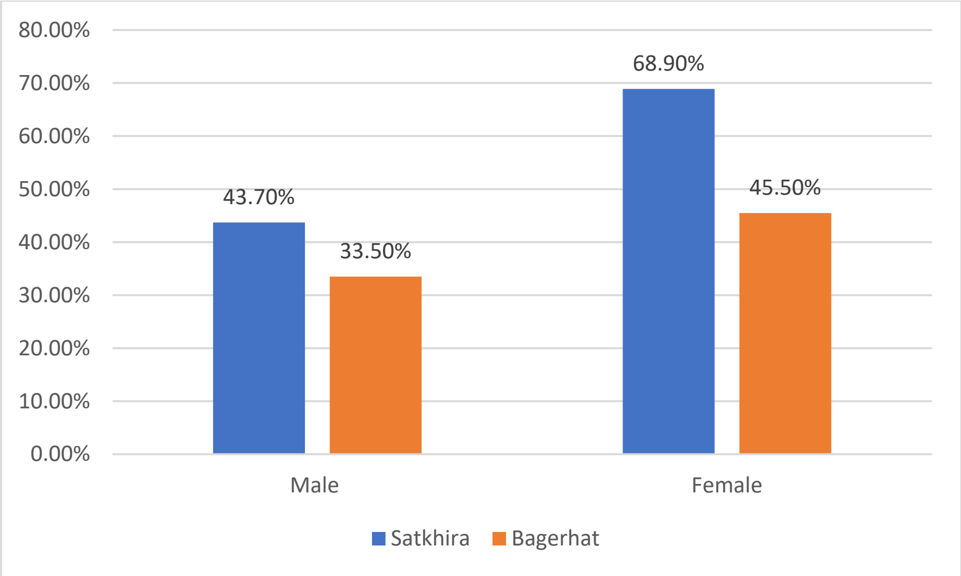


Figure 11: Gender-segregated heat-related health problems

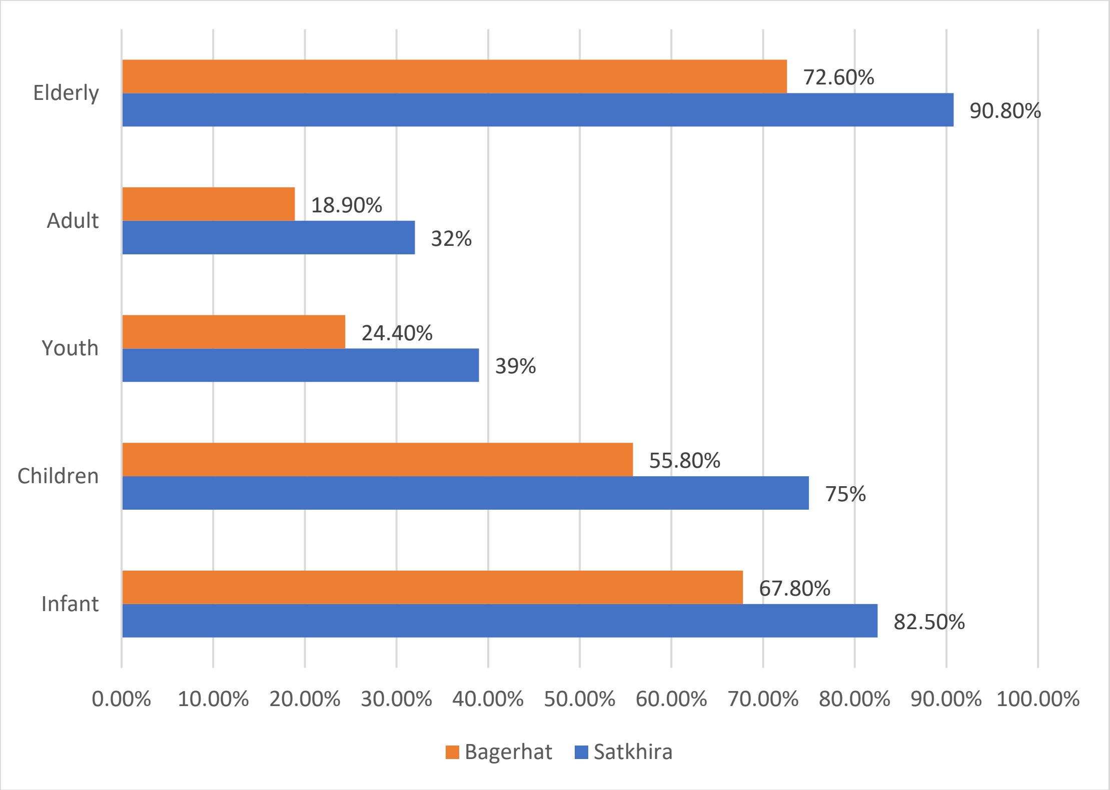


Figure 12: Age-segregated heat-related health problems

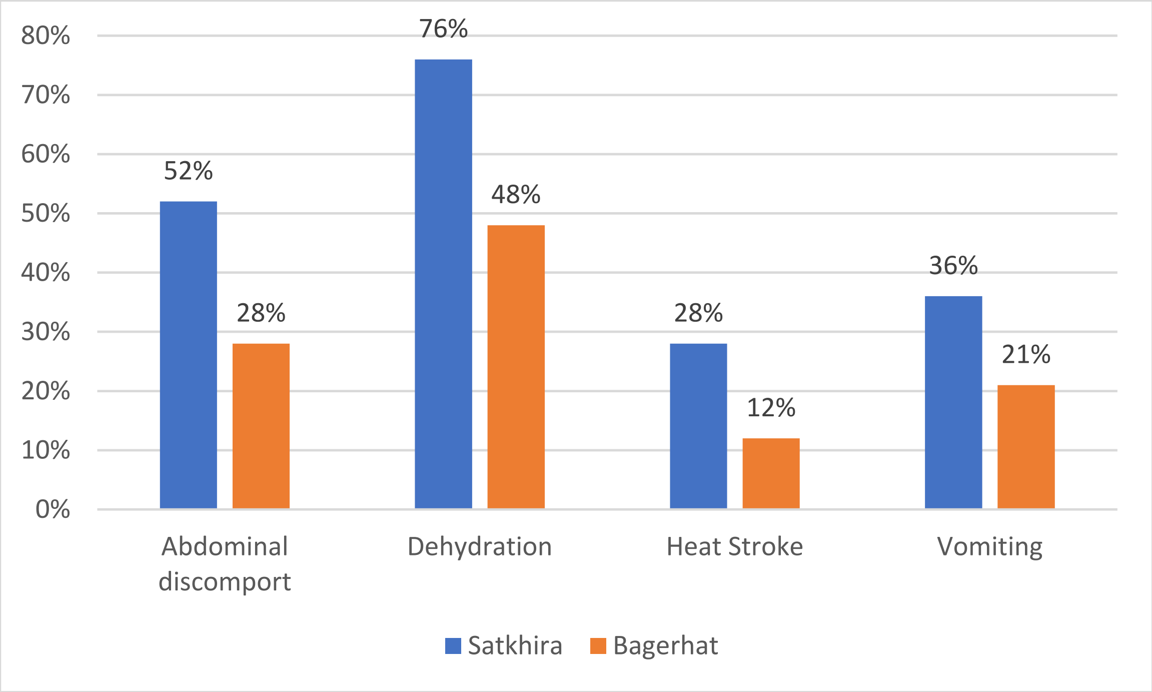


Figure 13: Health-related illness in Satkhira and Bagerhat Municipality

Table 2: Monthly heat-related illness

Health Issues	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abdominal discomfort	12%	12%	15%	48%	62%	60%	60%	26%	32%	42%	18%	10%
Dehydration	10%	10%	14%	78%	82%	55%	52%	30%	28%	27%	14%	9%
Heat Stroke	0	0	0	14%	19%	17%	0%	0%	7%	14%	0%	0%
Vomiting	9%	9%	11%	16%	19%	13%	6%	11%	5%	16%	0%	0%

Table 3: Percentage of land use in both municipalities

Land classification	Satkhira	Bagerhat
Vegetation	42.87%	67.55%
Open space	1.02%	1.16%
Agricultural land	39.39%	8.41%
Build-up area	8.52%	19.89%
Sandy lands	0.38%	0.42%
Waterbody	7.31%	2.53%
Lowlands	0.51%	0.05%

Dehydration, abdominal discomfort, heat stroke, and vomiting are found to increase with rising temperatures. Figure 13 presents the prevalence of heat-related illnesses among urban residents in Satkhira and Bagerhat. Residents of Satkhira (76%) and Bagerhat (48%) mainly suffer from dehydration, followed by abdominal discomfort in Satkhira (52%) and Bagerhat (28%). These findings highlight the heightened vulnerability of Satkhira residents to heat-related illnesses compared to those in Bagerhat.

According to the Civil Surgeon of Satkhira, heat stress contributes to an increase in hypertension among urban citizens, particularly affecting newborns and the elderly. The Civil Surgeon also noted that many individuals visit Sadar Hospital for treatment of hypertension during the summer. He cited a rise in cases of hypertension and kidney diseases in recent years, not only within the municipality but also across the district. Focus Group Discussion (FGD) participants from slum areas of Bagerhat Municipality reported that work challenges increase during heat waves. They stated that heat waves make it difficult for daily laborers such as rickshaw pullers, construction workers, van pullers, and street vendors to work outdoors for extended periods. These groups often suffer from fever and muscle pain during heat waves.

Monthly heat-related illness varies with temperature. Abdominal discomfort rises sharply from April (48%) to May (62%) and peaks in June and July (60%), then drops toward December (10%). In May (82%) and April (78%), people tend to suffer from dehydration, with a gradual decrease after July. Heat stroke peaks in May (19%) and June (17%), dropping to 0% from October onwards. Vomiting shows moderate incidence throughout the year, peaking in April (16%) and declining to 0% by November and December. Overall, April to July is the most critical period for heat-related illnesses (Table 2).

Discussion

Heat-related mortality in Bangladesh has been escalating due to rising temperatures and the increased frequency of heatwaves, with significant impacts observed in the southwestern coastal districts, including Satkhira and Bagerhat. In July 2019, amid the season's most extreme heat, with temperatures soaring to 43.4°C in Satkhira, four individuals died in Pabna and Manikganj, two in Bagerhat, and one in Satkhira [10]. In late April 2024, Satkhira experienced a severe heatwave, with temperatures reaching a peak of 42°C, resulting in significant health impacts. According to a report, at least one person reportedly died from heatstroke in Satkhira district on 30 April 2024, as the country continued to experience its most prolonged heatwave on record [11]. This extreme heat reportedly claimed another life after a school teacher died of heatstroke in Satkhira

[12]. Medical professionals confirmed that his death was due to heatstroke caused by excessive heat [11]. While specific data for Bagerhat is lacking, the broader region, including Khulna Division, reported multiple heatstroke fatalities during this period. The Directorate General of Health Services (DGHS) documented 15 heatstroke deaths nationwide between April 22 and May 6, 2024, including one heatstroke death in Khulna [13]. This event underscores the urgent need for improved heatwave preparedness and public health interventions in vulnerable regions like Satkhira and Bagerhat.

Table 3 shows the percentage distribution of land use across Satkhira and Bagerhat municipalities according to land classification. According to the data, 67.55% of Bagerhat's land is covered with vegetation, compared to only 42.87% in Satkhira. In contrast, Satkhira's percentage of agricultural land (39.39%) exceeds Bagerhat's (8.41%). Built-up areas in Bagerhat (19.89%) are higher than in Satkhira (8.52%). Both municipalities have minimal open space, sandy land, water bodies, and lowlands, though Satkhira holds slightly more water bodies (7.31%) and lowlands (0.51%) than Bagerhat. This contrast reflects differing urban and rural land use patterns. Due to higher vegetation coverage in Bagerhat Municipality compared to Satkhira Municipality, the Land Surface Temperature (LST) and formation of Urban Heat Island (UHI) are comparatively lower. With lower LST and UHI, heat-related health problems and illnesses are also less prevalent in Bagerhat Municipality than in Satkhira Municipality.

Heat adaptation activities

There is no formal heat adaptation plan in place. FGD participants from both municipalities reported that they usually preserve drinking water in *Mait* (mud-made water preservers), try to maintain ventilation in their homes, and informal workers take shelter under trees. The Chief Executive Officer of Satkhira Municipality urged the need for heat wave-resilient landscaping, developing a proper plan, securing sufficient funding, and generating scientific evidence. He also emphasized the importance of developing a heat early warning system for the municipalities and a location-specific heat wave adaptation plan. Additionally, he advocated for capacity building among local residents and municipal authorities to monitor heat islands and support vulnerable populations.

Conclusion

It is an important part of the heat-adaptive urban system strategy for the Satkhira Municipality and the Bagerhat Municipality; there is a need for an improved holistic action plan. In terms of increased household resiliency and its proper utilization, both municipalities and their allied stakeholders should consider how it might be able to tackle multi-sectoral heat vulnerability, focusing on where it can have the deepest impact. Heat adaptation training and awareness will be helpful in preparedness and improving life-saving capacity at the household level, primarily through health education. Urban land use planning incorporating green space, open space, and waterbodies will be effective to adapt to heat-related problems. In the urban planning and governance process, there needs to be integrated heat stress management in spatial planning, which may entail limiting new development in the municipal areas. Alleviation of the urban heat-island effect by greening areas, providing shade by using green coverage, and restoration of urban forest and water bodies is essential. There is also a need to increase the coverage of well-ventilated housing infrastructure services for low-income groups and slum people to enhance their adaptive capacity and prevent more inequities from heat stress and heat waves. To develop a sustainable, healthy municipality, the restoration and conservation of existing green vegetation and surface water bodies are highly essential. Eco-friendly materials should be promoted in road and building construction to reduce the urban heat-island effect. By addressing these challenges, Satkhira and Bagerhat Municipalities can improve heat adaptation with a special focus on health adaptation.

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Not applicable.

Competing Interests

The authors declare no competing interests.

Authors' Contributions

Not declared.

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Ethical Considerations

Not applicable.

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