Identification of Heat Threshold and Heat Hotspots IN RAJSHAHI, BANGLADESH

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Rationale for heatwave study in Rajshahi

The deadly impacts of extreme heat are rising globally. Heatwaves are causing an increase in the morbidity and mortality rates and corresponding financial losses across the globe. In 2003, a period of intense heat in Europe led to the deaths of at least 70,000 people and led to 13 billion Euros of financial losses (Umair, 2019). This trend is continuing. In 2019, parts of southern France, particularly the commune of Gallargues-le-Montueux, recorded 45.9°C for the first time resulting in around 1,435 heat-related deaths across the country (BBC, 2019). More intense and frequent heatwaves are now being experienced across the world, with further increases in such events expected due to the impacts of climate change.

South Asia is also facing the deadly impacts of extreme heat. According to a World Bank projection, the annual temperature in South Asia's hotspots is projected to increase 1.5-3°C by 2050 relative to 1981-2010. Almost half of the region's population, or 800 million people, live in South Asia's hotspots (Muthukumara & Gulrex, 2019).

Cities are particularly vulnerable to extreme heatwaves. Rapid urbanisation and its associated impacts, including: increasing concrete infrastructures, deforestation, filling up of water bodies, increasing amounts of dry and impervious surfaces, diverse economic activities, and the adverse impacts of climate change – all serve to exacerbate the heat island effect in cities. However, extreme heat impacts are preventable.

Cities have a unique potential to adapt to changing heat risks through effective risk management at multiple levels; connecting policies and incentives; and strengthening community adaptive capacity (Nullis *et al.*, 2019). Cities need to undertake a comprehensive plan for early warning systems, effective preparedness, and adaptive measures to combat the impacts of extreme heatwaves. Many cities in the region such as Ahmedabad in India, have been taking proactive measures to reduce the risks of extreme heat by developing heat action plans since 2013 and further iterations to the heat action plans (Ahmedabad Municipal Corporation, 2019). But in parts of Bangladesh and Nepal, especially central and northern Bangladesh and the Terai region of Nepal; heat related morbidity, mortality, and financial losses are rising (MoHA, 2019; Nissan *et al.,* 2017; Pakistan Times, 2005). Despite this, cities in the region are yet to mainstream their actions to combat extreme heat.

Rajshahi Metropolitan City is located on the north bank of the Padma River, near the Bangladesh - India border. Rajshahi lies in the northwestern region of Bangladesh and is among the districts that experience the highest temperatures. It is also the region that, after the South West Region, has the highest heat index (Rajib *et al.*, 2011). The maximum temperature exceeds 39°C almost every year and the humidity level sometimes reaches 65 per cent (BMD data, 1990-2020). In summer, temperatures reach about 42°C or even more in the city on some of the hottest days. (Shahid 2016). Exacerbating the heat island effect in the Rajshahi district has been the loss of about 188km^2 of vegetation from a total area of 2,428km^2, which previously covered the district from 1998 to 2018 (Kafy *et al.,* 2019). Although Rajshahi City Corporation and other stakeholders in the city are concerned about the growing incidence of heatwaves, there is no systematic assessment or actions on heat-health management or overall heat resilience undertaken in Rajshahi City. After Dhaka, the capital city of Bangladesh, Rajshahi is only the second city where the heat study has been carried out.

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List of Abbreviations

BBS:	Bangladesh Bureau of Statistics
BMD:	Bangladesh Meteorological Department
EPI:	Expanded Programme on Immunisation
HI:	Heat Index
KPI:	Key Personnel Interviews
LGED:	Local Government Engineering Department
LST:	Land Surface Temperature
ND-GAIN:	Notre Dame Global Adaptation Index
NDVI:	Normalised Difference Vegetation Index
NDWI:	Normalised Difference Water Index
NOAA:	National Oceanic and Atmospheric Administration
NWS:	National Weather Service
RCC:	Rajshahi City Corporation
RDA:	Rajshahi Development Authority
RUET:	Rajshahi University of Engineering & Technology
SD:	Standard Deviation
SOP:	Standard Operating Procedure
Tmax:	Maximum Temperature
UHI:	Urban Heat Island
WMO:	World Meteorological Organisation

Executive Summary

A heatwave is a meteorological phenomenon characterised by an extended period of unusually hot weather, frequently accompanied by high humidity, which usually happens in Bangladesh from mid-March to June. Cities in Bangladesh's central and northern areas, such as Rajshahi, have been experiencing rapid urbanisation with climate change impacts posing additional stress. Heatwaves have become more frequent, severe, and lengthier, resulting in rising heat-related morbidity, mortality and financial losses in Bangladesh in general and Rajshahi City particularly. In the city, the maximum temperature exceeds 39°C almost every year, and humidity levels sometimes reach more than 65 per cent.

This report aims to support the Rajshahi Metropolitan City and other emergency service providers in Rajshahi, such as the Disaster Management Department, the Rajshahi branch of Bangladesh Red Crescent Society (BDRCS), the unit responsible for determining the heat thresholds and hotspots indicating when and where to act before or during heatwave days. Moreover, the report intends to encourage city stakeholders to take fruitful actions in upcoming heat seasons to reduce the city's heat risks and build stakeholder's capacity on city heat actions.

The approach of the study has been based on investigation of both secondary and primary data. Secondary information such as demography and socioeconomic data, daily meteorological data on climate variables (temperature and humidity), historical evidence of heatwave impacts have been reviewed to design a model for understanding the heat threshold and exposed areas or heat hotspots. Satellite images and remote sensing data using GIS tools have also been investigated for inclusion in the above-mentioned analysis. Primary data has been collected through field surveys, using tools such as Key Personnel Interviews (KPI), to understand the impacts on the most vulnerable people in Rajshahi City and for ground-truthing exercises to corroborate the secondary data and other satellite data analysis findings.

Nissan *et al.*, (2017), defines a heatwave as the annual count of at least three consecutive days with a maximum temperature greater than the 95th percentile. The threshold temperature of Rajshahi has been determined by calculating the 95th percentile of maximum daily temperatures for 30 years (1990-2020). The analysis suggests that 38°C is the maximum daily temperature, becoming an extreme event in Rajshahi Metropolitan City.

The ward-level extreme temperature and hotspots analysis shows that wards 4, 7, 19, 25, 28, and 30 experience heat hotspots with higher temperatures than other city wards. The high concentration of built-up areas, the filling up of water bodies and the limited to no vegetation and proximity of char land[1], especially in wards 7 and 25 can be considered significant factors for maximum temperatures in these areas. This analysis also helps to understand that 2014 was the year when all the wards had a maximum temperature more significant than the threshold temperature, signaling that the heatwave exposure was most severe in 2014. Further, the Normalised Difference Vegetation Index (NDVI) shows that

1 The deposition of upstream sediments over downstream forms 'Char Land' which essentially builds new land on downstream.

Rajshahi City has very unhealthy or limited vegetation, which can contribute to the increase in temperatures in the city.

To understand heatwave risk, a combined exposure map and a vulnerability index is critical. A set of eight indicators have been used and normalised in assessing exposure and vulnerability to heatwaves in Rajshahi City.

The analysis suggests that the wards highly exposed to heatwaves in Rajshahi are 3, 4, 11, 14, 19, 24, 25, 28 and 30. Likewise, the vulnerability index indicates that wards 1, 2, 4, 7, 16, 17, 19, 24, 28 and 29 are the highly susceptible wards. The nine highly exposed wards (3, 4, 11, 14, 19, 24, 25, 28 and 30) have been further ranked with the vulnerability index score to recognise their degree of vulnerability and where to act. This shows wards 4 and 28 are highly vulnerable, followed by wards 19, 24, 3, 30, 25, 11, and 14.

Significant heat impacts are observed on daily workers, auto drivers, rickshaw pullers, people with tin houses, street hawkers, etc. Among these vulnerable groups, the most highly impacted are rickshaw pullers and auto drivers, as 20 per cent and 18 per cent of their income is lost respectively, during a heatwave period when the temperature is more than 38°C for three consecutive days. The heat index 41 is proposed as the impact threshold and 38°C as the maximum temperature threshold in Rajshahi.

As next step actions, the local city authority and other emergency service providers need to take stewardship of anticipatory actions and reduce human suffering and the impacts of heatwave events on livelihoods. Future work around heat action by the city authority and other emergency service providers in Rajshahi includes: formulation of a trigger model and simulation in the city, particularly in the vulnerable wards; development of an Early Warning Early Action (EWEA) Standard Operating Procedure (SOP), together with in-depth analysis and validation of the heatwave impact analysis by investigating public health data, would be some of the future direction of work for the city authority and other emergency service for heat action in Rajshahi.

An effective coordination mechanism between stakeholders for different critical roles for the heat actions must be mainstreamed. For instance, BMD and the Department of Health Services, can play an important role in issuing heat early warnings. Moreover, some of the simple city-level actions that the Rajshahi Metropolitan city can plan to undertake in collaboration with other city stakeholders, include conducting public awareness campaigns, increasing access to water, organising home outreach visits to vulnerable people, ensuring the safety of outdoor workers etc.

Chapter 1: Introduction

Bangladesh, geographically extending from 20° 34' to 26° 38' N latitude and from 88° 01' to 92° 41' E longitude, belongs to the subtropical Asian monsoon regime that has a humid climate characterised by moderately warm temperature with high humidity and wide seasonality in rainfall pattern (Rashid, 1991). The county borders India in the west, north, and east, Myanmar to the southeast, and the Bay of Bengal to the south. An estimated 164 million people live in Bangladesh – of which approximately 38.9 per cent live in cities, making Bangladesh less urbanised than other countries in the region and among the least urbanised countries in the world (Urbanisation, 2021). Bangladesh ranks 163 out of 181 countries in the Notre Dame Global Adaptation Index (ND-GAIN). This ranking indicates that Bangladesh has high vulnerability levels.

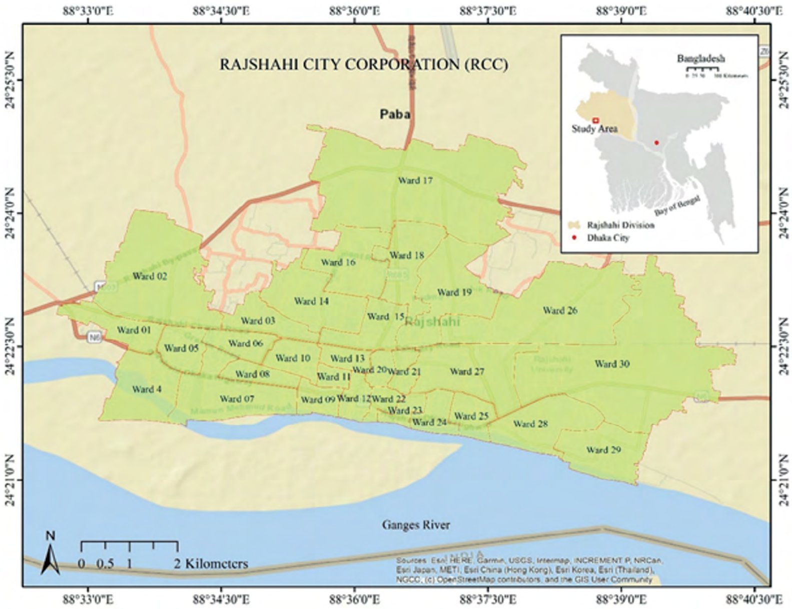


Figure 1. Location of Rajshahi City Corporation (RCC) in Bangladesh and in Rajshahi division (inset) and the location of administrative wards within the city corporation boundary

Source: Adapted from RDA (Rajshahi Development Authority), 2003

Rajshahi Metropolitan City, stands on the northern bank of the River Ganges and is the fourth largest city in Bangladesh, covering an area of 96.72 square kilometers. Geographically it lies between 24°07′ to 24°43′ north latitudes and between 88°17′ to 88°58′ east longitudes and is situated about 245 kilometers from the capital city Dhaka (Google Map; Bangladesh Bureau of Statistics/BBS, 2013).

Rajshahi City is divided into 30 different administrative wards (Kafy, 2018). The city's landscape is enriched with green and blue infrastructure (Haque *et al.*, 2020). It received the National Environment Award in 2013 (Abdullah, 2020). The Barind region lies to the northwest part of the city and the Padma River, which is the main distributary of the Ganges, flowing through the south of the city.

The geological composition of this region is mainly barind tract, diara, and char lands. Barind tract is covered by hard red soil and old alluvial deposits and is considered semi-arid and drought-prone (Kang, 2013). 'Char Land' has been formed on the Padma riverbank and on the adjacent land of Rajshahi. (Hussain, 2014).

1.1 Heatwave in Rajshahi

According to the climatology of Bangladesh, its northern regions are especially vulnerable to weather extremes like hot, humid summers and severe cold during winter. Rajshahi, as a northern city, holds these climatological characteristics too with heatwaves becoming a common phenomenon in recent years. After the southwest region, Rajshahi has the highest heat index score (Rajib *et al.*, 2011). The study of Khatun *et al.*, (2016) that used BMD observed data from 1981 to 2010, gives an overview of this climatic pattern. The number of maximum temperature days at Rajshahi is shown below:

Table 1: Number of maximum temperature days at Rajshahi, 1981-2020

Max temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total	% of total
40°C and greater	-	-	4	110	79	13	-	-	-	-	-	-	206	1.5%
38°C - 40°C	-	-	42	196	118	47	1	1	-	-	-	-	405	2.9%
36°C - 38°C	-	1	136	228	199	133	16	8	3	1	-	-	725	5.2%
30°C - 36°C	1	181	615	413	573	750	860	885	818	775	443	-	6314	45.6%
25°C - 30°C	368	581	349	185	226	234	346	320	342	363	681	685	4680	33.8%
20°C - 25°C	581	298	39	19	14	12	17	15	21	34	15	350	1415	10.2%
Less than 20°C	60	5	-	-	-	-	-	-	-	-	1	43	109	0.8%

Source: Adapted from Khatun et al., 2016 and BMD data (2011-2020)

In this 40-year period, the most common range of maximum temperature is 30-36°C recorded for 6,314 days (nearly 46%) out of 14,600 days (excluding the 414 missing records) of the study period. There is a total of 110 days in April and 79 in May when maximum temperatures exceed 40°C. The maximum number of days (196) with temperature 38-40°C is found in the month of April where a total of 228 days with a maximum temperature of 36- 38°C is recorded. This study also claims that there is a significant increase in heatwaves observed in Rajshahi. According to Shahid *et al.,* (2016), “the city falls within the dry humid zone and rainfall varies widely from year to year”.

1.2 Climatology and hydrology of Rajshahi

Being situated in the northwestern part of Bangladesh, Rajshahi is classified as one of the regions that experiences high temperatures during the pre-monsoon seasons (March to June). The average daily maximum temperature of Rajshahi is 30.9°C with a Standard Deviation (SD) of 4.2 where the daily mean minimum temperature is 20.6°C. Rajshahi also receives a good amount of rainfall, on average 1,466.4 mm (Shahid *et al.*, 2016).

Table 2: Statistical summary, average rainfall, and temperature in Rajshahi City over the time period 1958-2012

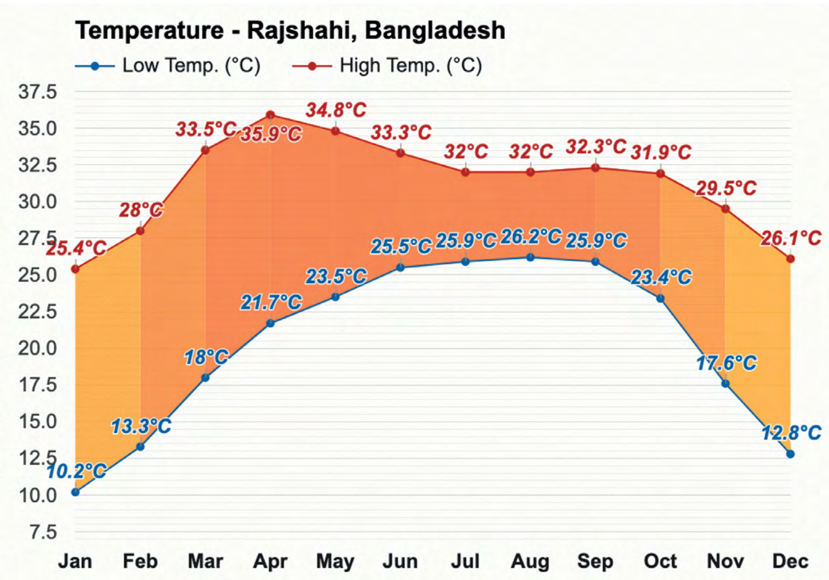
Parameters	Mean Rainfall	SD of rainfall	Daily mean temperature	Daily mean maximum temperature	SD of daily maximum temperature	Daily mean minimum temperature	SD of daily minimum temperature
Values	1466.4	323.7	25.8	30.9	4.2	20.6	6.0

Source: Shahid et al., 2016

March through June are the hottest months of the year, with maximum temperatures exceeding 40°C. March, April, May, and June have the highest average temperatures, while the night temperatures (low temperatures) are highest in July, August and September (Weather Atlas, 2021). The highest temperature ever recorded in Rajshahi was 43.5°C in 1995 (BMD, 1990-2020). Extreme temperatures generally cool off at night. For instance, in April 2021, the average daytime temperature was 36.6°C, but the average nighttime temperature cooled down to 22.8°C (Weather2visit, 2021). The historical weather data shows humidity during the hot days reaching around 65 per cent. However, sometimes it is not cool enough for people who have been exposed to high temperatures all day, which can lead to higher cumulative exposure to heat. The average precipitation of Rajshahi City is 1,466.4 mm or 57.73 inches (BMD 1990-2020).

Figure 2. Climatology of Rajshahi

Source: Weather Atlas, 2021



1.3 Demography

As of 2020, the total population of Rajshahi was 908,000 (PopulationStat, 2021). The densely populated areas in the city are ward no. 11, where 22,767 people live per square kilometer, followed by wards 24, 9 and 12 (BBS 2013). The largest household size lies in ward 30, followed by ward 7 and 10 (BBS 2013). The population density and distribution of household size is shown in the figure below:

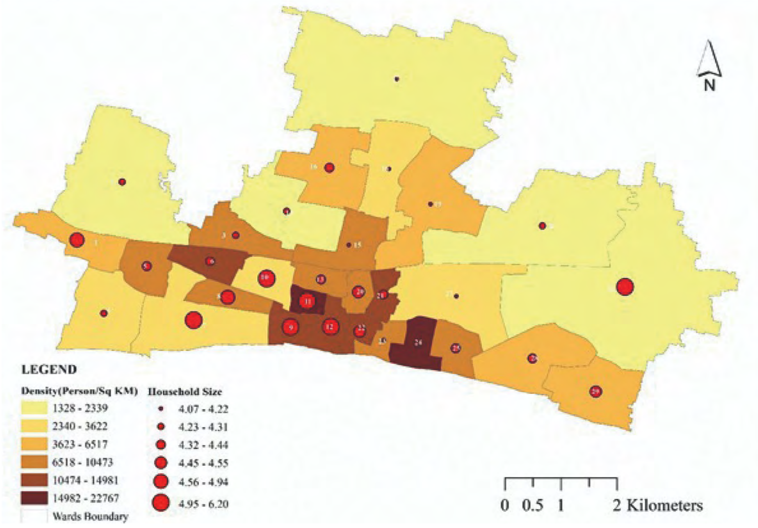


Figure 3. Population density and household size of RCC

Source: Author's illustration based on data obtained from BBS, 2013

1.4 Socioeconomic and physical characteristics

The following socioeconomic and physical characteristics have been discussed in the below section as these characteristics have been used as indicators for heat exposure and vulnerability assessment in the later segment.

Slums and their population: There are 32 slums in Rajshahi City, mostly concentrated in ward 2, 29, 1 and 28. No slums have been registered or reported during the key informant's interviews (KII) in ward 5, 6, 8, 9, 10, 13, 14, 15, 20, 21, 22, 25 and 27.

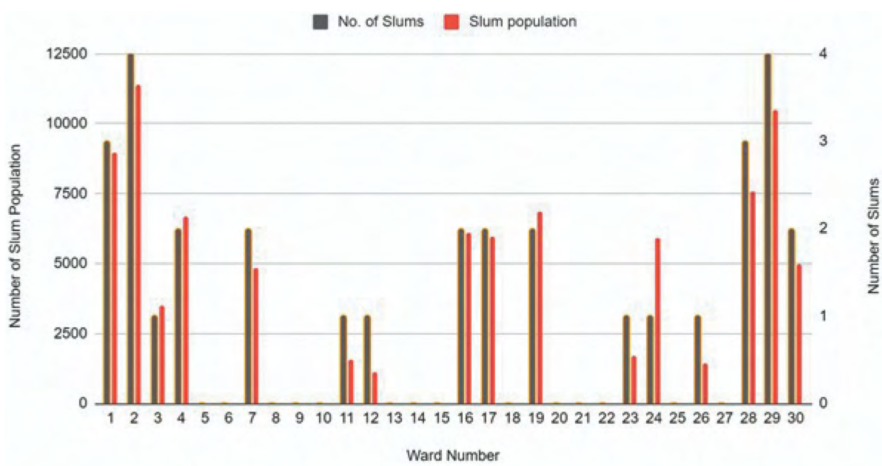


Figure 4. City ward-wise slum and slum population distribution

Source: Author's illustration based on data obtained from BBS, 2013

There are 23,261 households with a population of 89,050 living in the slum areas of Rajshahi Metropolitan City. Baze Kajla slum in ward 24 is the city's largest slum consisting of 1,562 households with 5,920 inhabitants (BBS 2013). Based on household shares (in percentage) of slum population, the slums are divided into five classes in the following map:

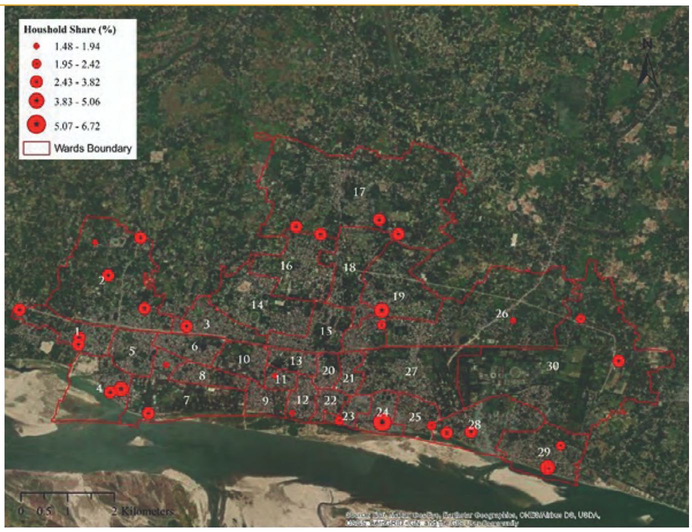


Figure 5. Slum household shares in different slums of RCC

Source: Author's illustration based on data obtained from BBS, 2013

Education: The highest literacy rate is registered in wards 11 and 12 whereas the lowest literacy rate is seen in wards 29 and 2 (BBS, 2013).

Health: There are a total of 758 different health facilities in the city. Figure 6 shows all types of health facilities and the spatial distribution of the health facilities in RCC.

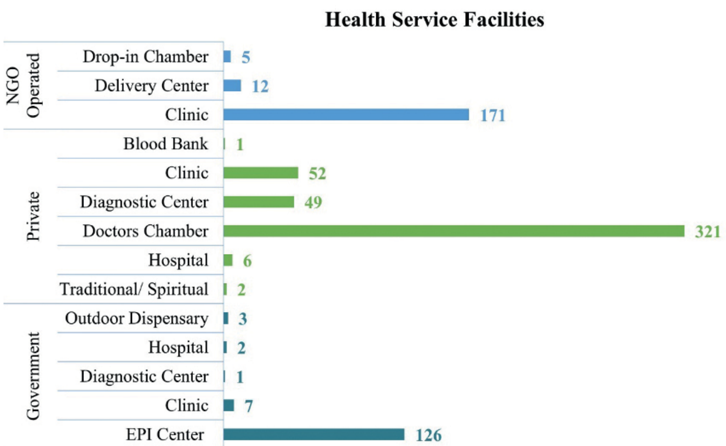


Figure 6. List of health facilities in RCC

Source: Islam et al., 2016

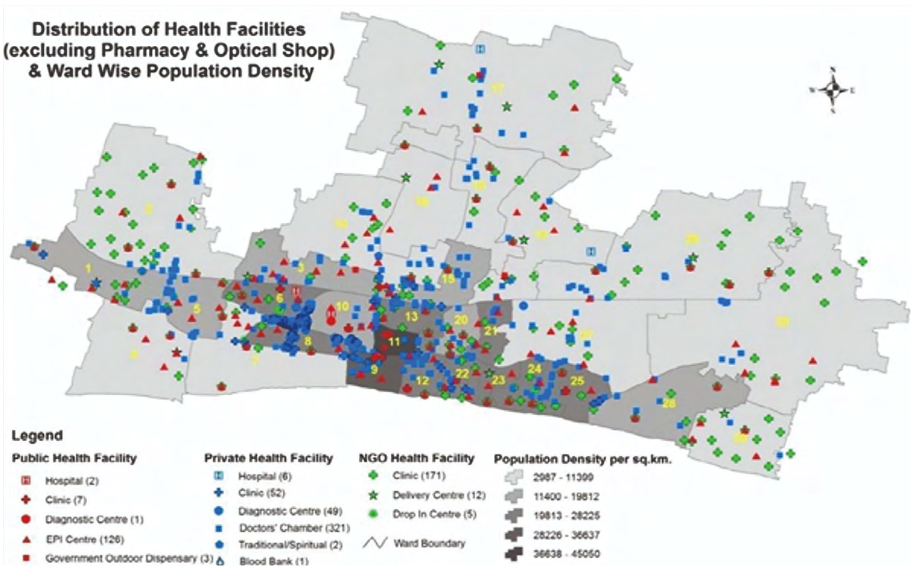


Figure 7. Health facilities distribution in RCC

Source: Islam et al., 2016

1.5 Approach and tools

The various steps and corresponding tools (defined by using different colour codes) that have been used to attain the aim of the initiative i.e. identification of heat threshold and hotspots, are illustrated in the following diagram:

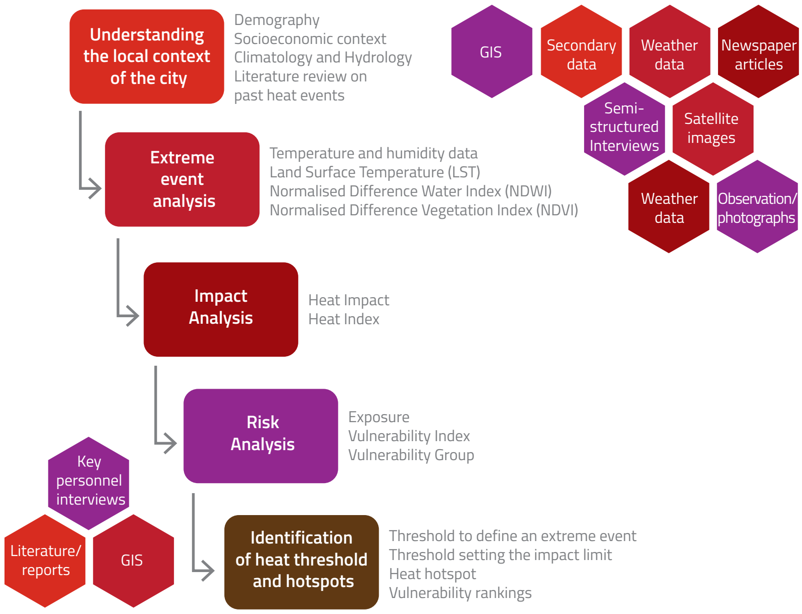


Figure 8. Study approach and tools

Source: Author's illustration adopted from BDRCS, 2021

The study has been initiated by investigating secondary information such as; demography and socioeconomic data, past studies on heatwaves and their impacts; to understand the local context of Rajshahi. Daily meteorological data on climate variables (temperature and humidity) of the last 31 years for Rajshahi Metropolitan City have been analysed for heatwave trend and heat index analysis. Likewise, satellite images and remote sensing data have been investigated using GIS tools for extreme events. The research on historical evidence of heatwave impacts in the study area has been done through literature review and newspaper articles. Some of the critical steps for this initiative are; heat index analysis and exposure, vulnerability index (underlying factors for the heatwave impacts) and identification of vulnerable groups. Tools such as Key Personnel Interviews (KPI) have been adopted to corroborate secondary data and other satellite data analysis findings. Additionally, ground visits or observation, and photographs have been used for ground-truthing exercises. Finally, the heat thresholds and hotspots are identified by investigating the above-mentioned processes and tools, which give information regarding when to act and where to act for the extreme heat days.

1.6 Study Limitations

This study has a few limitations:

- The heat threshold has been developed based on the availability of secondary data. Due to time constraints, the heat threshold model could not be tested extensively for months. However, it helps establish a concept that the city authority and other relevant stakeholders can refine, if required, in the future heat season.

- “Both exposure and vulnerability are dynamic, vary across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance-related, and environmental factors” (UNISDR, 2016). So, the heat hotspots can be varied over time due to climate change and developmental activities, and other variations in the socio-economic factors in the region.

- Due to the sudden spike in Covid-19 cases in Bangladesh in general and Rajshahi City particularly and the strict restrictions introduced to curb the pandemic, an extensive survey, and other participatory exercises to corroborate the impacts and exposure findings from secondary data analysis, could not be performed. However, a rapid and light survey to understand the vulnerability was undertaken.

Chapter 2: Extreme Temperature

2.1 Heatwave definition

The World Meteorological Organisation (WMO) defines a heatwave as: “five or more consecutive days during which the daily maximum temperature surpasses the average maximum temperature by 5°C (9°F) or more” (Rafferty, 2018).

According to the BMD, a heatwave situation occurs in Bangladesh when: “the maximum temperature goes above 36°C”. The heatwave classification is shown below:

Table 3: Heatwave classification

Heatwave	Temperature (°C)
Mild	36- 38°C
Moderate	38- 40°C
Severe	40 - 42°C
Extreme	> 42°C

Source: Karmakar & Das, 2019

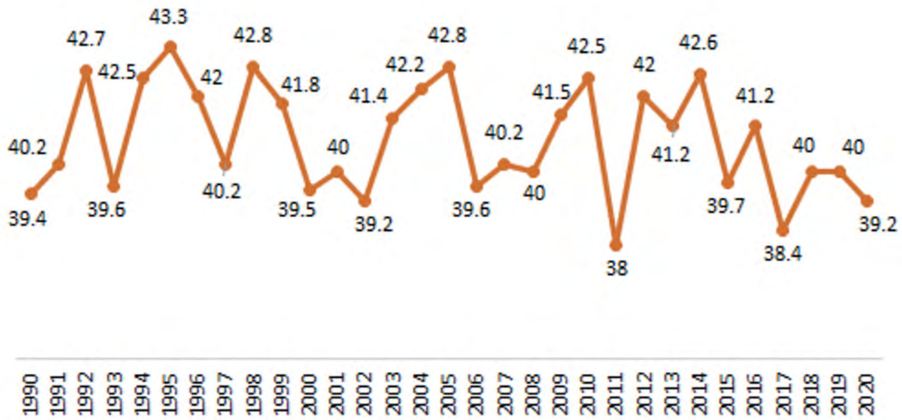
The BMD definition doesn’t incorporate other factors such as duration, humidity, night time conditions, etc. However, according to Nissan *et al.*, (2017), “the definition entails three consecutive days’ elevated maximum daily temperatures over 95th percentile, reinstating the importance of night time conditions for health impacts”.

2.2 Heat Threshold Temperature

The maximum temperature data has been analysed to identify the threshold temperature. The figure below shows the variation of extreme temperature in the past 30 years (1990 -2020).

Figure 9. Maximum temperature of each year from 1990 to 2020, Rajshahi station

Source: Author’s Illustration based on data obtained from BMD



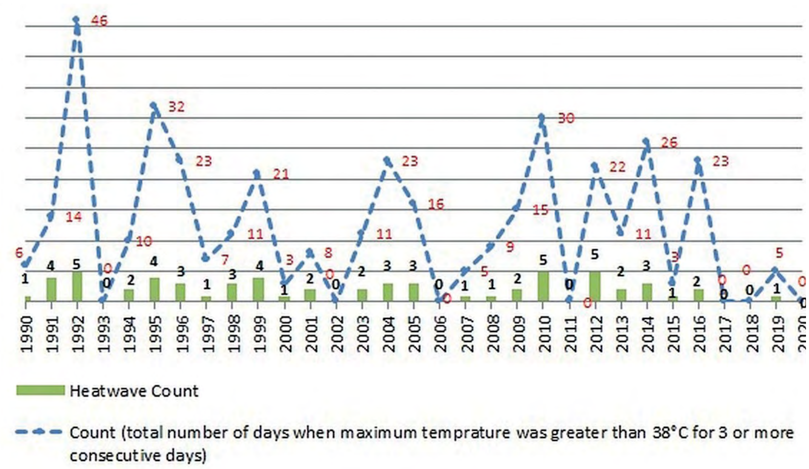
The threshold temperature has been determined by calculating the 95th percentile of maximum daily temperatures from 1990 to 2020, since, according to the definition of Nissan *et. al.,* 2017, the extreme temperature is the temperature that crosses the 95th percentile of the given data sets.

Based on the investigation of a historical data set of climatic variables for 30 years (1990-2020), 38°C has been recorded as the threshold maximum temperature. It refers that 95 per cent of the temperature from 1990 to 2020 is equal to, or lower than 38°C.

Considering the heatwave definition proposed by Nissan *et al.,* (2017), i.e. a maximum daily temperature of 38°C for three or more consecutive days, the following chart illustrates the number of heatwave events that have occurred from 1990 to 2020 in Rajshahi.

Figure 10. Number of heatwave events and the respective number of days in the heatwave events in Rajshahi City, from 1990 to 2020.

Source: Author's illustration based on data obtained from BMD



This chart helps to visualise the number of heatwave events that occurred in each year from 1990 to 2020. The numbers highlighted in red showcase the total number of hot days (i.e. above 38°C) during heatwave events in the respective year. For instance, in the year 2014, three heatwave events occurred and the total number of days in this heatwave period was 26 days i.e. from 16 to 18 April; 20 to 29 April; 11 to 23 May. In 2019, only one heat wave occurred during a five day heatwave period from 7 to 11 May.

It appears that Rajshahi has been experiencing more frequent hot days with extreme temperatures (equal to or above 38°C) from 1992 onwards. 1992, 1995 and 2010 are the years when the maximum number of days had reached extreme temperature limits. In 1992, the city experienced 46 extreme temperatures days, which is the highest recorded number to date. From 1990 to 2020, on average at least two heatwave events each year have occurred in the city.

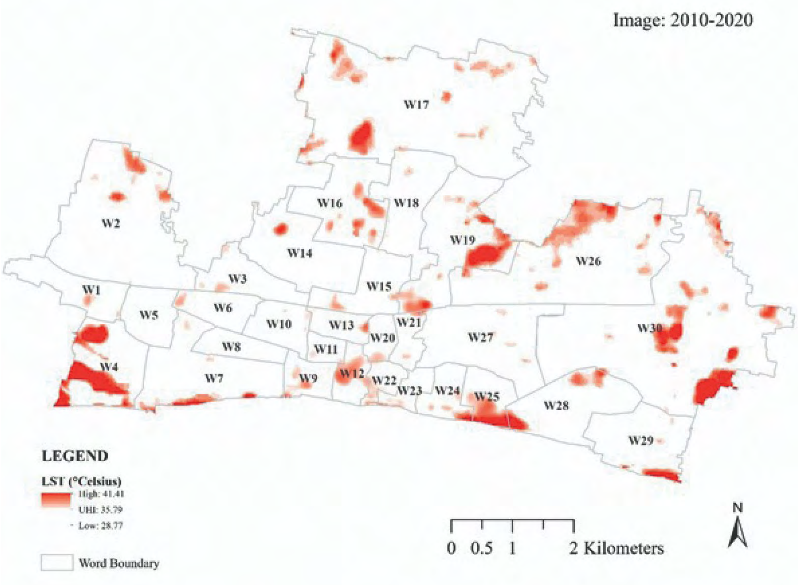
Chapter 3: Land Surface Temperature

Land surface temperature (LST) is the temperature felt while touching the land surface with one's hands or the ground's skin temperature (Rajeshwari & Mani, 2014). LST mapping aims to demonstrate a flexible and straightforward conceptual framework relying upon satellite thermal data that shows surface temperature trends and variability and areas at high risk (i.e. areas with high temperature compared to surrounding areas) in Rajshahi City.

The data used to determine LST, and surface emissivity are Landsat satellite images from 2010 to 2020, which are downloaded from the official website of the US Geological Survey (USGS). The study area is located in the Landsat path/row of 138/43.

Figure 11. Combined LST mapping for 2010-2020 to understand ward level max. temperature and hotspots

Source: Author's illustration based on data obtained from Landsat satellite images

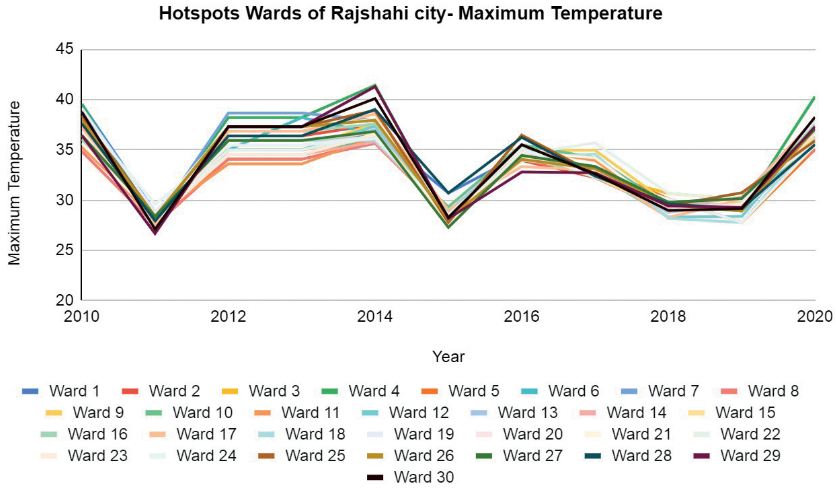


The LST analysis of the last 11 years (2010-2020) shows that wards 4, 7, 19, 25, 28, and 30 endure more heat hotspots with higher temperatures than other city wards. The high concentration of built-up areas, filling up of water bodies, limited to no vegetation and proximity of char land especially in wards 7 and 25, can be considered significant factors for maximum temperatures in these areas.

The maximum and minimum land surface temperatures have been extracted for each ward using a clipped raster by a mask layer, which uses a raster extraction tool in QGIS. The maximum temperature for each ward from 2010 to 2020 is presented in Figure 12.

Figure 12. Ward level maximum land surface temperature in Rajshahi

Source: Author's illustration based on data obtained from BMD



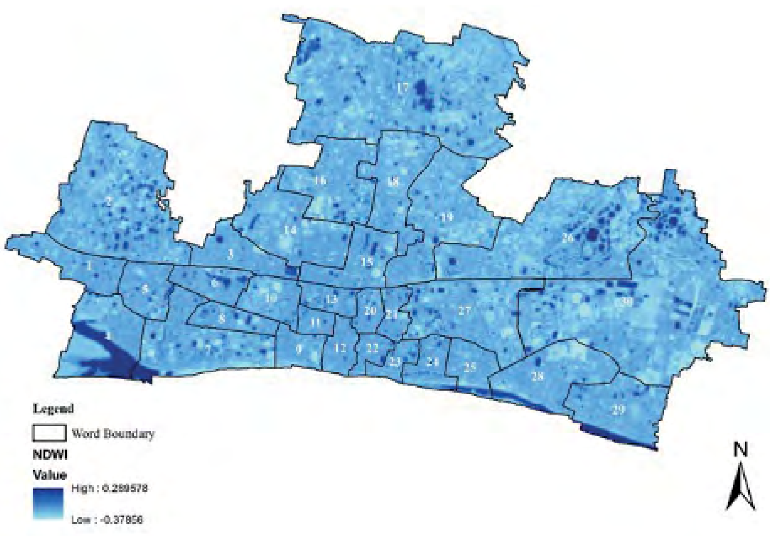
This analysis aims to identify the wards where maximum temperatures are above 38° C i.e. the threshold temperature. The above analysis exhibits that 2014 was the year when most of the wards experienced a maximum temperature significantly higher than the threshold temperature. It signals that the heatwave exposure was most severe in 2014. So, the analysis of heat risks has been conducted considering the ward level maximum temperature of 2014 heat data and corresponding hotspots.

3.1 Normalised difference water index (NDWI) and normalised difference vegetation index (NDVI)

To analyse the relationship between landcover changes and urban heat island effect (UHI), a quantitative method in studying the relationship between temperature and the NDVI and NDWI has also been investigated. The data for the year 2020 has been analysed for NDVI and NDWI investigations to get an overall understanding of the latest situation.

Figure 13. NDWI

Source: Author's illustration based on data obtained from Landsat satellite images



The high NDWI value is observed in Wards 30, 26, and 17, indicating that these wards have more water and vegetation surface content than other wards. At the same time, the lowest NDWI is found in ward 12, indicating the built-up area and bare land are more in this ward and hold few water surfaces compared to other wards. Although the western part of the city (such as ward 5) consists of highly populated areas, the temperature is still noticeably lower there, as the lower LST values are found in the central parts of the city. The NDWI study confirms this is because of the high vegetation water content in the city's western side.

Photo 1: A water body protected by local government at the *Padma Abashik* in ward 26, Rajshahi City

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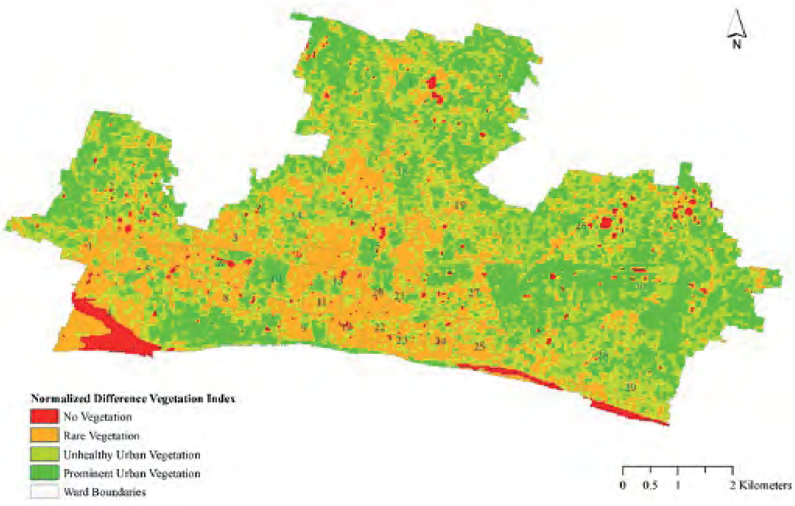
The NDVI is a measure of surface reflectance which gives a quantitative estimation of vegetation growth and biomass. Here, low values of NDVI (0.1 and less) correspond to vegetation-free regions and stony and sandy areas. Moderate index values (0.2–0.5) show sparse vegetation such as shrubs and grasslands or senescing crops. The NDVI values of RCC has been divided into five different classes: no vegetation (mainly water bodies), very unhealthy vegetation (mostly built-up areas), unhealthy vegetation (vegetation among the built-up areas), moderately healthy vegetation (vegetation in the agricultural lands) and healthy vegetation (vegetation in forest/urban parks).

Figure 14. NDVI

Source: Author's illustration based on data obtained from Landsat satellite images



Ward 30 of Rajshahi City has the highest NDVI whereas wards 6, 9, 11, and 12 have very little or no vegetation. As seen in Figure 14 above, the northern and eastern area of Rajshahi City has prominent vegetation. The central area of Rajshahi has very unhealthy or limited vegetation, which can contribute to the increase in temperature in the city centre. As we know, trees and vegetation have lower surface and air temperatures resulting from the shade they provide and through evapotranspiration (Akbari *et al.*, 1997). Summer peak temperatures can be reduced by 1–5°C when evapotranspiration is used alone or in combination with shading (Huang *et al.*, 1990; Kurn *et al.*, 1994).

3.2 Urban heat island effect

The urban heat island effect (UHI) makes one neighborhood hotter than another. UHI can be detected by taking temperature readings on the ground or in the air (BDRCS, 2021). Surface temperatures influence air temperatures in an indirect but critical way. Parks and vegetated spaces, for example, contribute to cooler air temperatures since they have cooler surface temperatures (Wong & Yu, 2005). Densely populated places, on the other hand, tend to have warmer air temperatures. The relationship between surface and air temperatures is not constant because air mixes within the atmosphere (Ngie *et al.*, 2017; Wong & Yu, 2005). Due to impervious surface and/or higher reflection of the roofs of buildings, the temperature starts rising and in the summer days, roof and pavement surface temperatures can be higher than the air temperature (BDRCS, 2021). People who work outside, on the ground, on roofs or on roads, as well as those who live in slums or on the street, are the most vulnerable to UHI effects (BDRCS, 2021). So, the measurement of UHI is done at various levels (surface level and atmospheric level) and by different tools.

The UHI could be established by a deduction of the air temperature from the LST. Although the two temperatures have different physical meanings and responses to atmospheric conditions, there is a link between LST and near-surface air temperature (Ngie *et al.*, 2017). The parameter 'delta T' helps to calculate the difference between LST and air temperature.

Delta T

Delta T is calculated by computing the following equation:

$$\Delta t \text{ (UHI Effect)} = \Delta\mu - \Delta\sigma/2$$

Here, Δμ is the mean of the differences and Δσ is the Standard Deviation (SD) of the differences.

Method to compute Delta T for Rajshahi city: All raster images were taken or sensed by the sensor around 10:25 am of the respective day. We calculated the LST for each of the images.

Since the hourly temperature was not available, the maximum air temperature from BMD was subtracted by 3°C. Since the three-hourly data was available for 2010 to 2016, to get the temperature around 10:25am, 1 SD was added with mean values of the maximum temperature at 9:00 and 12:00 hours. For the rest of the years (2017-2020), the daily maximum temperatures were considered, then the air temperatures were subtracted from LST and the mean and SD of the differences were calculated. To get a higher level of accuracy, UHI was calculated by adding the full SD with mean and half of SD was subtracted from the mean of differences between LST and air temperature.

Computations show that, on average, the surface temperature is 3.68°C greater than the air temperature. Therefore, this temperature difference value of 3.68°C, which is recognised as the UHI effect or delta (t), needs to be added up with the air temperature value to calculate the Heat Index (HI) and further risk assessment.

Photo 2: Aerial view of *Bhadra Mor* – a critical road junction in Rajshahi City

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Chapter 4: Heat Impact Limit Analysis

4.1 Heatwave impact

The critical aim of heatwave impact analysis is to identify the maximum temperature condition and its impacts on the residents of the city and accordingly, to identify the respective year and days when the heatwave impacts were maximum. It facilitates setting thresholds for anticipatory actions.

The heatwave impact analysis has been undertaken through newspaper article analysis for roughly the last 25 years. Given the dearth of public healthcare data in the city and the limitation to undertake extensive community-level heatwave impacts surveys due to restrictions caused by the Covid 19 pandemic, this alternative approach has been undertaken to identify the respective years when the heatwave impacts were maximum.

From the impact analysis, the heatwaves in 2005, 2010, 2014, and 2016 have been identified as the most severe ones in Rajshahi city over the last two decades, with impacts reported as maximum in these four years. Based on newspaper articles of 2005, 2010, 2014, and 2016 and later substantiated by the daily temperature data collected from BMD, it has been observed that the maximum temperature mainly occurs from March to June. These three months tend to be the hottest months in Rajshahi. The average maximum air temperature varies for these four years from 35°C to 37°C. The humidity value ranges from 8 per cent and goes up to 56 per cent.

The 2003 and 2005 heatwave led to a health crisis with a death toll of more than 122 people in northwestern Rajshahi districts (ADRC Asia, 2005; The Irish Times, 2003). Due to the absence of rainfall, the people of Rajshahi experienced scorching heat from dawn to dusk. Other major impacts observed included a doubling of patients admitted at hospitals for diseases such as jaundice, viral fever, and diarrhea. Other medical conditions included raised blood pressure, kidney ailments, and sunstroke (Dhaka Mirror, 2010).

4.2 Heat Index

The Heat Index (HI), commonly known as the apparent temperature, is the temperature that the human body perceives when combining relative humidity and air temperature. This has significant implications for the comfort of the human body. The HI analysis helps to understand how hot current weather conditions make it feel to the average individual.

The temperature and humidity analysis in Rajshahi from 1990 to 2020 indicates a slight decrease in maximum temperature (by 0.04° Celsius), but an increasing trend in relative humidity over the last 30 years (BMD, 1990-2020). The air temperature and relative humidity directly correlate with the heat index, which means that when the air temperature and relative humidity increase, the HI also increases and vice versa.

National Oceanic and Atmospheric Administration's (NOAA), of the United States, National Weather Service (NWS) has categorised the HI into four different classes, considering the severity to health effects for its practical applications, as shown in Table 4 below:

Table 4: Health risks to various heat index categories adapted from NOAA

Heat Index	Categories	Health Risk
27 – 32	Caution	Fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps.
32 – 41	Extreme caution	Heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.
41 – 54	Danger	Heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.
> 54	Extreme danger	Heat stroke is imminent.

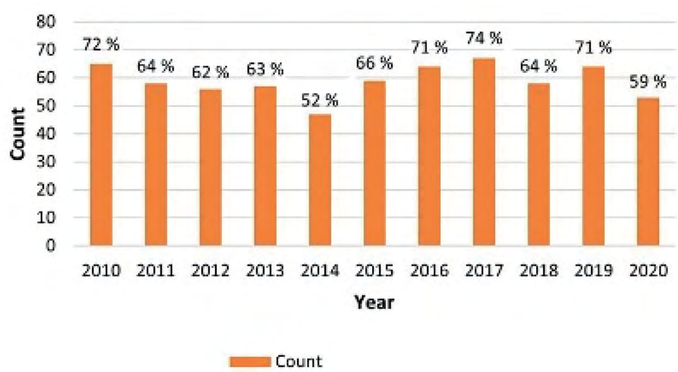
Source: NOAA, 2009

The analysis of long-term climate records reveals evidence of changes in the frequency of extreme temperature events across Rajshahi, particularly during the summer (BMD, 1990-2020). As it has been recognised from the literature review and daily temperature analysis in the above sections, March, April, May, and June are the peak summer months in Rajshahi. So, the HI analysis has been calculated for these four months from 2010 to 2020 to identify the years when HI or apparent temperature exceeds the extreme danger level i.e. above 54°C.

To calculate an accurate HI, UHI effect or delta (t) value i.e. 3.68°C, has also been added to the observed temperature, as the recorded temperature data in the city does not include the UHI effect already. The UHI is one of the critical factors for the heat risk assessment.

Figure 15. Number of days with HI at extreme danger level (i.e. > 54°C) during the peak summer months from March-June, 2010-2020

Source: Author's illustration based on data obtained from BMD

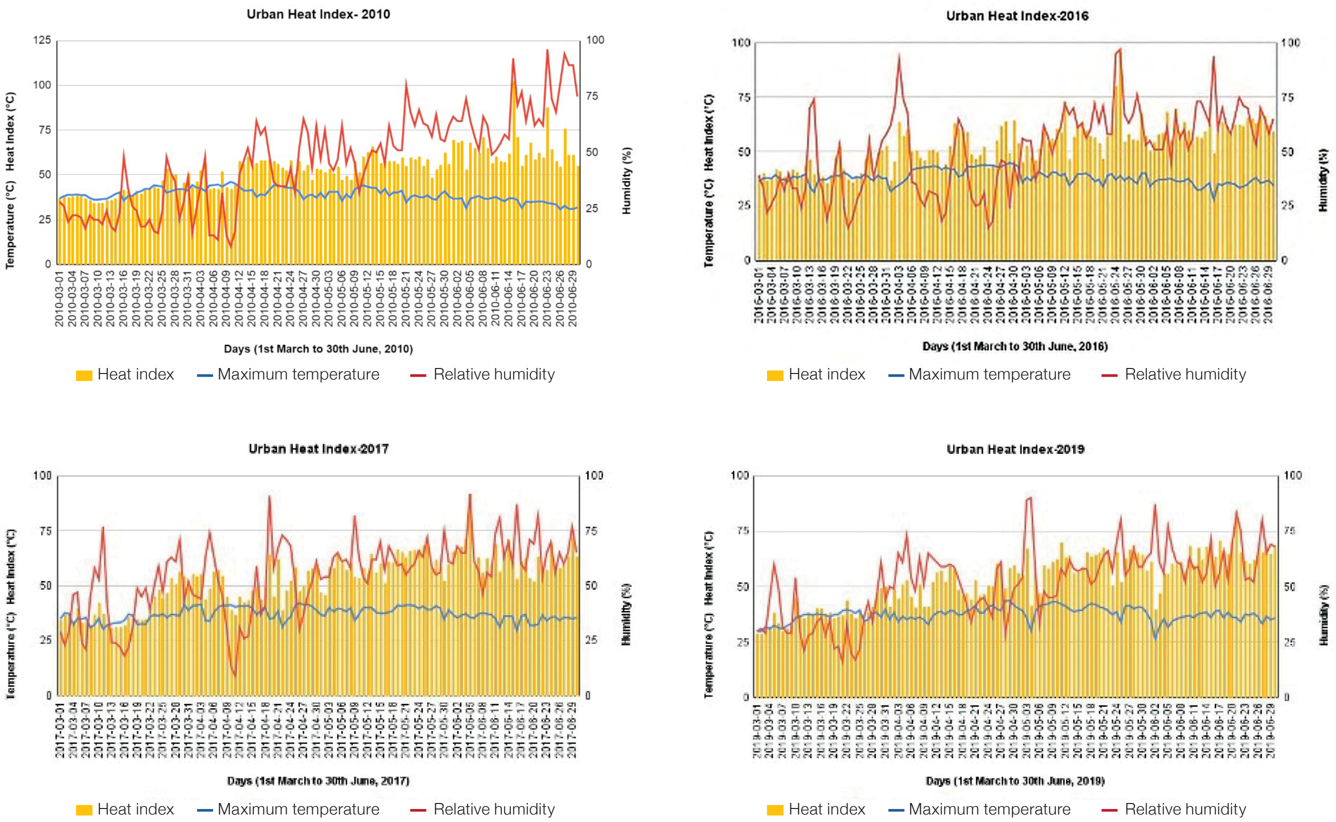


The above chart suggests that 2010, 2016, 2017 and 2019 had over 70% of days or, on average more than 60 days in the entire peak summer months (i.e. March-June) when apparent temperature or HI was above the extreme danger level. The HI of these four years has further been examined (below charts) to identify the months and days of maximum HI and maximum HI value. Analysis of newspaper articles also corroborates that the heatwave impacts in 2010, 2016 and 2017 were severe, although not many news articles reported on the heat-health impacts in 2019. However, it facilitates to set the impact limit for setting up thresholds and anticipatory actions.

Figure 16 illustrates that in the four years when heatwaves occurred, the minimum temperature, humidity and heat index were 41.28°C, 8 per cent, and 41.23 respectively. Similarly, the maximum temperature, humidity, and heat index were 46.18°C, 58 per cent, and 70, respectively (shown in Table 5). The heat index is seen as a maximum when both temperature and humidity are high.

Figure 16. Urban Heat Index 2010, 2016, 2017 and 2019

Source: Author's illustration based on data obtained from BMD



Newspaper articles indicated significant impacts during those days when HI was above extreme danger or above 54. For instance, on 26, 27 and 28 April 2016, the HI was above 54. In a newspaper article on 30 April 2016 (BusinessNews24, 2016), it was reported that people suffered extreme health impacts due to scorching heat that caused an acute water crisis in about 25 sub-districts of Rajshahi. The livelihoods of daily wage earners were also affected.

Few newspaper articles, such as an article published in May 2019 reported about heatwave, however, the article didn't report anything specifically related to health impacts (Prothom Alo, 2019). The newspaper articles on 23 April 2010 (Dhaka Mirror, 2010), reported that older adults and children suffered a lot from extreme heat and the number of patients suffering from jaundice, viral fever, and diarrhea had doubled. A growing number of people suffering from diseases like high blood pressure, kidney ailments and sunstroke, had also been reported.

The signs of rising HI on a day basis and its various impacts as reported in the newspaper articles in the following day facilitate to set the impact limits. The impact limits projects an indication to set a threshold for anticipatory actions in the city by the respective authorities. From the HI and primary heat impacts analysis, the limit of the following impact can be drawn:

Table 5: Impact Limits

Heatwave day	Impact Based Rank	Temp max range °C	Humidity (%)	Heat Index
2016 (7 to 16 April; 19 April to 1 May)	Low	41.78-44.88	15-52	41.23-64.24
2010 (21 to 25 March; 29 March to 3 April; 5 to 12 April; 20 to 25 April; 9 to 14 May)	Medium	41.28-46.18	8-51	41.55-65.89
2019 (7 May to 11 May)	High	41.88-43.18	45-58	58.05-70

Source: Author's illustration based on data obtained from BMD

It is important to note here that the impact assessment based on newspaper articles' analysis gives an overall indication of the heat-health impacts. However, a detailed investigation on the public health data and community-level impact survey is necessary for an in-depth analysis of the heat-health impact and adverse impacts on livelihoods, relative to the extreme temperature events.

Photo 3. Rickshaw or *Toto* (three-wheelers) stand at Upor Bhadra in ward 27, Rajshahi City

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Chapter 5: Heat Hotspots Identification in Rajshahi

A combined exposure map along with a vulnerability index is critical to understand heatwave risk. A set of eight indicators have been used in assessing exposure and vulnerability to heatwaves in Rajshahi City. The below table presents a list of indicators along with the rationale behind their inclusion in the assessment.

Table 6: List of indicators, their dimensions and category, and rationale for the selection

Indicators	Dimension	Category	Rationale for selection
Population density	Sensitivity (Positive)	Exposure	Increased population density, population growth, and dispersal increase heat susceptibility.
Built-up area	Sensitivity (Positive)	Exposure	Increasing built-up surfaces, means of transport and industrial activities are major factor towards increasing temperature in the city area as compared to other areas.
Heat hotspot areas	Sensitivity (Positive)	Exposure	This gives information about the area with high temperatures.
Low-income status	Sensitivity (Positive)	Socio-economic vulnerability	People with low incomes are among the most vulnerable. They have little to no financial capital, hence have the least ability to combat heatwave impacts and the effects of climate change (Rothfusz, 1990).
Education	Adaptive Capacity (Negative)	Socio-economic vulnerability	Literacy rates have a direct relation to reducing vulnerability. As the literate population increases, better livelihoods will be adopted. High literacy rates also demonstrate a significant connection with low infant mortality rates and better sanitation facilities.
Housing Materials	Sensitivity (Positive)	Physical vulnerability	Tin houses/ metal roofs absorb heat when directly exposed to the sun, impacting the population living under the tin roofs.
NDVI	Sensitivity (Positive)	Physical vulnerability	This gives a quantitative estimation of vegetation growth and biomass.
Hospital	Adaptive Capacity (Negative)	Adaptive Capacity	As access to functional healthcare facilities increases, opportunities for communities' overall health and well-being and getting first aid/ treatment for heat-related illness also increases.[2]

Source: Author's Illustration

Furthermore, all the parameters are normalised to compute normalised heat index scores. The normalisation process has been explained in Table 7 below.

2 Here, access to functional healthcare facilities refers to only medical infrastructures, availability of doctors and other medical staff. However, other factors that can impact adaptive capacity, such as cost, availability of free medicines in the hospital, health insurance, stigma, kinds of treatment, health staff-patient ratio, etc., also need to be assessed for the in-depth analysis on heatwave and health.

Table 7: Normalisation of indicators for exposure, vulnerability, and capacity

Normalisation is based on the indicator's functional relationship with vulnerability.
For positively related indicators, i.e. where vulnerability increases with an increase in the value of the indicator, the following formula has been used. NP= ((P - Pmin) / (Pmax - Pmin)) × 100 where P is the value of the respective indicator; Pmax is the maximum value of the indicator; Pmin is the minimum value of the indicator. Here, positive indicators are population density, hotspots, built-up area, slum population and physical structure.
For negatively related indicators, i.e. where vulnerability decreases with an increase in the value of the indicator, the following formula has been used: NN= ((Pmax - P) / (Pmax - Pmin)) × 100 where P is the value of the respective indicator; Pmax is the maximum value of the indicator; Pmin is the minimum value of the indicator. Here, negative indicators are NDVI, education, and health capacity as their vulnerability decreases with an increase in the value of the indicator.
The **higher value of normalisation** refers to the region or ward with **maximum vulnerability** and the **lower value of normalisation** corresponds to the ward with **minimum vulnerability** with respect to a particular indicator.

Source: Author's Illustration

Photo 4. Older adults living under the scorching sun in informal settlements in ward 26, Rajshahi City

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5.1 Exposure

Exposures are the location, attributes, and value of assets critical to communities (people, buildings, factories, farmland, etc.) which could be affected by a hazard. Due to the predominance of concrete surfaces in the city, temperatures in built-up areas and dense parts tend to be hotter than those in the surrounding countryside. The heatwave exposure indicators used in this study are population density, heat hotspot areas and built-up areas.

Parameters to calculate the following indicators:

Population density: ward-level population density data has been analysed.

Hotspots: the year 2014 has been selected because the maximum number of wards have a higher temperature than the 95th percentile value i.e. 38°C. The mean value of 2014 is 37.36.

Built-up area: to construct the heatwave exposure index, ward-level built-up area data has been extracted from land cover (ArcGIS).

5.1.1 Exposure analysis

The exposure analysis has been conducted by using normalised scores of population density, hotspots, and built-up areas. The sensitivity for all these indicators is positive, which indicates the higher the normalisation value, the greater the exposure.

The formula for the combined exposure:

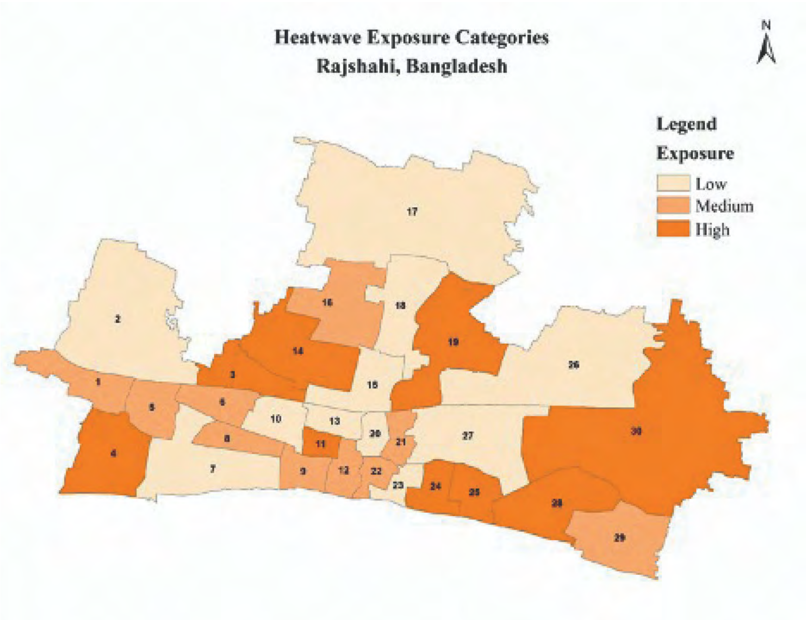
$E = W_{t1} \times \text{Population density} + W_{t2} \times \text{Hot spots} + W_{t3} \times \text{Built-up}$

After the normalisation process, the individual parameters have been transformed by scaling so that all the parameters come in a similar range. Each normalised value of population density, heat island, and built-up has been multiplied with 0.5, 0.3, and 0.2 respectively. This individual weighted value was selected on the basis of socioeconomic context through expert judgments.

Figure 17.

Heatwave exposure

Source: Author's illustration based on data obtained from BBS and Landsat satellite images



The exposure analysis suggests that ward numbers 3, 4, 11, 14, 19, 24, 25, 28, and 30 are the highly exposed wards, which could be affected more by heatwave effects. More specifically, ward 11 is highly exposed due to the high concentration of built-up areas and population density. Urban growth is happening significantly in wards 3 and 14. Furthermore, wards 3 and 14 are located close to the barren tract[3].

In ward 4, the maximum surface temperature value was observed in 2014 (Figure 12). The built-up area is also relatively high in ward 4. Moreover, in wards 4 and 25, the NDVI value is significantly low. NDVI analysis also suggests very little to no vegetation in these wards. Exposure in wards 24, 25, 28 are relatively high due to high built-up and proximity to the char land in the south.

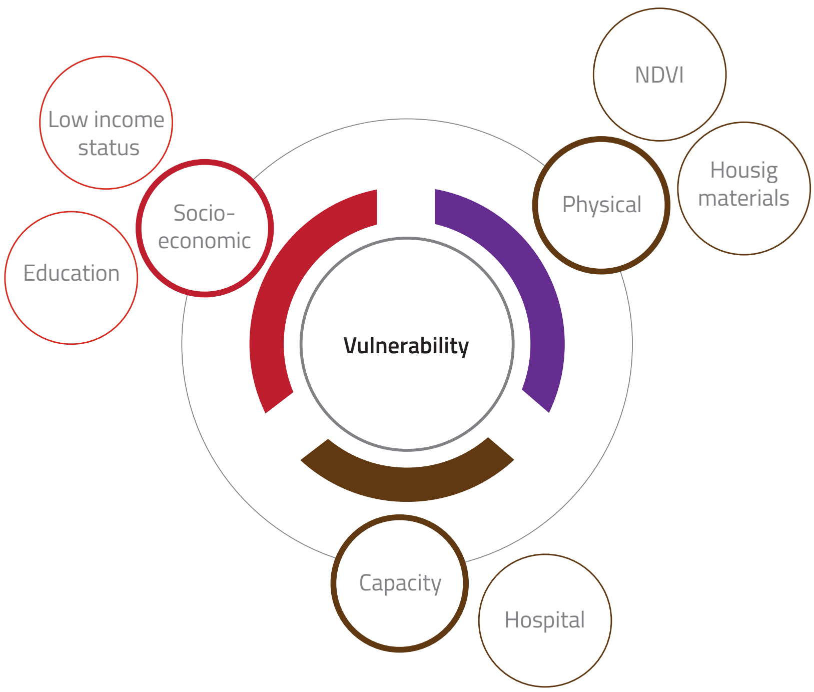
5.2 Vulnerability

Vulnerability can be defined as a person's or a group's inability to predict, cope with, resist and recover from the effects of a climatic disaster. Vulnerability has been categorised into three different types, with each type further classified into different categories as presented in Figure 18 below.

Weightage: Each normalised value is multiplied with a weighted scale. The individual weighted score for all parameters has been determined through expert judgments, considering the socioeconomic and anthropological context of the city. This scaling has been done so that all parameters are brought to a similar range.

Figure 18. Vulnerability Indicators

Source: Author's Illustrations



3 Vast tracts of barren land.

5.2.1 Socioeconomic vulnerability analysis

Socioeconomic vulnerability is defined as a set of social, economic, and demographic factors that unite together to influence people's ability to cope with stress. People living in tin houses, slum populations, daily workers like auto and rickshaw drivers, construction workers, street hawkers, etc., are the populations most vulnerable to heatwaves. These population groups are more likely to become dehydrated and suffer from different diseases like headaches, diarrhea, fever, and skin and heat-related illnesses.

Rajshahi's social and economic characteristics directly impact the city's social vulnerability. Individual factors such as slum population and literacy rates have been analysed to understand the socioeconomic vulnerability[4].

After calculating the normalisation score, the socioeconomic vulnerability score has been calculated. Higher normalisation shows that populations living in those areas are more vulnerable to heat stress in all three cases.

The formula for socioeconomic vulnerability is:

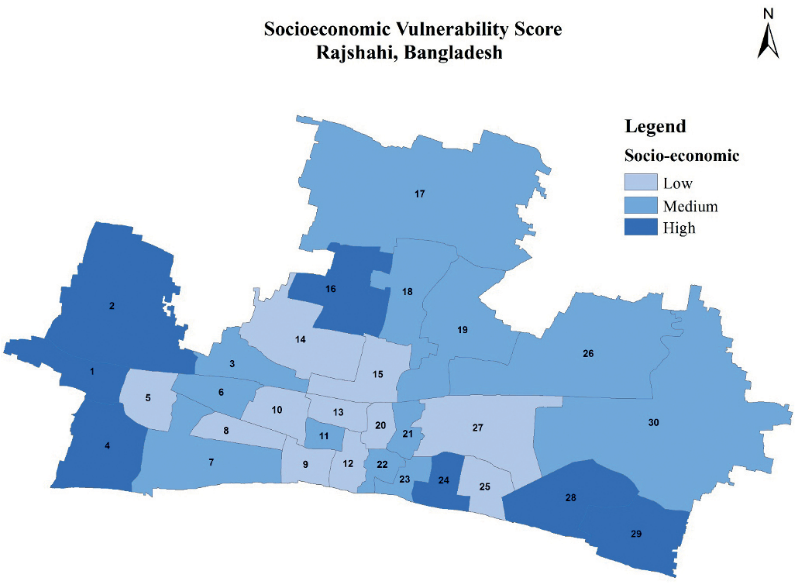
$VSE = W_{t1} \times \text{Low-income population} + W_{t2} \times \text{Literacy rate}$

After the normalisation process, the individual parameters are transformed by scaling so that all the parameters are in a similar range. For this, the obtained normalised value of low-income population and literacy rate, have been multiplied with 0.7 (Wt1) and 0.3 (Wt2) respectively. This individual weighted value has been selected through expert judgments.

The socioeconomic vulnerability index is shown in Figure 19 below.

Figure 19. Socioeconomic vulnerability

Source: Author's illustration based on data obtained from BBS



The socioeconomic vulnerability is high in wards 1, 2, 4, 16, 24, 28, and 29. These wards are highly vulnerable because they have a high number of low-income population groups. For instance, the types of occupations of the low-income

4 Dependent population i.e. population age group below five years and above 65 years, is also another important parameter for measuring socioeconomic vulnerability. However, due to lack of available local-level data, this indicator was not used.

population groups in wards 4, 24, 28, 16, 29 are rickshaw pullers, *toto* (3 wheeler) drivers, street vendors etc., whereas low-income population groups in wards 1 & 2 are primarily associated with farming or agricultural activities.

5.2.2 Physical vulnerability analysis

There are many indicators that can be used for analysing physical vulnerability such as house types, materials, NDVI, etc. Here, the rooftop materials data and NDVI have been analysed to construct the physical vulnerability score. People living in houses with tin thatched roofs are impacted significantly by heatwaves as metal roofs absorb heat when directly exposed to the sun.

The sensitivity for house type indicators is positive, which indicates that the higher the normalisation value the greater the exposure, whereas the sensitivity for NDVI is negative indicating vulnerability decreases with an increase in the value.

The formula for physical vulnerability is:

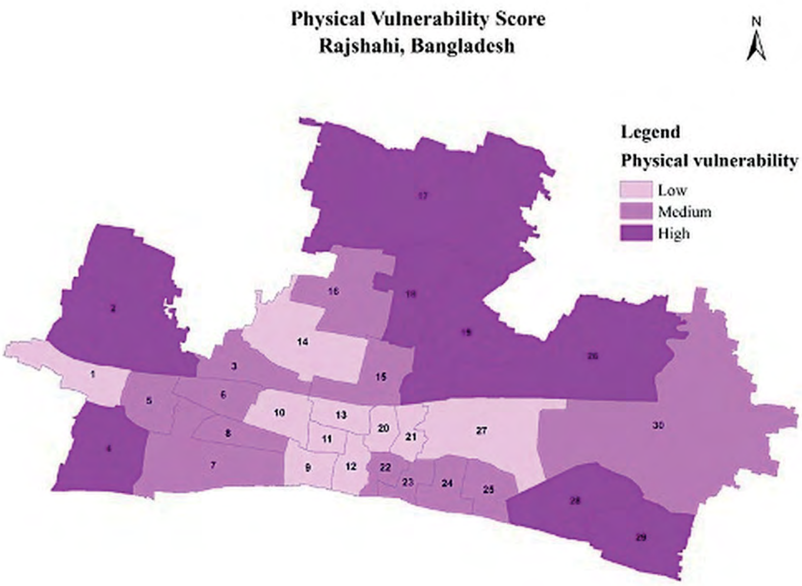
$VSE = W_{t1} \times \text{Tin house} + W_{t2} \times \text{NDVI}$

After the normalisation process, the individual parameters are transformed by scaling so that all the parameters are in a similar range. For this, the obtained normalised value of housing structure and NDVI have been multiplied with 0.7 (W_{t1}) and 0.3 (W_{t2}) respectively. This individual weighted value has been selected through expert judgments.

Figure 20.

Physical vulnerability

Source: Author's illustration based on data obtained from RDA



The physical vulnerability is seen high in wards 2, 4, 17, 18,19, 26, 28, and 29. Among these wards, wards 28 & 29 are the most vulnerable as most low-income groups' habitations with tin thatched houses are stationed in these wards. Furthermore, these wards also have a very low NDVI value. Most of these wards are located on the north side, a few in the southeast and one ward on the west side of the city.

5.2.3 Infrastructure/capacity

Health services facilities are considered to analyse the capacity vulnerability. The higher the health services facilities in a particular ward, the fewer people are vulnerable to heat.

There are five different health facilities in Rajshahi city: hospitals, clinics, doctor's chambers, diagnostic centers, and drop-in centers. Since details related to the treatment of the number of patients monthly or yearly are not available, this normalisation process has been adopted for this analysis. To get the normalised value of individual health services - hospitals, clinics, doctor's chambers, diagnostic centers, and drop-in centers have been normalised by multiplying it with 1, 0.7, 0.4, 0.3, and 0.15 respectively. The weighted value is selected through expert judgments. This normalisation has been done with respect to the capacity equivalent to hospital services.

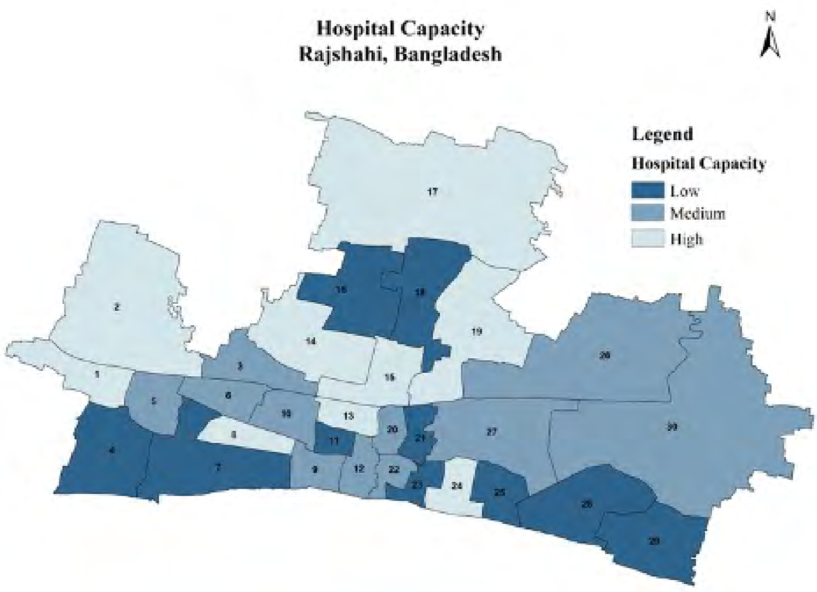


Figure 21. Capacity

Source: Author's illustration based on data obtained from Islam et., al 2016

There are 10 wards with minimal health services, which indicates the population of these wards is less able to access health care facilities to recover from heat illness than the other wards. The highly vulnerable areas are primarily located on the city's south-east and south west, and very few on the northern side of the city. Although there are limited health facilities in wards 21 and 23, access to the healthcare facilities is still better than other low-capacity wards due to proximity with wards with high capacity of healthcare facilities.

Photo 6. Youths spending their leisure time in the Char lands on the Padma riverbank, Rajshahi City

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5.2.4 Vulnerability index

To obtain the overall vulnerability index, each normalised socioeconomic, physical, and capacity value has been multiplied with the predetermined weightage values 0.6, 0.4 and 0.1. This scaling is done so that all the parameters are in a similar range.

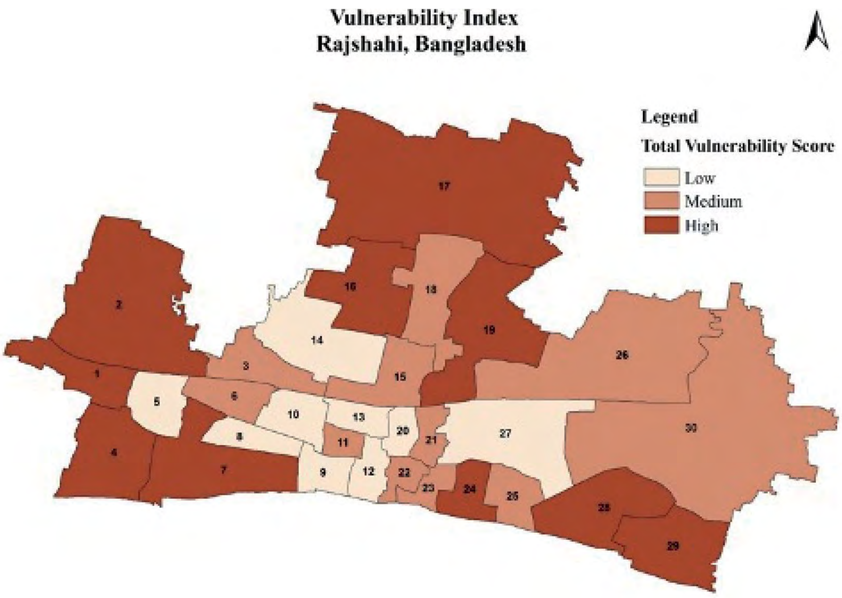

Figure 22.
Vulnerability index
Source: Author's illustration

The ward-level vulnerability map embedding the socioeconomic, physical vulnerability and capacity factors, exhibits that there are ten highly vulnerable wards in Rajshahi City. Eleven are moderately vulnerable, and nine wards are less vulnerable. The most vulnerable wards are 1, 2, 4, 7, 16, 17, 19, 24, 28, and 29.

The climate vulnerability assessment carried out by ICLEI South Asia indicates that ward 17 is the climate-vulnerable hotspot, as the fragility of the urban system due to climate change impacts are significantly high. It is followed by wards 1, 29 and 30 where vulnerability is also significantly high.

5.2.5 Vulnerable groups

The heatwave impacts in the socioeconomic context are mainly the loss of income (loss of working hours) and increase in expenditure (illness and other) facing the exposed, vulnerable population. Some of the population most vulnerable to heatwaves are individuals with low socioeconomic status; people living in tin thatched houses, daily workers like auto/toto (three wheelers) and rickshaw drivers, construction workers, street hawkers/vendors, etc.

Among these vulnerable groups, the most impacted in the city are rickshaw pullers and auto drivers. The survey results indicate they lose 20% and 18% of their income, respectively, if they reduce four hours of work in three days during high heatwave days. Medium impacts are observed among construction workers and people living in tin roof houses, whereas street hawkers bear a relatively low mark compared to other vulnerable groups[5].

Photo 5. Informal workers (rag-pickers) working under the scorching sun in ward 26, Rajshahi City

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5 Construction workers have the option to work in the evening and at night time. Street hawkers also have the option to work in the evening, whereas rickshaw pullers and auto drivers don't have that option. So, less impact is seen in construction workers and street workers compared to auto-rickshaw drivers.

Chapter 6: Conclusion: Heat Threshold and Hotspots in Rajshahi

6.1 Heat threshold in Rajshahi

Two thresholds are important for triggering early action for heatwaves: (a) threshold to define an extreme event and (b) setting the impact limit.

Nissan *et al.,* (2017) defines a heatwave as when the daily maximum temperature exceeds the 95th percentile and remains above it for three days or more. The analysis in the above sections suggests that 38°C is the maximum daily temperature in Rajshahi City, becoming an extreme event.

During an extreme heatwave period, the temperature ranges from 41°C to 42°C, humidity ranges from 8 per cent to 52 per cent and HI ranges from 41 to 70. The least impact limit, or HI 41, is considered when setting the threshold for anticipatory actions in Rajshahi.

6.2 Heat Hotspots in Rajshahi

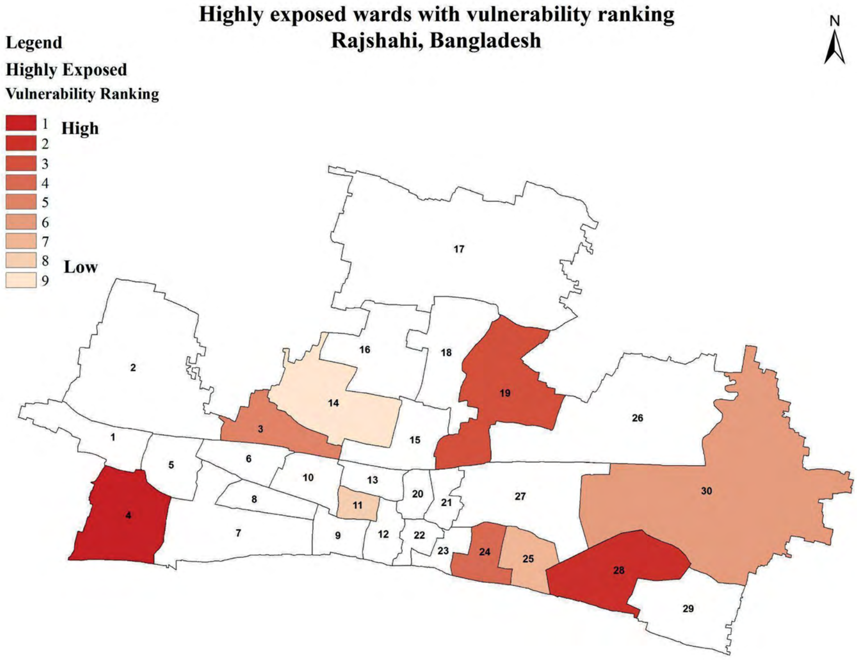
After the activation threshold is reached, it is necessary to know where to act. Identification of heat hotspots and most vulnerable groups (which may or may not overlap and may not necessarily be geographically defined) based on exposure and vulnerability to heatwaves, helps understanding around where and for whom early action or preparedness measures by the city authority and other emergency service providers, need to be taken.

The wards based on heat exposure are classified into three categories: high, moderate, and low levels of exposure. There are nine highly exposed wards, eleven wards are moderately exposed and the rest of the ten wards have low exposure (shown in Figure 17). The nine highly exposed wards are 3, 4, 11, 14, 19, 24, 25, 28 and 30. The heatwave exposure in these wards is high primarily due to rapid and high-density urban growth, low healthy vegetation and proximity to char land and barren tract.

These nine highly exposed wards have further been ranked with the vulnerability index score (shown in Figure 23) to determine their degree of vulnerability. As a result, depending on available resources and capacity, the respective city authority and other emergency service providers can prioritise actions before or during a heatwave that are indispensable if a heatwave reaches the threshold in Rajshahi.

Figure 23. Highly exposed to heatwave wards with vulnerability ranking

Source: Author's illustration



The analysis interprets that wards 4 and 28 are highly vulnerable, followed by wards 19, 24, 3, 30, 25, 11 and 14. It has been reported that one of the most low-income groups' habitations are housed in ward 28. On the other hand, the increasing trend of built-up areas and the reducing trajectory of water bodies and green coverage have been observed in ward four in past years. These can be considered as some of the key factors for high vulnerability to heatwaves. It suggests that in addition to the preparedness measures for imminent heatwaves or actions during a heatwave, long-term and policy level interventions to reduce urban heat risks are also critical, especially in wards 4, 28, 19 and 24.

Photo 7. Informal settlements near the Padma *Abashik*, Rajshahi City

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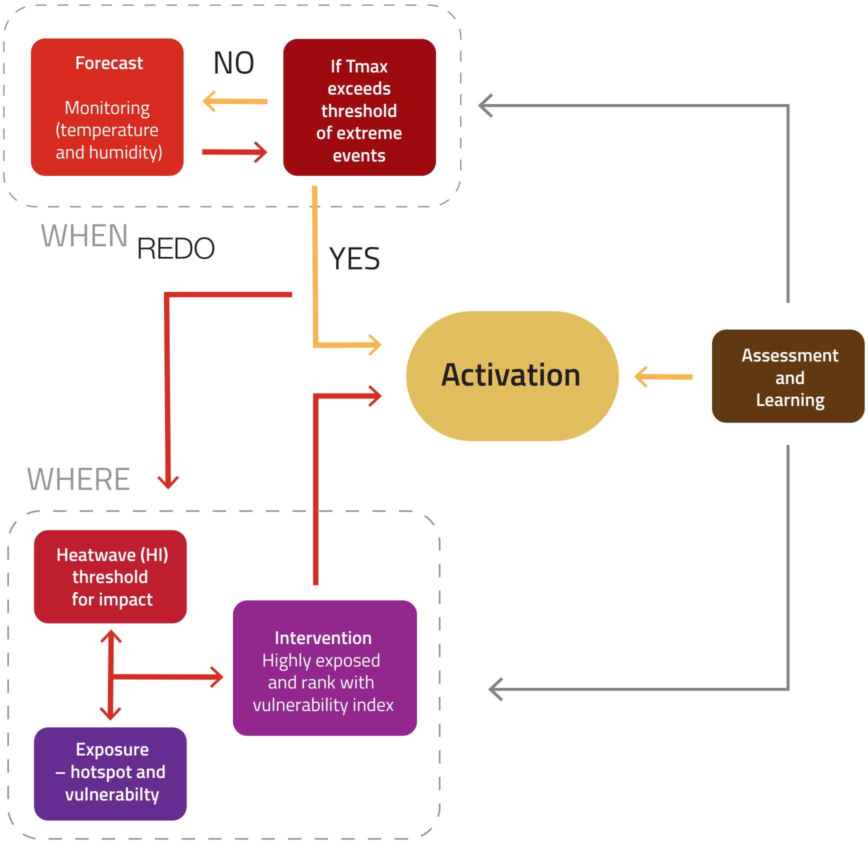
Chapter 7: Way Forward

Heat threshold and hotspots help to understand when and where to act during heatwave days. It is also determined that the heatwave risk (heat index) is high enough to impact the health and livelihood of vulnerable groups in the hotspots of Rajshahi City. As a next step, the local city authority and other emergency service providers need to take stewardship and consider anticipatory actions to reduce heatwave impacts and related losses in the city. Anticipatory actions for a heatwave are aimed at reducing human suffering and impacts on livelihoods, acting before disaster strikes by using skilled heatwave forecasts. Formal engagement with BMD, the respective authority in the case of Rajshahi, would need to take place. A forecast service that included temperature and humidity could be set up (subject to the availability of resources), with the extreme event used as the trigger threshold. Alongside this there would need to be the establishment of effective coordination with the RCC and emergency response authorities to provide forecast information and/or the issuing of heat warnings for short-term and long-term responses. The RCC, BMD and BDRCS could refer to the following schematic diagram that shows the steps and criteria around the activation of action for heatwave risk:

Figure 24.
Workflow of activation action for heatwave
Source: Author's Illustration



There would be a requirement for a forecast lead time of up to 10 days to enable anticipatory measures to be put in place.

7.1 Future directions

The future direction of work for the city authority and other emergency service providers involves:

- Initiating stakeholder engagement on heatwave preparedness and response using existing materials and through consultation with relevant stakeholders such as BMD, city officials, health officials and the city disaster management body.
- Relevant stakeholders focusing on extending support for heatwave management planning to priority wards, monitoring the process and its effectiveness, and updating the plan accordingly.
- A community-level in-depth impacts analysis and capacity assessment.
- Rolling out awareness and capacity-building programmes.
- In-depth analysis and validation of the heatwave impact analysis by investigating public health data.
- Formulation of a trigger model and simulation in the city, particularly in the vulnerable wards and, development of an early warning early action standard operating procedure (SOP).

7.2 Key roles and the stakeholders in the city

This section gives an overview on the different critical roles for heat actions in the city and the list of potential stakeholders in Rajshahi.

Table 8: Roles of different stakeholders in the city for heat actions in Rajshahi

Roles	Potential Departments and partners
Developing a heat action plan	- Rajshahi City Corporation (RCC) - Rajshahi WASA - Rajshahi Development Authority (RDA) - Local Government Engineering Department (LGED) - Rajshahi University - Rajshahi University of Engineering and Technology - ICLEI Local Governments for Sustainability. South Asia, Rajshahi City Unit
Developing and issuing heat early warnings	- Bangladesh Meteorological Department (BMD)
Leading emergency response	- Rajshahi City Corporation (RCC) - Bangladesh Red Crescent Society (BDRCS), Rajshahi branch - BRAC - Caritas - Society for Action Research and Development - Nikunja Basti Unnayon Shangstha - Resource Integration Centre (RIC)
Liaising with the media	- Rajshahi City Corporation (RCC) - Rajshahi News24
Liaising with city residents	- Rajshahi City Corporation (RCC) - Society for Action Research and Development - Nikunja Basti Unnayon Shangstha - Resource Integration Centre (RIC) - Association for Community Development (ACD)
Strengthening health systems	- Rajshahi Medical College Hospital - Rajshahi City Corporation (RCC) - Urban Primary Health Care Service Delivery Project (UPHCSDP) - NGO Health Service Delivery Project (NHSDP) - BRAC Manoshi
Mainstreaming heat into city planning	- Rajshahi City Corporation (RCC) - Rajshahi WASA - Rajshahi Development Authority (RDA) - Local Government Engineering Department (LGED)

7.3 Simple actions to reduce heat risks

Some of the simple city-level actions that the Rajshahi City Corporation in collaboration with other city stakeholders can plan to undertake are:

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Annex I: Glossary

The climatic terms used in this report are derived from the Intergovernmental Panel on Climate Change's (IPCC) reports. According to IPCC, definitions of the climatic terminologies are as follows:

Adaptation: Adaptation is an adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive capacity: It is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, or cope with the consequences.

Climate change: Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).

Disaster: A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its resources.

Exposure: The nature and degree to which a system is exposed to significant climatic variations. In this document, exposure is considered as the characteristics and magnitudes of climate change, climate variability, and associated hazards including the extreme events to which a system is exposed

Hazard: A dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Risk: Risk is the combination of the probability of an event and its negative consequences. The degree of risk is expressed in terms of monetary value in this document.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Susceptibility: The state or fact of being likely or liable of a system or an element to be influenced or harmed by a particular thing or hazard.

Variability: It is the state or characteristic of a system of being variable, in this case, that of the climate. In this document, variability will be mostly associated with climate.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

Heat index: Heat index is a measurement of perceived temperature in the human body indicating how hot it feels when the relative temperature is added to the actual air temperature.

Land surface temperature: The land surface temperature is the radiative skin temperature of the land surface, as measured in the direction of the remote sensor.

Percentile: A percentile is a number where a certain percentage of scores fall below that number. Example: If a value of X is 95th percentile, this means that the value of X is higher than 95% of the total dataset.