



Trend of heat waves in Dhaka Metropolitan City and its impact on livelihood and health of exposed people

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Abstract

The exponential growth in population and physical infrastructure since 1980 has imposed immense pressure on Dhaka Metropolitan City (DMC), triggering extensive urbanization and a surge in built-up areas. This urban expansion has intensified the urban heat island (UHI) effect (the phenomenon where urban areas experience significantly higher temperatures compared to surrounding areas), resulting in adverse global urban climate changes such as temperature spikes, erratic rainfall, and compromised air quality. This study aims to discern the heat wave trends in DMC from 1972 to 2020 and elucidate their impact on public health and livelihoods. Employing a blend of quantitative and qualitative methodologies, the research analysis of land surface temperatures (LST) and land cover indices reveals a significant increase in built-up areas, particularly in western and central parts of the city, correlating with higher LST. Satellite imagery (Landsat 5 and 8) with 30-m resolution and meteorological data indicate a rise in surface temperatures. Analysis reveals April, May, and June as the peak months for heat wave occurrences, with DMC enduring a total of 328 heat wave days according to heat index (a measurement of perceived temperature in human body indicating how hot it feels when relative temperature is added to the actual air temperature) classifications. Notably, the density of built-up areas, particularly in central and western regions, exacerbates the UHI effect, evident in rising surface temperatures reaching 40.1 °C in 2014. The study underscores the dire health hazards posed by heat waves, with vulnerable populations, such as slum dwellers and outdoor laborers, facing heightened risks. Despite widespread impacts, public awareness about heat waves remains deficient, as evidenced by respondents' limited understanding of the term. These outcomes and prepared maps of the current research will be supportive for the local inhabitant, urban planner, and environmental resources management manager, national and international policy advisor, government and non-movement stakeholder, and researcher to observe the urban climate, trend of heat wave, and its impact on exposed people.

Keywords Heat wave · Heat index (HI) · Urban heat island (UHI) · Urbanization · Remote sensing (RS) · GIS

Introduction

The increasing occurrence and severity of heat waves underscore a global challenge, affecting cities worldwide as temperatures rise and urban heat islands intensify. As the capital and

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primate city of Bangladesh, Dhaka has experienced tremendous growth in different fields and become the hub of economic, social, industrial, educational, etc., after the liberation war of 1971. The level of urbanization went up to 29.1% from 7.1% in 2020 and 1972, respectively (BBS 2019). Extensive extraction of natural surfaces modifies heat retention, its dispersion, and evaporative and transvaporative rates which in-turn modifies local climate, air flow, and atmosphere (McGregor et al. 2007). Combined, these factors can create an urban heat island (UHI) effect, where urban atmospheric and surface temperatures become significantly warmer than their natural surroundings. High air temperatures can affect human health and lead to deaths (heat-related illness like heat stroke) even under current climatic conditions (Awange et al. 2013; Robinson 2001; Sekertekin and Bonafoni 2020; Shahmohamadi et al. 2010).

There are many studies focusing on the effects of climate change on global temperatures and their distribution in space and time (Suparta and Yatim 2017). With climate change, climate variability and thus the incidence of heat waves are likely to increase (Panda et al. 2017). In the USA, heat waves are the leading cause of weather-related deaths with an estimated 688 deaths reported to be directly related to heat each year (Bai et al. 1995). In 1980, a heat wave recorded across the USA claimed the lives of an estimated 10,000 individuals (Basu and Samet 2002). In August, 2003, Western Europe experienced one of its worst heat waves which resulted in an estimated 70,000 heat-related deaths (Brooks et al. 2005). France was the worst affected country with over 14,800 heat-related deaths recorded (Burke 2010). A heat wave could be defined as a prolonged period of extremely hot weather. A review carried out by Cerne et al. (2007) in Europe found that the operational definition for heat wave was based on country-specific conditions which relied on either an air temperature circuit and a minimum duration or the indices based on a combination of air temperature and relative humidity (Chan et al. 2008). Heat is a familiar weather-related hazard and has been associated with increases in both mortality and morbidity (Chen et al. 2020; Ma et al. 2011, Nairn et al. 2018). Heat waves are defined as extended periods of extreme high temperature, and are regarded as one of the primary weather-associated threats to human life. For instance, the excess mortality during the extremely hot summer of 2003 in Europe was estimated to be about 50,000 (Zacharias et al. 2015). There are many studies focusing on the effects of climate change on global temperatures and their distribution in space and time (Suparta and Yatim 2017). With climate change, climate variability and thus the incidence of heat waves are likely to increase (Panda et al. 2017). In Pakistan, the months of June and July are usually prone to cause heat-related deaths. For example, in 2003 over 230 heat-related deaths were reported in the country (Wilhelmi and Hayden 2010; Jillani 2015), and in 2005, over 175 people died as a result of a sweltering heat wave when temperatures exceeded 45 °C for over a week (Jillani 2015). Analysis of long-term climate records has provided evidence of an increase

in the frequency and duration of extreme temperature events in all over Bangladesh, particularly during summer (Nissan et al. 2017). Summer stays for a longer period while winters have shortened in Bangladesh. The increased heat of summer thus affects the lives of the people engaged in outdoor activities during scorching sun hours (Rajib et al. 2011). Excessive heat causes discomfort, fatigue, heat cramps, heatstroke, heat exhaustion, etc. (Nitschke et al. 2007). Humans are exposed to climate change through direct effects such as the health impacts of extreme temperatures or other extreme weather events like cyclones, storms, and hurricanes (Costello et al. 2009). Other impacts are considered by indirect pathways which consist of health conditions related to air quality and aeroallergens, water- and food-borne diseases, vector- and rodent-borne diseases, and other contagious diseases (Arbuthnott and Hajat, 2017). Climate change would also affect food production systems, and the availability and quality of freshwater that would further increase the risk of communicable diseases (Das and Smith 2012). Further indication shows that increase in climate-related extremes will result in more deaths, injuries, and population displacements (Dewan 2013; Zittis et al. 2016; Zhang et al. 2011; Turner et al. 2003; Diniz et al. 2020). One direct effect of climate change on human health is the threat posed by an increase in heat waves (Grumm 2011; Nairn and Fawcett 2014; NASA 2005; NASA 2007). The existing and potential changes connected with climate change, including increases in the frequency of heat waves and their intensity, are recognized as a public health concern since they are linked with heat-related illnesses, deaths, and injuries (Hajat et al. 2010). In addition, heat waves are also connected with other well-known social, environmental, and economic consequences which have implications for human health (Huang et al. 2010). Heat waves are a normal occurrence in some parts of Southeast Asia, although they seemed to have gained little attention like those in the western countries (Liang et al. 2020; O'Neill and Ebi 2009; Rabbani et al. 2011; Rinner et al. 2010). In the Indian sub-continent for example, heat waves are common during summers (March–June). Heat index (HI) is a measurement of perceived temperature in human body, indicating how hot it feels when relative temperature is added to the actual air temperature (Luber and McGehee 2008). Heat index is measured to determine the in-laid stress in human by excessive levels of atmospheric temperature and moisture (Tan et al. 2004; Vidal and Walsh 2010; Telesca et al. 2018; Kalkstein and Smoyer 1993). Increase of relative humidity in the atmosphere restrains the ability of human body to release heat through evaporation resulting in discomfort and stress (Delworth et al. 1999). The increase in heat index can even lead to collapse and death to humans and animals (Aggarwal et al. 2008). Forecasts from the climate models indicate that global surface air temperature will increase significantly in future due to radioactive effects of enhanced atmospheric concentrations of gases (Steadman 1984). Having studied associated and contemporary literature, the study has been conceptualized based upon the identification

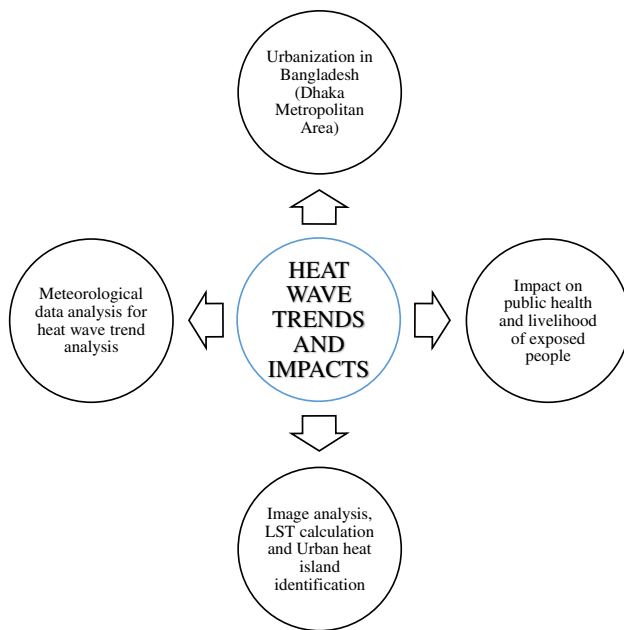


Fig. 1 Conceptual framework of the research

of research gap and develop a conceptual framework for the research (Fig. 1).

The goal of this research is to assess the urban heat island using ArcGIS interface and the trend of heat wave originated from the potential climate change impact. Also, the aim of the current study is to illustrate the impact of heat waves on public health and livelihood of exposed people due to the increasing frequency of heat waves. Heat index (HI) and meteorological data are used for assessing the urban heat waves of Dhaka Metropolitan City. The findings of the study could be applied in future decision-making processes for urban development. Besides, the urban areas of Bangladesh are always vulnerable due to high temperature, so urbanization of megacity like Dhaka Metropolitan City (DMC) requires more supervision for sustainable growth. In addition to short-term adaptation measures, there is also the need to develop long-term adaptation strategies to reduce the impacts of heat waves on human health. Therefore, prior to any development activities, vulnerability of urban areas should be acknowledged. As a justification of the above statement, the capital city of Bangladesh (Dhaka city) has been chosen as the study area, where physical and human vulnerability is very high due to frequent heat-related mortality and unplanned urban expansion.

Background of the study area

Dhaka, one of the world's fastest growing megacities, is surrounded by six rivers (Turag, Balu, Shitalakshya, Buriganga, Tongi khal, and Dhaleshwari) and located in central Bangladesh at 23°42'N 90°22'E. The city lies on the lower reaches

of the Ganges Delta and covers a total area of 306.38 square kilometers (118.29 sq mi). Dhaka is bounded by the districts of Gazipur, Tangail, Munshiganj, Rajbari, Narayanganj, and Manikganj. It has formed in the center portion of Bangladesh, known as the Madhupur-Bhawal Garh Region, on more elevated Pleistocene terrace land or Order Alluvium (Helal et al. 2010). Dhaka and the municipalities that make up the Greater Dhaka Area have a combined population of about 18 million people, with the city growing at a rate of approximately 4.2% each year. Migration and population expansion have been aided by the lively culture and hundreds of Bangladeshi companies and multinational corporations. Dhaka is one of the hottest regions in Bangladesh with an average daily high temperature of 31 °C. With a yearly average of 31 degrees the climate is very warm, but has only a very few tropical and humid months. The climatic point of view, three distinct seasons can be recognized—the cool dry season from November through February, the pre-monsoon hot season from March through May, and the rainy monsoon season which lasts from June through October. The annual temperature of Dhaka City has increased. The annual maximum temperature of 40.2°C was recorded in 2014. The humidity of Dhaka Metropolitan city has decreased in alter to temperature has increased. The annual average highest humidity is 77% and the lowest is 70% (Figs. 2 and 3).

Data sources and methodology

Data sources

The study uses both primary and secondary data. Primary data is collected by questionnaire survey through kobo tool-box (ODK). The study is mainly based on secondary data. Secondary data also has been collected to complement the primary data from various sources. These include books, journals, articles, unpublished theses, project papers, and websites (published and unpublished) (Fig. 4).

Survey data

Random sampling was conducted in both Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) (Fig. 5). The data was collected through Kobo Tool-box, an open-source suite of tools designed for field data collection, management, and analysis. A total of 320 respondents were interviewed (representing each group-rickshaw/van puller, hawker, construction worker, and pedestrian).

Climatic data

All meteorological data were collected from Bangladesh Meteorological Department (BMD). To account for the

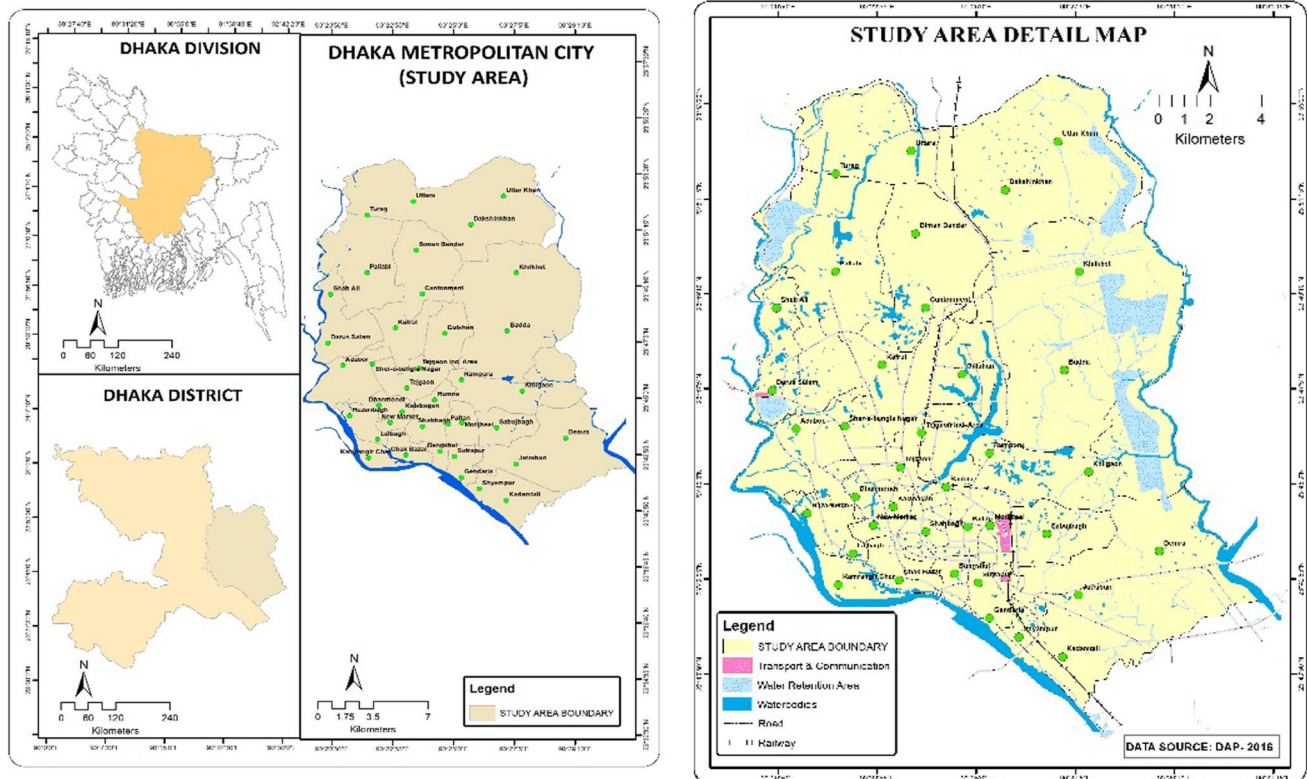


Fig. 2 Study area details map

influence of weather on the UHI, data regarding temperature, precipitation amount, and humidity have been retrieved for the relevant measurement period. Humidity has been retrieved to determine the heat index (how hot it feels when relative temperature is added to the actual air temperature). The minimum, average, and maximum values of temperature and cloud cover have been retrieved, since the UHI is known to be largest under calm and clear weather conditions.

Satellite images

For identifying urban heat island (UHI), 12 cloud free multi-temporal images of Landsat 5 TM (Thematic Mapper), Landsat 8 OLI (Operational Land Imager), and TIRS (Thermal Infrared Sensor) were acquired (downloaded from USGS global visualization viewer) for the years 1990, 1992, 1995, 1999, 2001, 2004, 2006, 2009, 2011, 2014, 2019, and 2020. Different properties of satellite imageries are shown in Table 1.

Tools and methodology

The major tools used in the research are ArcGIS (version 10.8) and supporting image analysis software like Erdas Imagine and ENVI. Some statistical tools like SPSS (Statistical Package

for the Social Sciences) and Microsoft Excel are also used for analysis of the data that are shown in Table 2.

Land surface temperature (LST) calculation

Land surface temperature (LST) refers to the temperature of the Earth's surface, and it is one of the significant factors that affect surface energy balance, heat fluxes, regional climates, and energy exchanges (Dash et al. 2002). In this research, the TIR band 10 (Landsat 8) and TIR band 6 (Landsat 5) were used to estimate brightness temperature, and also bands 4 and 5 (Landsat 8) and bands 3 and 4 (Landsat 5) were used for calculating the NDVI (Avdan and Jovanovska 2016). We present an operational algorithm for creating Landsat LST reliably for all sensors that will be executed by the US Geological Survey (USGS) (Malakar et al. 2018). The metadata of the satellite images used in the algorithm is shown in Table 3.

First, we have to calculate top of atmospheric (TOA) and spectral radiance ($L\lambda$) by using the following formula (Eq. 1):

$$\text{TOA } (L\lambda) = M_L * Q_{\text{cal}} + A_L \quad (1)$$

where,

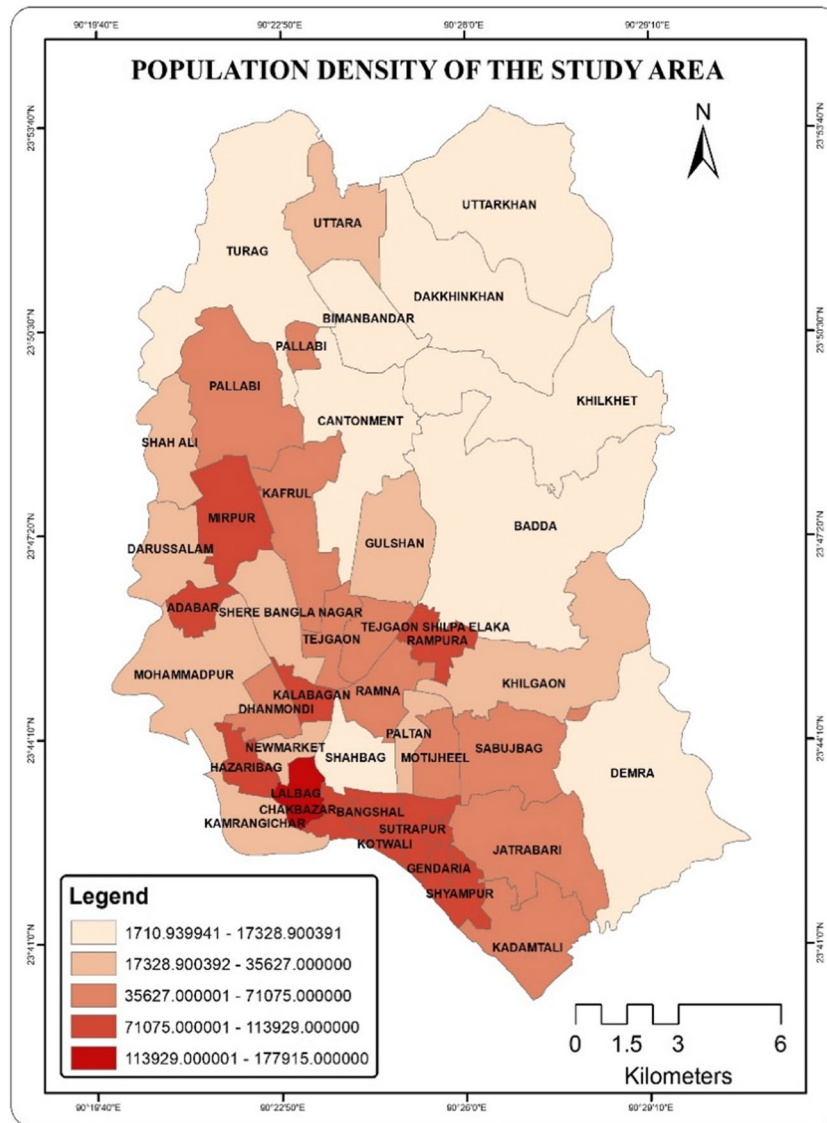


Fig. 3 Population density of the study area

M_L represents the band-specific multiplicative rescaling factor.

Q_{cal} the band 10 image (Landsat 8) or the band 6 image (Landsat 5).

A_L band-specific additive rescaling factor.

After calculating TOA, the TIRS band data should be converted from spectral radiance to brightness temperature (BT) using the thermal constants (K_1 and K_2) provided in Table 3. The following equation (Eq. 2) is used to calculate brightness temperature (BT):

$$BT = \left\{ \frac{K_2}{\ln \left(\frac{K_1}{L\lambda} \right) + 1} \right\} - 273.15 \tag{2}$$

where K_1 and K_2 stand for the band-specific thermal conversion constants from the metadata.

To calculate the proportion of vegetation (P_V), we have to measure NDVI that is highly related to emissivity (ϵ) that must be calculated using the following equation (Eq. 3):

$$PV = \text{Square} \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right) \tag{3}$$

Generally, the minimum and maximum values of the NDVI image can be shown directly in the image; otherwise, we have to open the properties of the raster to get those values.

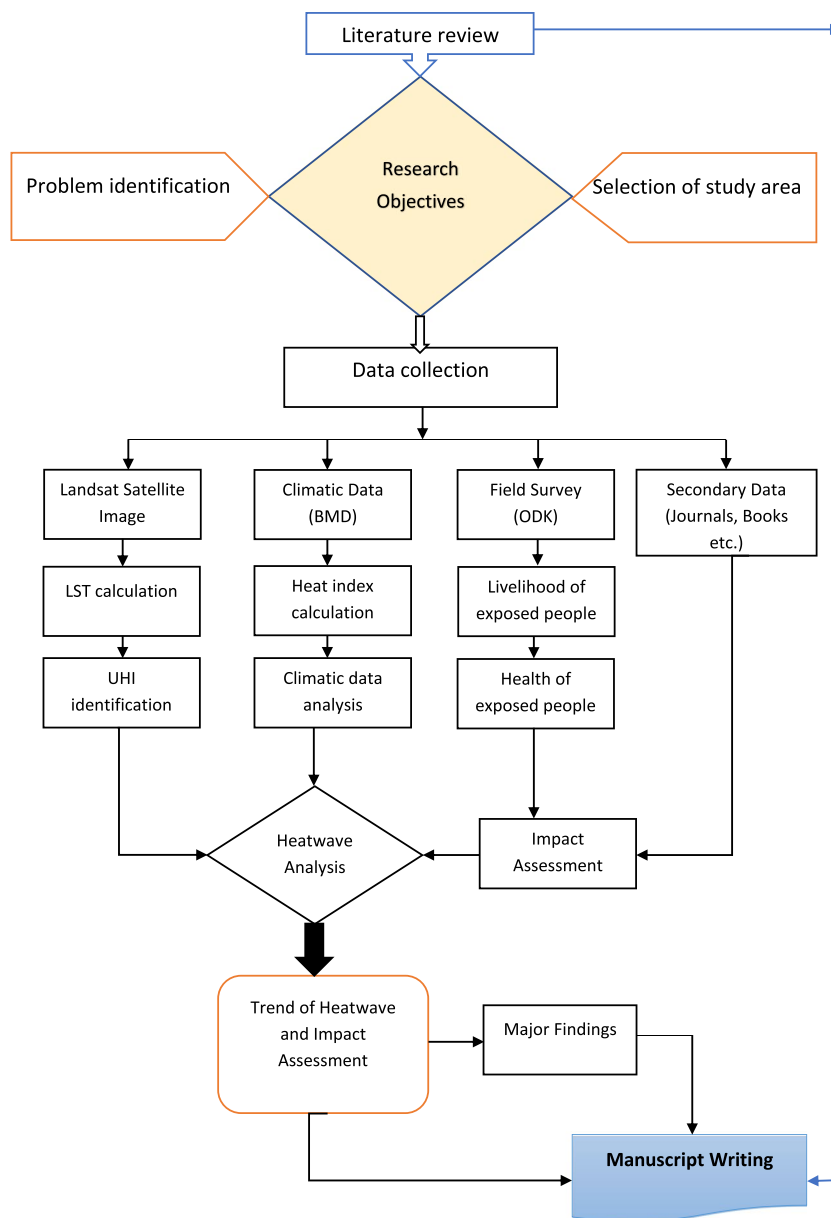


Fig. 4 Methodology of the research

Then we have to calculate the emissivity to predict emitted radiance by using the following formula (Eq. 4) in the raster calculator:

$$\epsilon = 0.004 * P_V + 0.986 \tag{4}$$

Here, the value of 0.986 corresponds to a correction value of the equation.

Finally, we have to apply the LST equation to obtain the land surface temperature map. The following equation (Eq. 5) is used in the tool’s algorithm to calculate LST:

$$LST = (BT / (1 + (0.00115 * BT / 1.4388) * \ln(\epsilon))) \tag{5}$$

Urban heat island (UHI) identification

The urban heat island (UHI) effect refers to areas where temperatures tend to be higher in urban zones than in surrounding non-urban areas, representing a major anthropogenic alteration to the Earth’s environments (Zhou et al. 2019). To identify the urban heat islands, we first calculated land surface temperature (LST) of Dhaka from satellite imageries and used the equation mentioned below. Generally, UHI is identified using the following equation (Eq. 6):

$$UHI = LST > \mu + \sigma / 2 \tag{6}$$

where μ is the mean and σ is the standard deviation of LST.

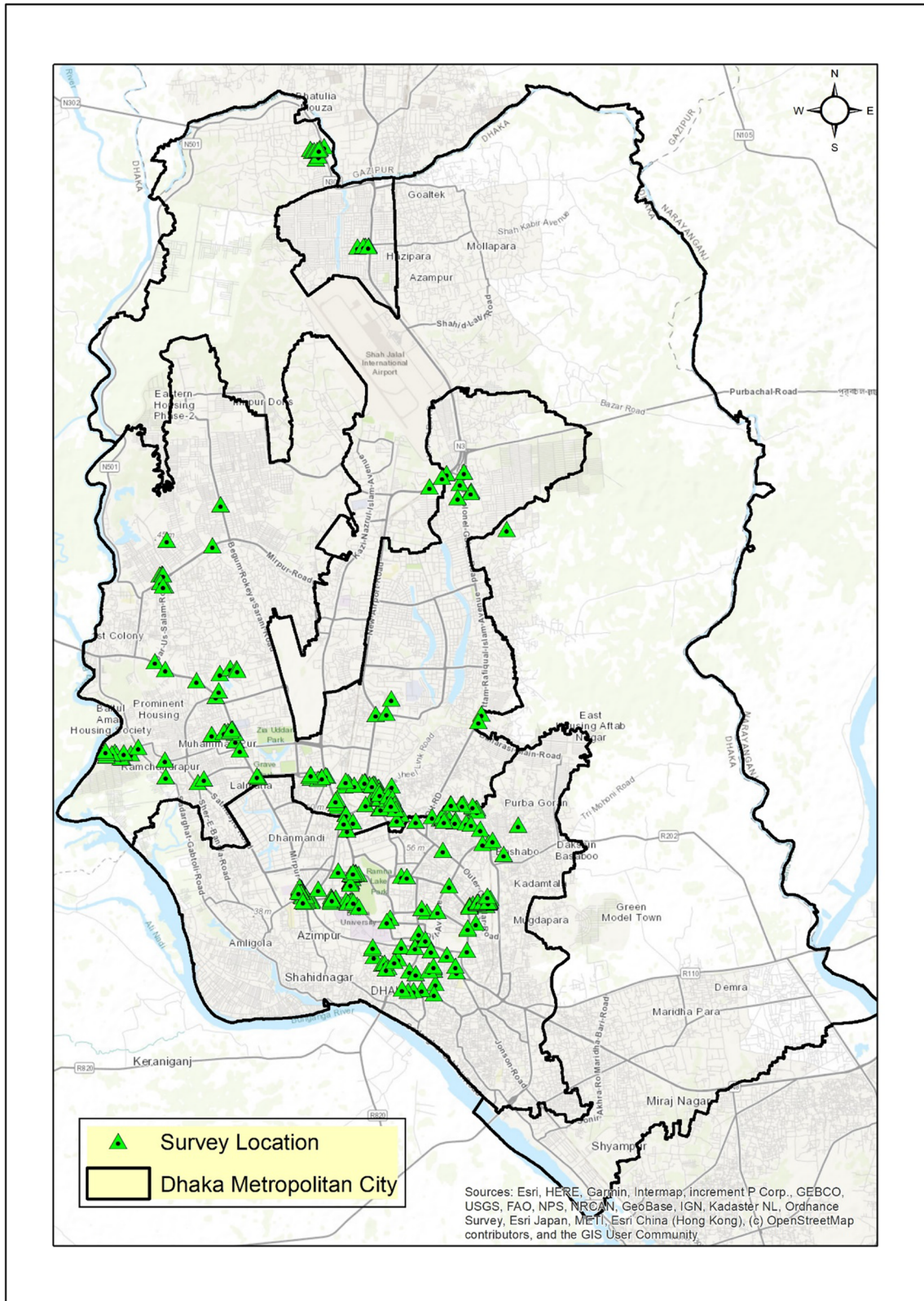


Fig. 5 Geographical location of the survey data (respondents)

Table 1 List of satellite imageries with detail properties

Satellite and sensor	Acquisition date	Time	Path/row	Spatial resolution (m)	Weather condition	
					Temperature (°C)	Humidity (%)
Landsat TM 5	29/04/1990	3:24 am	137/44	30	30.2	63
Landsat TM 5	02/04/1992	3:48 am	137/44	30	33	21
Landsat TM 5	11/04/1995	3:46 am	137/44	30	28.5	64
Landsat TM 5	21/03/1999	3:33 am	137/44	30	32.4	10
Landsat TM 5	10/03/2001	4:01 am	137/44	30	31	40
Landsat TM 5	02/03/2004	4:03 am	137/44	30	35	17
Landsat TM 5	25/04/2006	4:04 am	137/44	30	30.4	44
Landsat TM 5	01/04/2009	4:03 am	137/44	30	30	58
Landsat TM 5	07/04/2011	4:16 am	137/44	30	32.8	48
Landsat OLI_TIRS 8	30/03/2014	4:19 am	137/44	30	33.6	23
Landsat OLI_TIRS 8	28/03/2019	4:14 am	137/44	30	34.2	50
Landsat OLI_TIRS 8	30/03/2020	4:24 am	137/44	30	36.2	37

Table 2 Tools and techniques for analysis

Research techniques	Procedures	Major tools
LST	Land surface temperature calculation	ArcGIS 10.8 Erdas Imagine
UHI	Urban heat island identification	ArcGIS 10.8 Erdas Imagine
HI	Heat index calculation	MS Excel
Statistical analysis	Graphical presentation and analysis	SPSS MS Excel
Questionnaire survey	Gathering information	KoBo toolbox

Table 3 Metadata of the satellite images

Satellite images	Thermal bands	Thermal constant		Rescaling factor	
		K_1	K_2	M_L	A_L
Landsat 5	Band 6	607.76	1260.56	5.5375E-02	1.18243
Landsat 8	Band 10	774.8853	1321.0789	3.3420E-04	0.10000

However, to make the UHI estimate more precise, we have used full standard deviation rather than half of it (Eq. 7).

$$UHI = LST > \mu + \sigma \tag{7}$$

Calculation of NDVI, NDBI, and MNDWI

In remote sensing, normalized difference of vegetation index (NDVI) has been used to quantify vegetation greenness or to measure density of vegetation. Mathematically to measure the NDVI, following formulas (Eq. 8) have been used for calculating this index value (X. L. Chen et al. 2006).

$$NDVI = (NIR - red)/(NIR + red) \tag{8}$$

For Landsat 5, $NDVI = (band\ 4 - band\ 3)/(band\ 4 + band\ 3)$

For Landsat 8, $NDVI = (band\ 5 - band\ 4)/(band\ 5 + band\ 4)$

Normalized difference built-up index (NDBI) is used to extract built-up features as well as impervious surface can be measured by using the following formula (Eq. 9) (Zha et al. 2003):

$$NDBI = (SWIR - NIR)/(SWIR + NIR) \tag{9}$$

For Landsat 5, $NDBI = (band\ 5 - band\ 4)/(band\ 5 + band\ 4)$

For Landsat 8, $NDBI = (band\ 6 - band\ 5)/(band\ 6 + band\ 5)$

Heat index calculation from climatic data

In order to reach an equation which uses more conventional independent variables, a multiple correlation analysis was performed on the data from Steadman’s table. National Weather Service has modified this index for operational purposes such as specific ranges to health effects and extreme heat warnings when required (Steadman 1979).

The resulting equation could be considered a heat index (HI) equation (Eq. 10),

$$\begin{aligned}
 HI = & -42.379 + 2.049(1.8C + 32) + 10.14R \\
 & - 0.224(1.8C + 32)R - 6.83 \times 10^{-3}(1.8C + 32)^2 \\
 & - 5.48 \times 10^{-2}R^2 + 1.22 \times 10^{-3}(1.8C + 32)^2R \quad (10) \\
 & + 8.52 \times 10^{-4}(1.8C + 32)R^2 - 1.99 \\
 & \times 10^{-6}(1.8C + 32)^2R^2
 \end{aligned}$$

where *R* stands for the relative humidity (%) and *C* is the temperature (°C). The original equation was used Fahrenheit (°F) unit for temperature, but in this study, it was converted into Celsius (°C) unit. Based on this equation, it is can be used only when air temperature and humidity are higher than 26 °C and 39%, respectively. Because this equation is obtained by multiple regression analysis, the value of heat index (HI) has an error of ± 1.5 °C (NOAA 1990).

Results and discussion

Investigating the trend of urban heat wave

Bangladesh Meteorological Department (BMD) has classified heat waves into four categories based on their corresponding temperature—types of the heat waves are captured in Table 4 below.

As observed from the above analysis, in terms of heat wave in Bangladesh, the threshold for heat wave starts at 36 °C. This directly links with adaptability of human body to the temperature of ambient air, i.e., TW 35 °C which is considered the threshold beyond which human body stops cooling itself.

Table 5 shows that Dhaka city faces a total of 328-day heat wave according to heat wave classification by BMD.

Table 4 Heat wave classification by BMD

Temperature range	Type of heat wave
36–38 °C	Mild heat wave
38–40 °C	Moderate heat wave
40–42 °C	Severe heat wave
> 42 °C	Extreme heat wave

Table 5 BMD classification-wise heat wave day count

Year	Mild	Moderate	Extreme	Severe	Total
1972	4	0	0	0	4
1973	8	2	0	0	10
1975	4	0	0	0	4
1976	8	4	0	0	12
1977	0	0	0	0	0
1978	4	0	0	0	4
1979	10	8	1	0	19
1980	4	3	0	0	7
1981	1	0	0	0	1
1982	6	0	0	0	6
1983	3	0	0	0	3
1984	3	0	0	0	3
1985	0	0	0	0	0
1986	9	0	0	0	9
1987	10	1	0	0	11
1988	12	2	0	0	14
1989	20	2	0	0	22
1990	0	0	0	0	0
1991	5	0	0	0	5
1992	16	0	0	0	16
1993	2	0	0	0	2
1994	5	0	0	0	5
1995	18	0	0	0	18
1996	12	0	0	0	12
1997	0	0	0	0	0
1998	3	0	0	0	3
1999	16	0	0	0	16
2000	1	0	0	0	1
2001	7	0	0	0	7
2002	0	0	0	0	0
2003	2	0	0	0	2
2004	11	0	0	0	11
2005	2	0	0	0	2
2006	6	0	0	0	6
2007	8	0	0	0	8
2008	3	0	0	0	3
2009	10	3	0	0	13
2010	10	0	0	0	10
2011	0	0	0	0	0
2012	5	0	0	0	5
2013	7	0	0	0	7
2014	28	5	0	0	33
2015	0	0	0	0	0
2016	13	1	0	0	14
Total	296	31	1	0	328

In 2014, the highest number of days heat wave occurred in Dhaka city and day by day it has increased.

ICDDR, B has developed a heat index threshold using the formula by NOAA and proposed to use for consecutive

2 days instead of 5 days defined by the WMO considering the context of Bangladesh. To develop the heat health index ICDDR, B has used the formula developed by the NOAA.

Heat index, also known as the apparent temperature, is what the temperature feels like to the human body when relative humidity is factored in with the actual air temperature. While analyzing heat index data and its impact, we observed that the proposed threshold of 95th percentile is quite high considering the impacts observed at that level (Nissan et al. 2017). We further analyzed below (Fig. 6) the heat index and thresholds proposed by the International Centre for Diarrheal Disease Research, Bangladesh (ICDDR, B).

The thresholds (caution, low danger, high danger, and extreme danger) proposed by ICDDR, B also did not exactly correspond with the impacts that were available (bold faces index value in heat index and Fig. 6). In fact, impacts appear

much earlier—from 35 to 39.5 °C and a corresponding heat index of 38 to 45.5 for Dhaka. However, BMD has not developed any heat-index-based heat wave forecast.

A study conducted by Nissan et al. has tried to define heat wave for Bangladesh that requires elevated minimum and maximum daily temperatures over the 95th percentile for 3 consecutive days, confirming the importance of nighttime conditions for health impacts.

From the climatic data, it is clear that maximum daily temperatures over the 95th percentile are total 224 days and 32 number of times (3 consecutive days).

Based on our analysis of daily 3-h interval observed temperature for 48 years (from 1972 to 2020 for Dhaka station), we found that April, May, and June are identified as the hottest months in Bangladesh when heat wave is likely to hit. Parts of the county may also experience

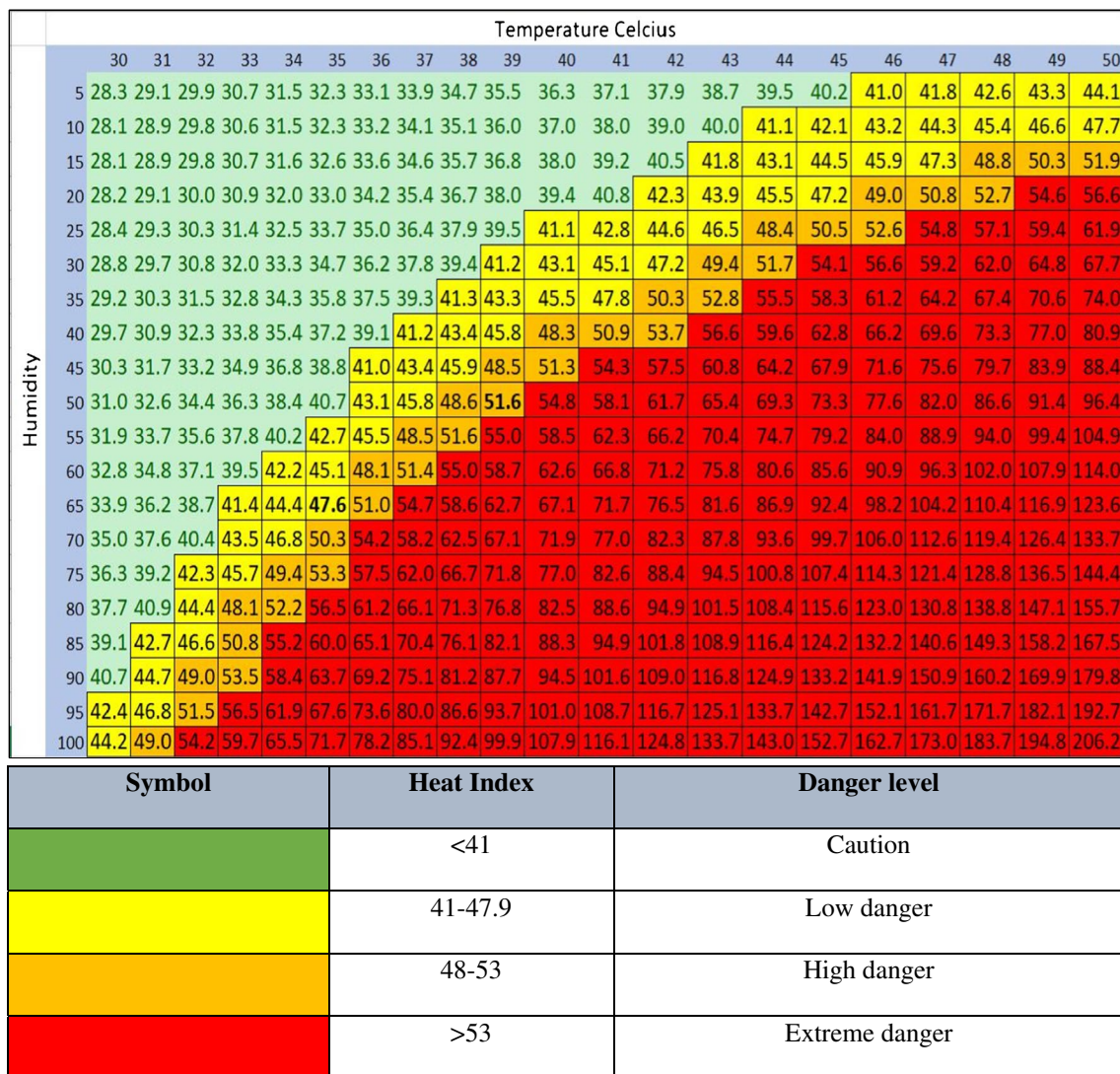


Fig. 6 ICDDR, B category wise heat index calculation

higher temperature in August, September, and October, but it might not reach at the level of a heat wave due to higher amount of rainfall.

Daytime temperatures (daily maxima) reach their highest values (close to 35 °C on average) in April and May, decreasing distinctly as rainfall increases with the start of the monsoon season in early June and remaining unevenly constant until the monsoon retreats in September/October. Nighttime temperatures do not show the same peak in the pre-monsoon season as daytime temperatures, reaching their highest values in the mid-monsoon season. Relative humidity peaks at approximately 90% during the early part of the monsoon season, later than the peak in maximum temperature, and then decreases toward the end of the rainy season.

Identification of urban heat island (UHT) and associated indices

The land surface temperature (LST) maps show that there are a few regions where the calculated LST is higher than the surrounding areas (Fig. 7a and b). The comparison between the LST maps and earth imagery shows higher temperature in the areas with high built-ups. Badda, Gulshan, Kamrangirchar, Mirpur, Gabtoli, Goran, Bashabo, Tongi, Sahid Nagar, Babubazar, Postogola, Zurain, Hazaribagh, Jatra-bari, Saydabad, Kurmitola, Azampur, Uttara, Kamarpara, Mohammadia housing area, Adabar, Farmgate, Tejkunipara, Nakhhalpara, Mohakhali, etc., areas show high temperature value (29–35.17 °C) on average. From Fig. 7(a), the average land surface temperature for the years of 1990, 1992, 1995, 1999, 2001, and 2004 were, respectively, 24.05 °C, 28.64 °C, 25.07 °C, 30.37 °C, 26.21 °C, and 28.23 °C. And from Fig. 7(b), the average land surface temperature for the years of 2006, 2009, 2011, 2014, 2019, and 2020 were, respectively, 28.73 °C, 23.84 °C, 29.06 °C, 35.15 °C, 28.29 °C, and 35.17 °C.

The density of built-up area was the highest in the middle and western parts of the city where the proportion of other land use types was small. Those areas are characterized by a higher degree of LST. LST was low in the eastern part of the study area, which is mostly covered with vegetation.

On the other hand, normalized difference built-up index (NDBI) is higher where the LST is also higher. The density of built-up area was the highest in the middle and western parts of the city where the proportion of other land use types was small. Those areas are characterized by a higher degree of NDBI. NDBI was low in the eastern part of the study area, which is mostly covered with vegetation.

The spatial distribution of NDBI showed that most of the western part in Dhaka city is highly built-up in comparison with eastern part of the study area. The mean NDBI value ranged from -0.06 to $+0.08$. Negative values of NDBI

showed the non-built-up region while the positive value reflected the built-up area of the study area.

The result of NDBI portrayed that built-up area was less compared to non-built-up areas. The built-up area increased with the increase in LST. The built-up area was more in south Dhaka compared to north Dhaka which holds more built-up towns and industrial areas. However, in, 1990, NDBI map showed that Dhaka has a more vegetative area (less built-up area) compared to non-vegetative which might be the result of lesser air temperature (Fig. 8a and b).

Normalized difference vegetation index (NDVI) is highest where the LST shows lowest value. The density of built-up area was the highest in the southern and eastern parts of the city where the proportion of other land use (built-up area) types was small. Those areas are characterized by a higher degree of NDVI. NDVI was low in the middle and western parts of the study area, which is mostly covered with built-up areas.

From Fig. 9a and b, it is clear that the mean NDVI value for the years of 1990, 1992, 1995, 1999, 2001, 2004, 2006, 2009, 2011, 2014, 2019, and 2020 were, respectively, 0.25, 0.27, 0.23, 0.23, 0.19, 0.21, 0.17, 0.17, 0.17, 0.17, 0.17, and 0.17.

The spatial distribution of NDVI showed that most of the eastern part in Dhaka city is vegetative compared to western part of the study area. The mean NDVI value ranged from 0.17 to 0.27. Negative values of NDVI showed a built-up region while the positive value reflected the non-built-up area of the study area. Statistical data of NDVI, NDBI, and LST are shown in Table 6.

UHI was calculated based on mean and standard deviation (SD) of LST. It has been found from recent studies that surface temperatures are higher in urban areas than in surrounding rural areas for a number of reasons, including the concentrated release of heat from buildings, vehicles, and industry. In the USA, this urban heat island effect results in daytime temperatures of 0.9–7.2 °F (0.5–4.0 °C) higher and nighttime temperatures of 1.8–4.5 °F (1.0–2.5 °C) higher in urban areas, with larger temperature differences in humid regions and in cities with larger and denser populations.

The urban heat island effect will strengthen in the future as the structure, spatial extent, and population density of urban areas change and grow. On a hot, sunny summer day, roof and pavement surface temperatures can be higher than the air. Because of the impervious surface and/or higher reflection of roof, the temperature starts rising as it is trapped in those areas.

The spatial and temporal distribution of UHI for Dhaka city was developed for each year using the surface temperature for the same month (Fig. 10). Distribution of UHI showed that for all the years, central part experienced higher temperature and thus may be considered heat islands which were further supported by LST, NDVI, and NDBI in earlier sections.

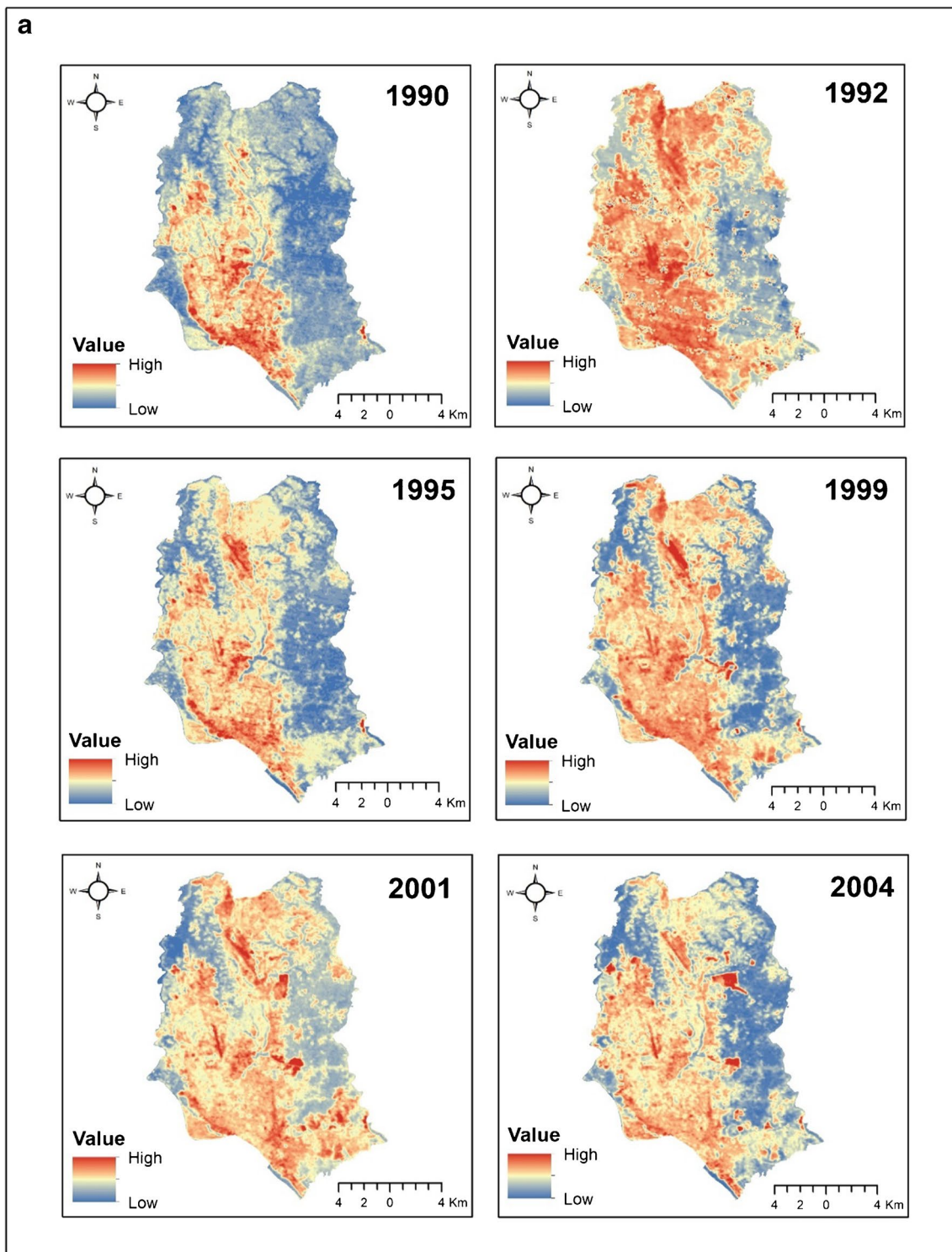


Fig. 7 a Spatial and temporal distribution of land surface temperature (LST) for Dhaka Metropolitan City. **b** Spatial and temporal distribution of land surface temperature (LST) for Dhaka Metropolitan City

Compared to northern regions, the southern region is highly populated (as can be seen from NDBI maps), and thus these regions experienced higher temperatures.

The result of UHI analysis also shows an increasing trend in UHI especially in the peri-urban areas. Spatial analysis revealed that the UHI zones were more concentrated in the central and southern regions of the study area. Eastern parts

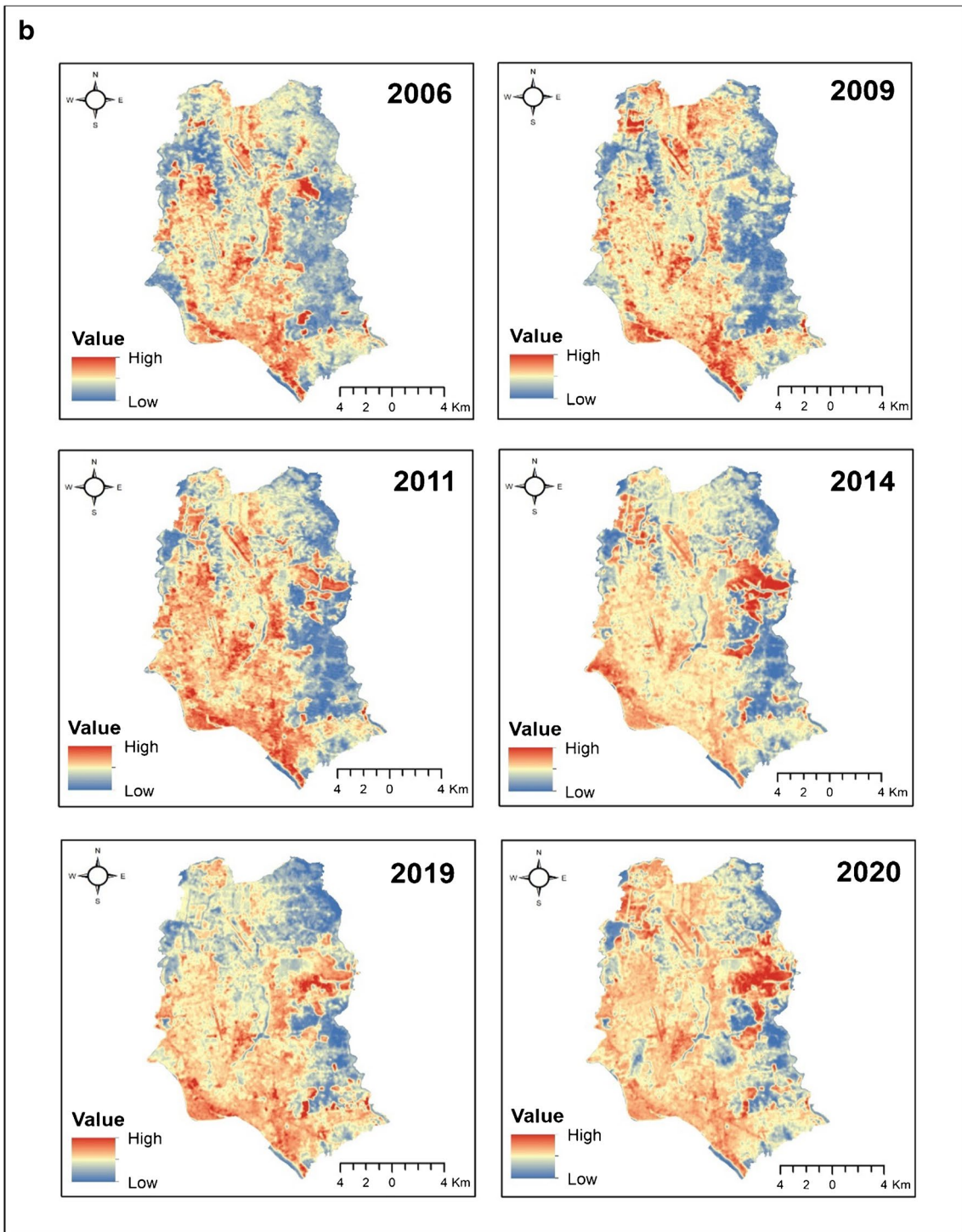


Fig. 7 (continued)

of Tejgaon and Keraniganj were identified as UHI regions for each year is associated with a higher density of impervious structures such as concrete buildings and paved roads in the region.

The potential impact of UHI is increased by the rising surface temperature in Dhaka city from 28.5 °C in 2004 to 40.1 °C in 2014 (Fig. 11a and b).

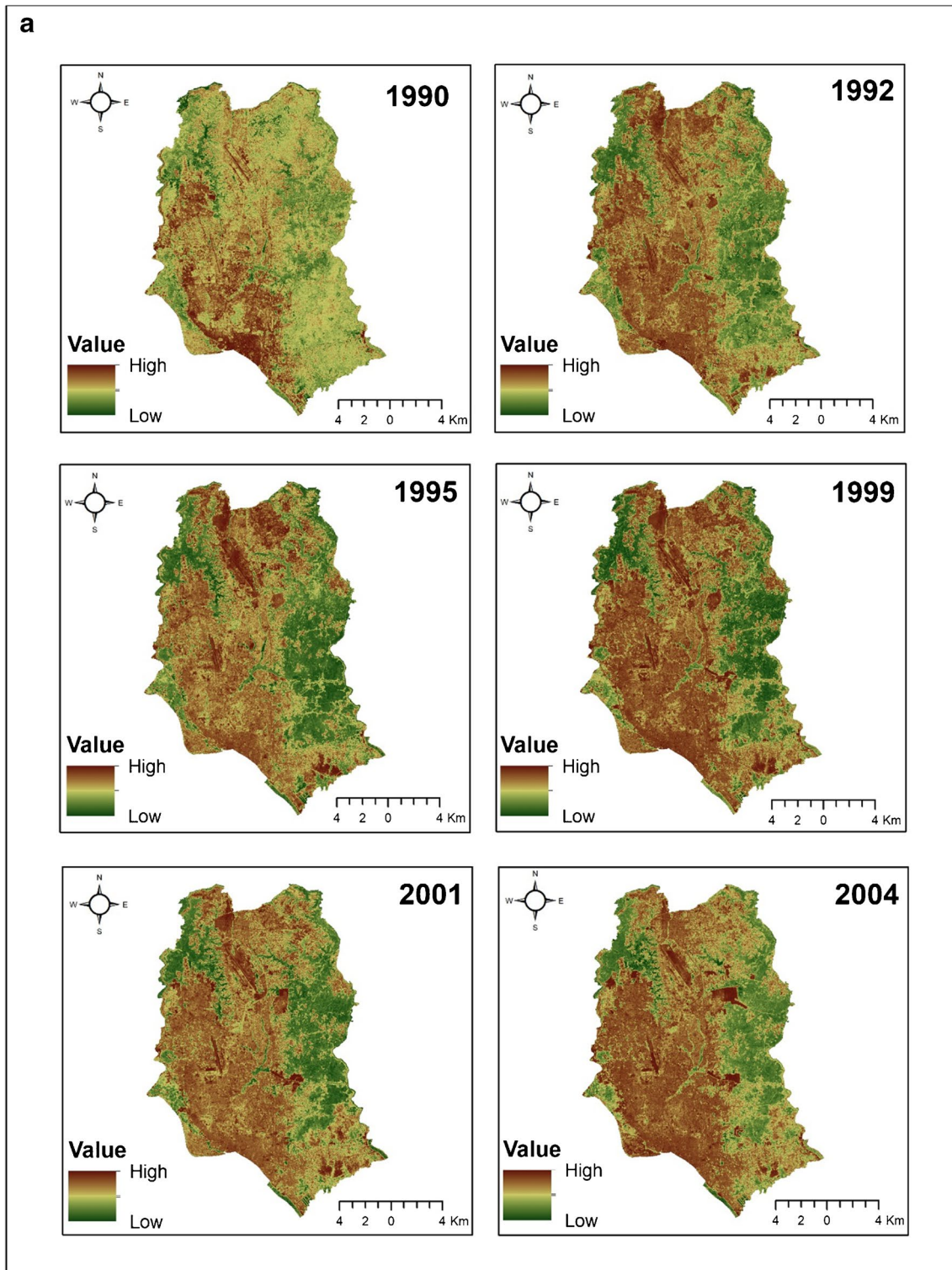


Fig. 8 a Spatial and temporal distribution of normalized difference built-up index (NDBI) for Dhaka Metropolitan City. **b** Spatial and temporal distribution of normalized difference built-up index (NDBI) for Dhaka Metropolitan City

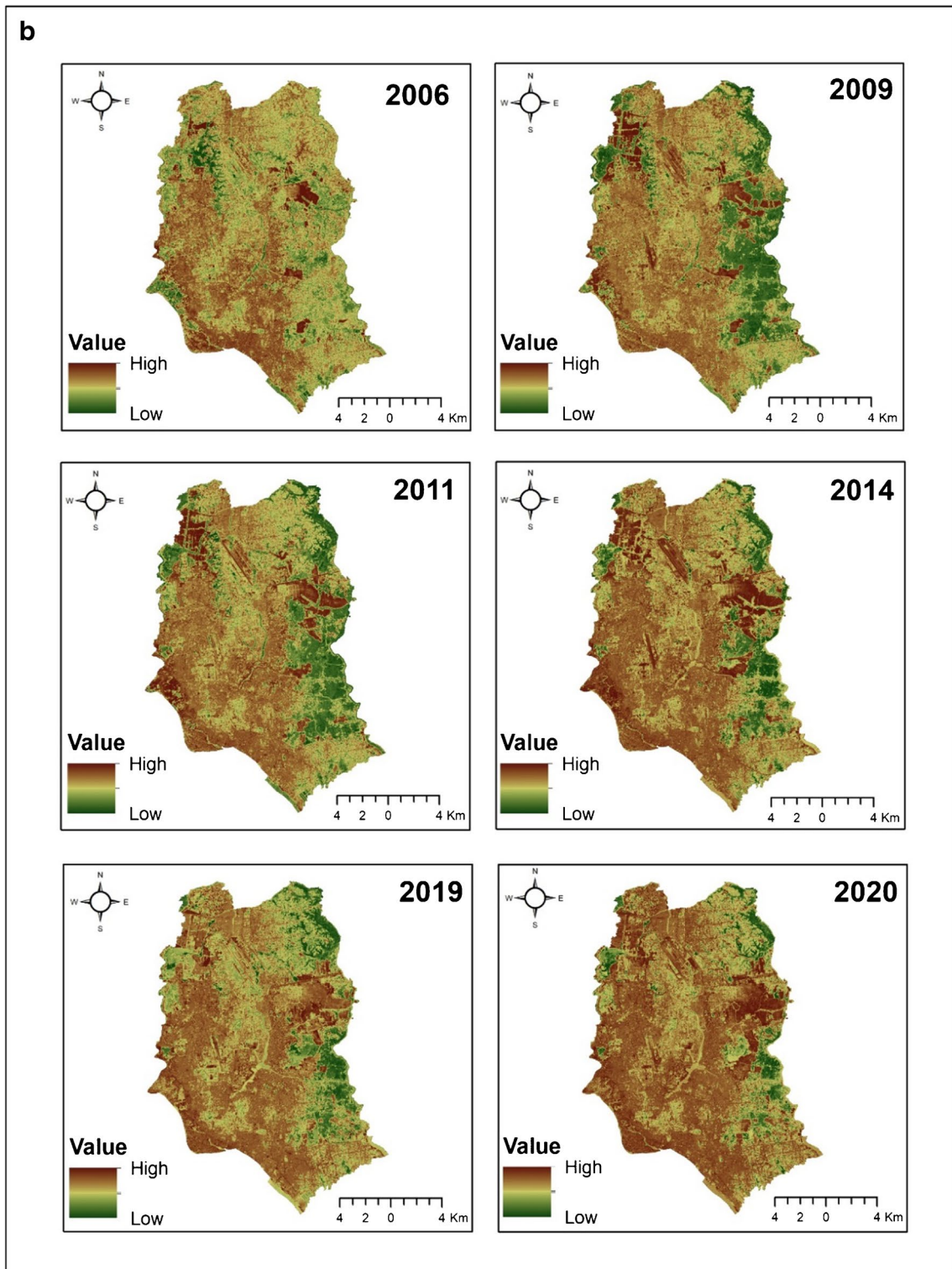


Fig. 8 (continued)

Impact assessment of urban heat wave

During a heat wave, human health hazard increases. However, literature on health and socio-economic impact of

heat waves and extreme temperature in context of Bangladesh is very scant. Nissan et al., after analyzing the nationwide death counts collected within Sample Vital Registration System, concluded that death rate increases

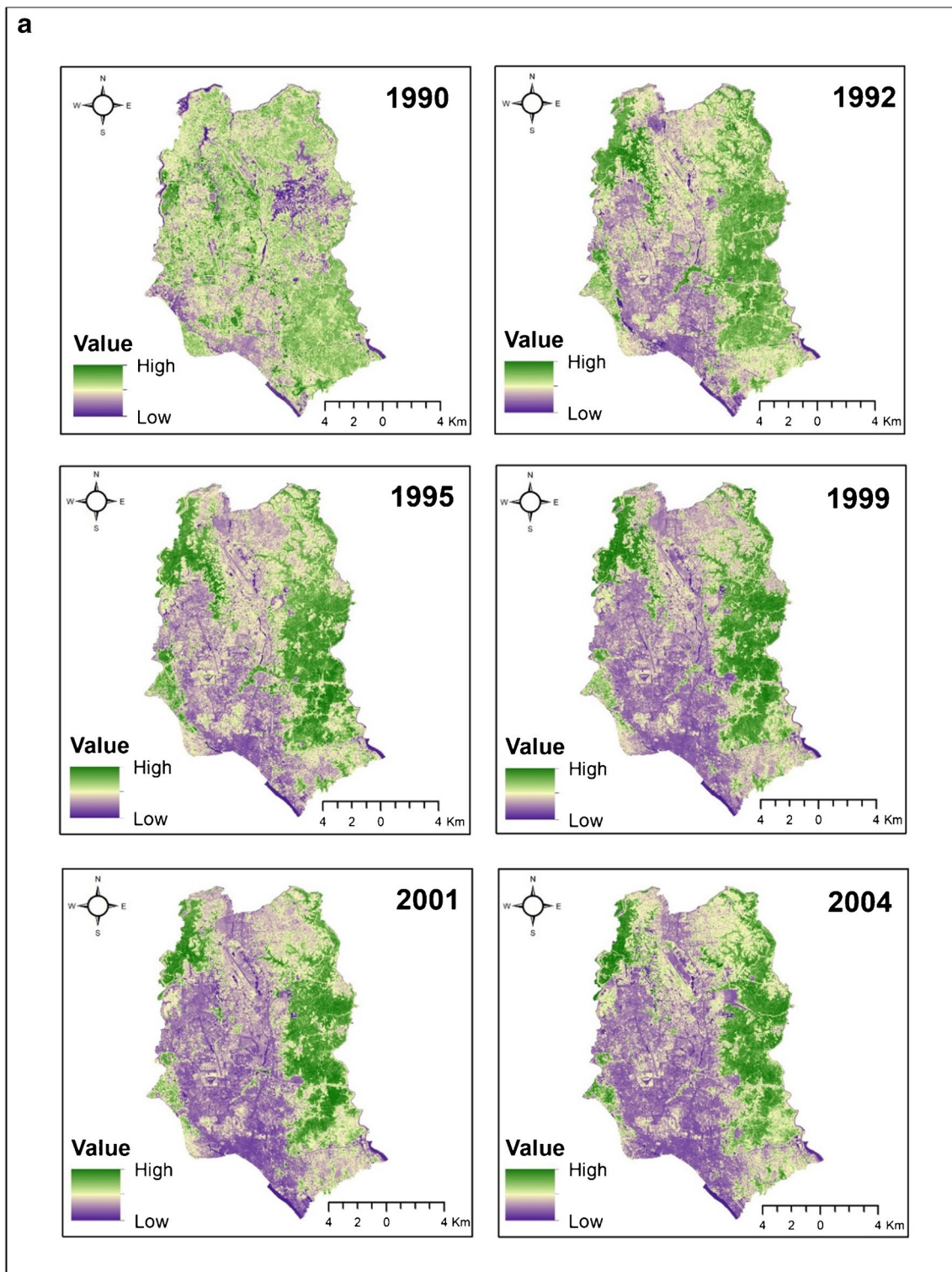


Fig. 9 **a** Spatial and temporal distribution of normalized difference vegetation index (NDVI) for Dhaka Metropolitan City. **b** Spatial and temporal distribution of normalized difference vegetation index (NDVI) for Dhaka Metropolitan City

by 20% during heat wave season. Moreover, there are some media reports pointing to the adverse impacts of temperature and heat waves on human health. For

example, on April 24, 2014, Dhaka Tribune reported that about 786 patients were admitted to the International Centre for Diarrheal Disease Research, Bangladesh

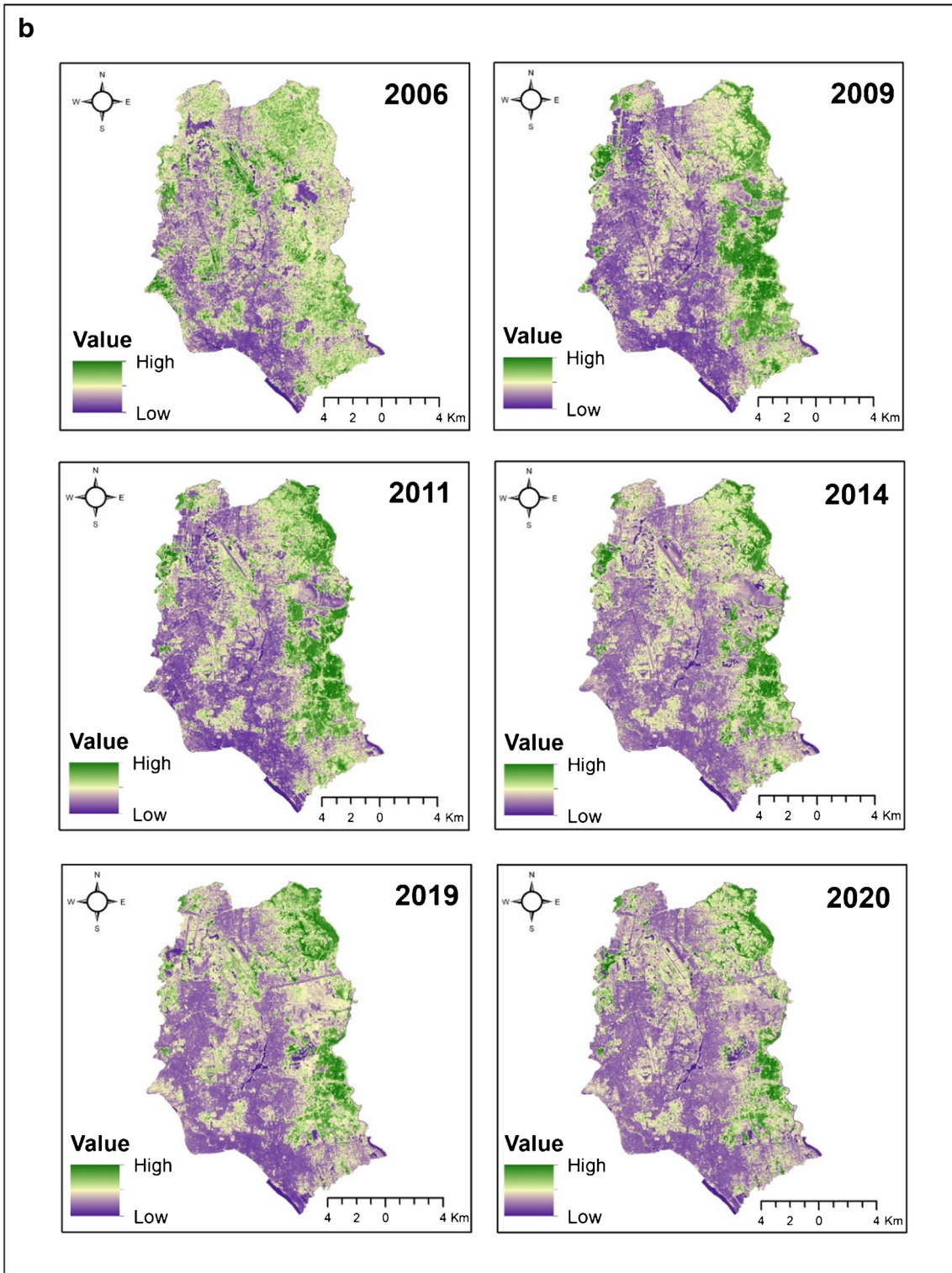


Fig. 9 (continued)

(ICDDR'B) hospital in the last 24 h and about 60% of them were infants suffering from water-borne diarrheal diseases.

A video documentary prepared by BBC media action reported that nearly 3500 people died in 2005 due to different heat waves in Bangladesh (Lowe et al. 2011).

Table 6 Statistical data of NDVI, NDBI, and LST

Year	NDVI				NDBI				LST			
	Max	Min	Mean	Standard deviation	Max	Min	Mean	Standard deviation	Max	Min	Mean	Standard deviation
1990	0.73	-0.39	0.25	0.17	0.42	-0.63	-0.03	0.13	32.46	21.50	24.04	1.41
1992	0.86	-0.88	0.27	0.16	0.93	-0.93	0.03	0.15	63.04	8.98	28.64	3.68
1995	0.62	-0.29	0.23	0.16	0.49	-0.45	0.05	0.14	31.24	22.38	25.07	1.27
1999	0.67	-0.33	0.23	0.19	0.39	-0.53	0.07	0.16	45.58	22.82	30.37	3.56
2001	0.61	-0.27	0.19	0.16	0.73	-0.44	0.08	0.14	35.66	18.38	26.21	2.30
2004	0.70	-0.37	0.21	0.20	0.39	-0.56	0.07	0.15	38.01	22.38	28.23	2.71
2006	0.60	-0.28	0.17	0.12	0.51	-0.41	0.08	0.10	37.23	24.12	28.73	1.80
2009	0.65	-0.22	0.17	0.16	0.50	-0.38	0.07	0.13	31.24	20.62	23.84	1.38
2011	0.61	-0.31	0.17	0.16	0.51	-0.43	0.07	0.13	37.62	24.11	29.06	2.15
2014	0.55	-0.18	0.17	0.11	0.26	-0.45	-0.06	0.09	44.72	27.56	35.15	2.89
2019	0.51	-0.08	0.17	0.10	0.41	-0.36	-0.06	0.08	37.07	23.65	28.29	1.72
2020	0.61	-0.21	0.17	0.12	0.33	-0.50	-0.05	0.09	44.57	24.43	35.17	3.12

In 2003, at least 62 people died in heat waves across Bangladesh due to heat wave.

Heat island analyses show that the densely populated areas like slum areas happened to be the areas with high-temperature zones. People living in slum areas and the people working outdoors are the most vulnerable group. Densely populated area, lack of proper ventilation inside the house, low height of the roof, housing material, increased load shedding, lack of accessibility to proper health care system, lack of greenery around living areas, low income, and unhygienic living condition make them vulnerable to heat waves mostly.

Heat waves are most likely to affect people who work or live outdoors. The heat wave brought sufferings to lower income class due to their poor income and as they have to work outside (rickshaw puller, van puller, street hawkers, construction workers, agriculture laborers), children and elderly people because of their age and dependency, and slum dwellers as the slum area is overpopulated and congested.

In the FGD, people mentioned how they try to cope with excessive heat or heat waves. In most of the cases, they mention that they use hand fans, try to stay in an open and airy place instead of congested places, take more water and liquid foods, cover their body with wet towels, and often wipe their body with wet cloths. Some of them take showers several times in a day. Those who have shops close their shop from 12:00 to 3:00 pm due to extreme heat. Rickshaw and van pullers also try to avoid working during these hours.

While interacting with the community people, some of the major heat wave impact-related findings are the following:

- Health impact: People in the community mentioned about skin disease, fever, cold, heat stroke, fatigue, increase of water borne diseases (diarrhea, cholera, etc.), dehydration, and respiratory problems during heat wave and excessive hot temperatures.
- Impact on working hour and income: Impacting daily income of laborer/rickshaw/van puller group due to loss of working hours. Most of the respondent of this group mentioned that they are forced to skip working between 12:00 to 3:00 pm due to excessive heat outside (Fig. 12).
- Increase of health expenditure: Most of the slum people mentioned that during the season of excessive temperature, their health expenditure increases due to increasing events/occurrences of disease they mentioned.
- Trigger other hazards: Excessive heat makes the corrugated tin shade get highly vulnerable to catch fire and it increases fire incidence in slum areas. Excessive temperature helps the fire get spread too soon over the whole slum area.
- Impact on students: Students suffer from lack of concentration and heat exhaustion due to excessive heat in the school.

The pharmacy owners, during the focus group discussion, mentioned that during heat waves, their sales of IV saline and oral saline increases by almost three times than the regular sales which verify the statement of the community people of getting infected by disease like diarrhea/cholera during heat waves and increased health expenditure.

According to doctors on duty at emergency wing/department from different hospitals, during heat waves they mostly receive adult patients from the streets as parents are protective about kids moving in the street. Most of their

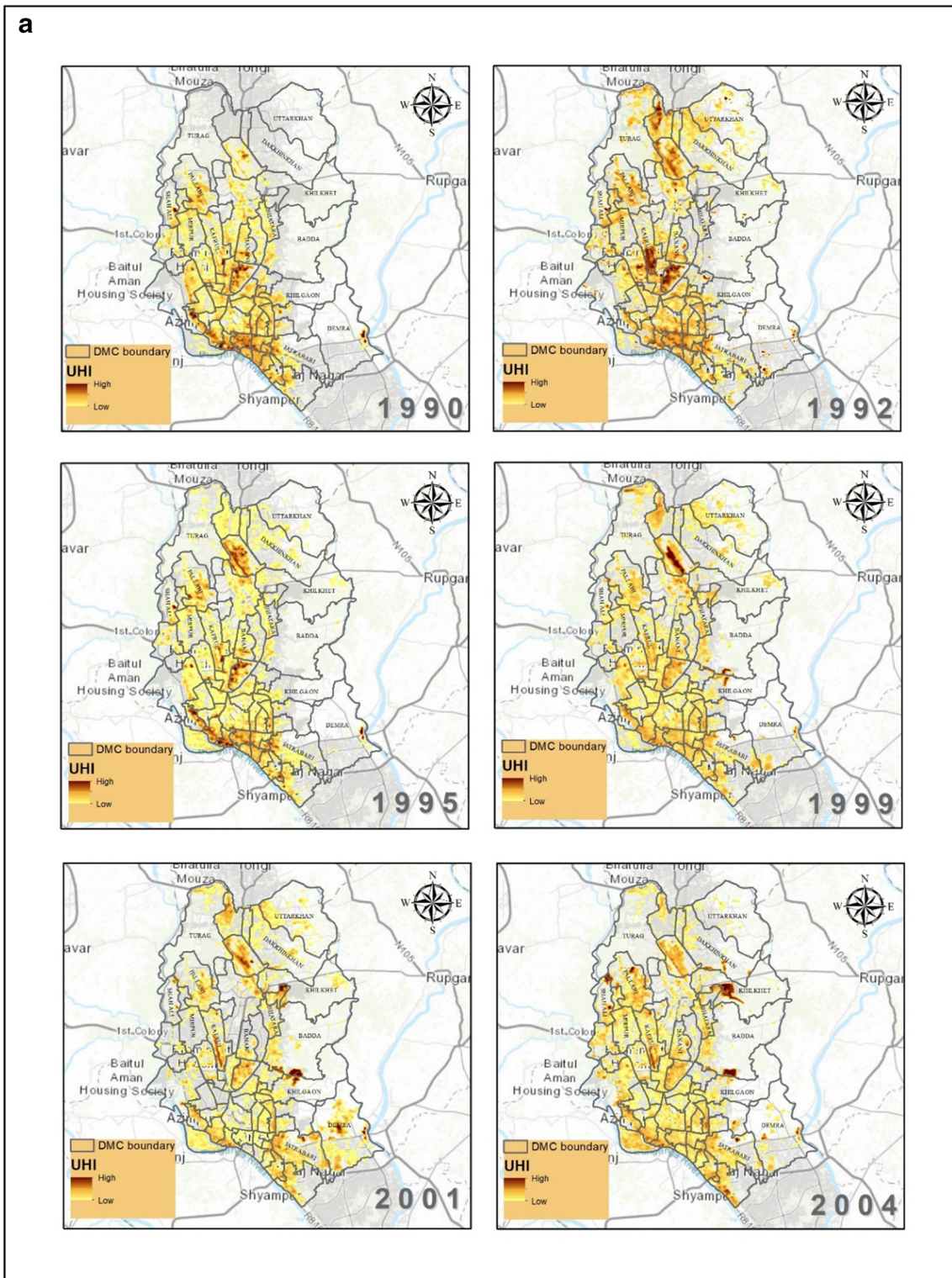


Fig. 10 Concentration map of urban heat island (UHI) for Dhaka Metropolitan City (from 1990 to 2020)

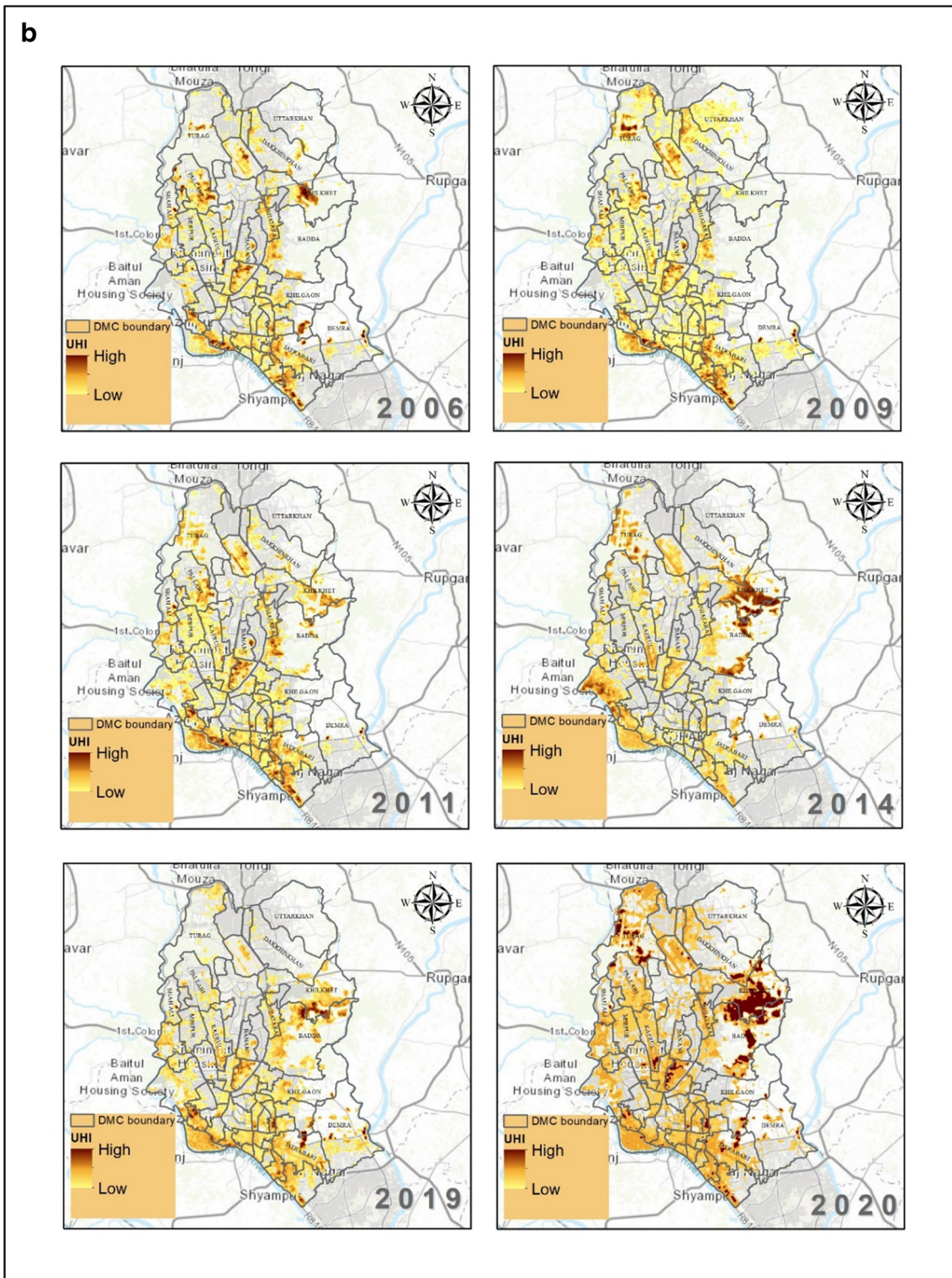


Fig. 10 (continued)

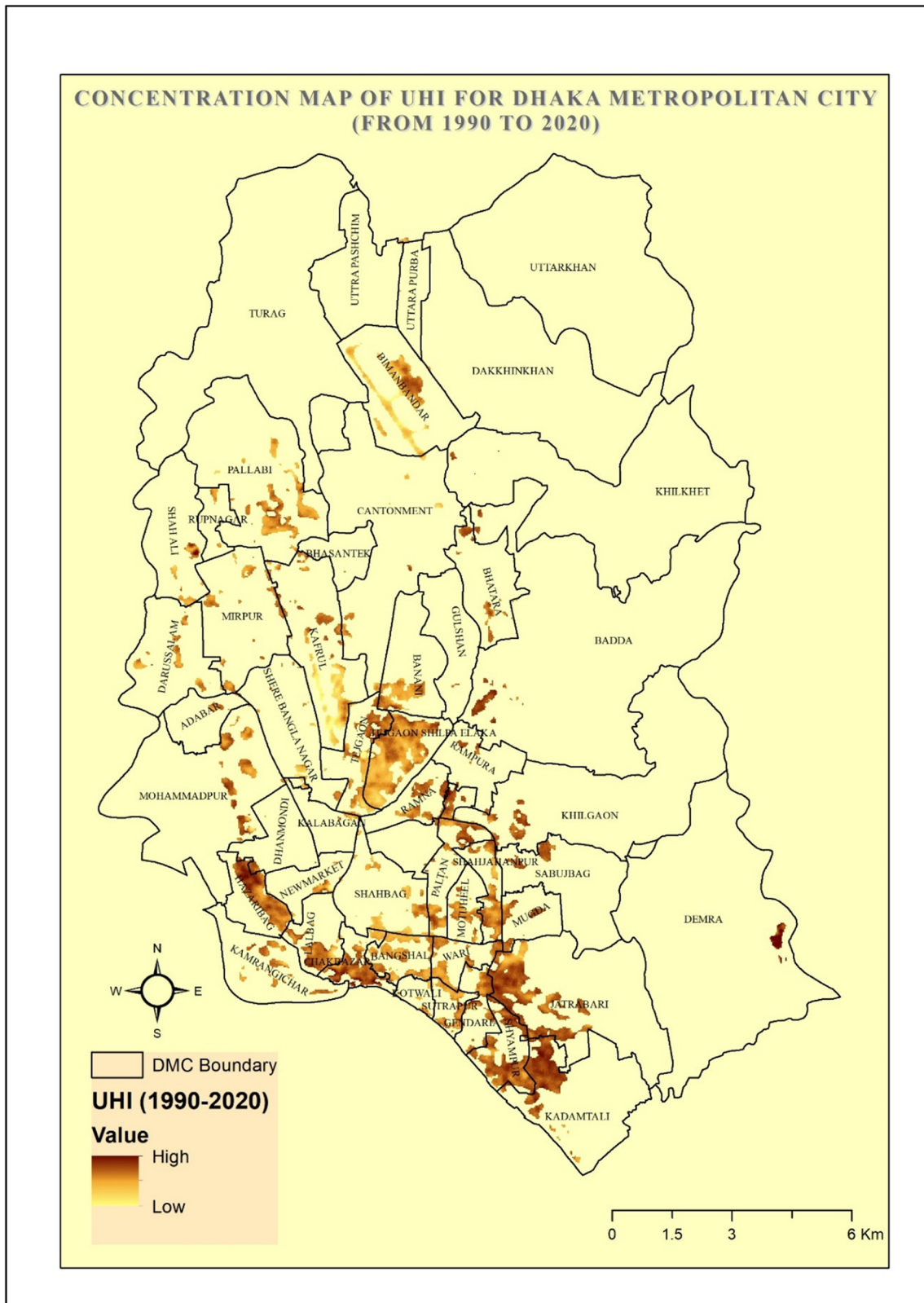


Fig. 11 a Spatial and temporal distribution of urban heat island (UHI) for Dhaka Metropolitan City (from 1990 to 2004). b Spatial and temporal distribution of urban heat island (UHI) for Dhaka Metropolitan City (from 2006 to 2020)

Fig. 12 Percentage of reduction of income of different respondent groups during heat wave

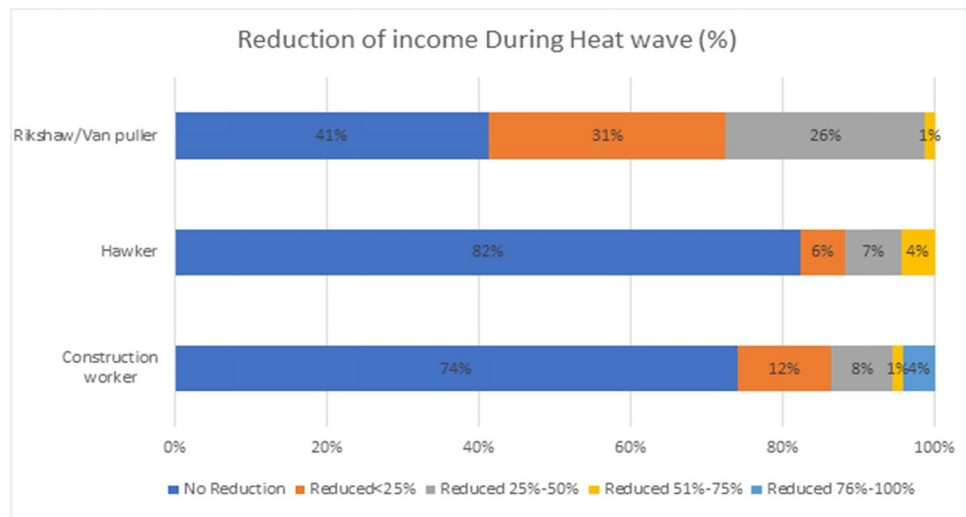
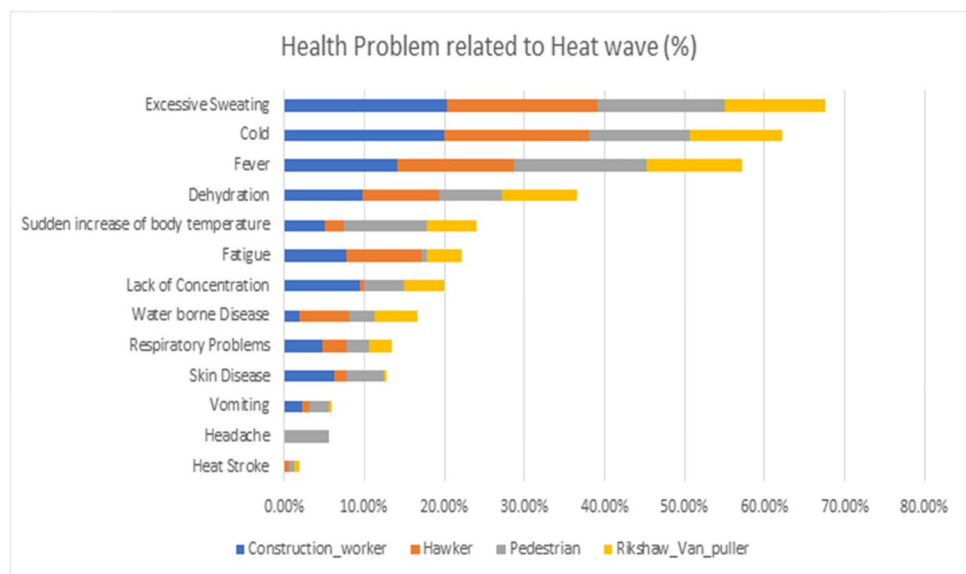


Fig. 13 Health problem related to heat wave (%)



heat-wave-related patients belong to lower income groups of society. Usually, patients come to the hospitals with symptoms of heat exhaustion and dehydration. The number of patients with heat stroke is low.

From a comparison group of 80 respondents, it was found that among them 64% of the total respondents said that they feel sick more frequently with different diseases during the summer season compared to other seasons (Fig. 13). About 81% of the respondents said that their healthcare expenditure increases in summer due to more frequent seasonal illnesses.

All of these respondents were asked general questions not specified to heat wave. This helped to identify when most of the respondents fall sick without relating to any specific disease or illness. The data was then further analyzed based on each group of respondents and with different age groups

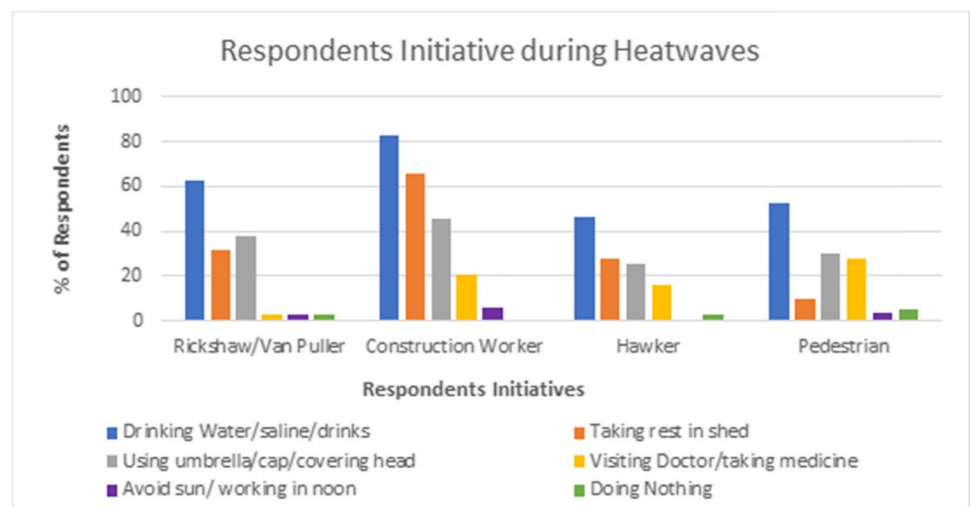
to find out the relation between heat wave and their income and health expenditure.

It also tried to find out if any early action could reduce the impact on their income and health during the heat wave. According to the respondents, they lose about 2.87 h (average) daily from their working hours due to heat wave which led to the losses of their income or working additional hours. Figure 12 shows the reduction of income during heat wave.

A preliminary analysis of the data produced several compelling results. Among the initial takeaways are as follows:

- Around 86.56% of the respondents ($n = 320$) said that they feel hotter than the previous years. But 84.06% of the respondents have no idea about what the term “heat wave” refers to.

Fig. 14 Respondents personal initiatives to protect themselves during heat waves



- The rickshaw/van pullers travel 7–8 km on an average distance from their garage (surveyed rickshaw/van pullers are working on an average of 8.5 years).
- Average working hours for a rickshaw puller in 10 h/day and their average income is 650–700 taka/day.
- During the heat wave of a particular year, people fell sick and could not go for work for about 3.27 days on average.
- Around 3.12 h of working hours has been lost due to feeling exhausted and cannot work full time.
- Around 82.81% of respondents said that their healthcare expenses have increased on average by 535 taka.

Heat waves have different types of impact on the human body. This can adversely impact the life and livelihood of people who are exposed to heat waves. Heat stroke, for example, affects not only health but also economic productivity at the individual level, particularly in poor income groups who are day laborers. The burden of costly health treatment in the city area and the loss of productivity due to illnesses would push these poorer groups into further poverty and vulnerability (Fig. 14).

Conclusion

This study assesses the impact of urban heat islands (UHIs) and heat waves on public health and livelihoods in Dhaka Metropolitan City (DMC), highlighting the challenges posed by rapid urbanization and the proliferation of built-up areas. This analysis reveals an alarming trend of increasing heat wave occurrences in DMC, exacerbated by urban development. These heat waves disproportionately affect vulnerable populations, underscoring the urgent need for targeted interventions to mitigate heat-related health hazards and ensure community well-being. In order to formulate a comprehensive strategy to address urban heat islands (UHIs), it

is essential to comprehend the causes of UHIs and identify the factors that contribute to people's exposure and vulnerability to heat. Various adaptation measures can be implemented to mitigate the impact of UHIs, including enhancing biomass through initiatives such as tree planting, green space creation, and the installation of green roofs and living walls. Additionally, efforts to increase the albedo of roof and ground surfaces, including driveways and sidewalks, can help to reduce heat absorption. Improving the thermal performance of buildings and urban infrastructure through climate-sensitive design and materials is also crucial. Furthermore, reducing waste heat through the implementation of anti-idling bylaws, building energy retrofits, and the adoption of energy-efficient appliances can contribute significantly to alleviating the effects of UHIs. These adaptation strategies play a vital role in enhancing resilience to heat waves and safeguarding public health in urban environments.

Policy implications of the study

This study prioritizes human health in addressing the urgent challenge of heat waves. By focusing on vulnerable demographics such as the elderly, young, low income, and those living alone, we aim to tailor adaptation interventions effectively. This research underscores the necessity of strong leadership, governance, and robust legislative and institutional frameworks to develop successful heat wave adaptation strategies. Implementing these strategies can significantly reduce human vulnerability to heat wave threats in a changing climate, emphasizing the importance of proactive measures and effective governance in safeguarding public health. To address these pressing challenges, proactive measures are imperative. Recommendations include enhancing green spaces, optimizing building thermal efficiency, and implementing policies to minimize waste heat.

Strengthening governance structures and institutional frameworks is essential for effective implementation.

In conclusion, this study underscores the urgency of addressing the escalating threats posed by UHIs and heat waves in DMC. By bridging research insights with actionable recommendations, we strive to empower stakeholders to make informed decisions and take proactive measures to build resilient communities in the face of climate change.

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Author contribution Md. Yachin Islam and Md. Mohiuddin was the main investigator of this study. They have conducted research, analyze the data, and compile the preliminary manuscript. Md. Salauddin and Khandaker Tanvir Hossain have supported the analysis of the data with the first and second authors. Samiya Farin has also reviewed the manuscript and put technical support to improve the manuscript. All authors read and approved the final manuscript.

Data availability While this study does not specifically relate to big data, the primary and corresponding authors of this paper are willing to provide the datasets that were generated or analyzed during the research upon reasonable request.

Declarations

Ethics approval and consent to participate There are no ethical concerns in this research.

Conflict of interest The authors declare that they have no competing interests.

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