FEASIBILITY STUDY ON HEATWAVE

in Dhaka

BANGLADESH RED CRESCENT SOCIETY BDRCS

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FOREWORD

Bangladesh Red Crescent Society (BDRCS) has been working in the arena of Forecast-based Financing (FbF) since 2015 in partnership with German Red Cross (GRC) and technical support from the Red Cross Red Crescent Climate Centre (RCCC). The goal of FbF was to reduce loss of life, livelihoods, assets and livestock by taking effective early action based on a credible extreme event forecast.

The concept of FbF was piloted in three countries of the world and Bangladesh was one of them and now Bangladesh is the good practice model in FbF. During first and second phase of the FbF, BDRCS made evidence by reducing impact in Flood and Cyclone by through effective early action. The forecast-based financing initiative is scaling up into forecast-based action and anticipatory action in Bangladesh as well in the world.

Through effective advocacy by the FbF/A Technical Working Group (leading by BDRCS), the Government of Bangladesh (GoB) has included FbF/A Taskforce in the revised version of the Standing Orders on Disaster (SOD). The FbF/A will also be included in the government's disaster's strategic plan.

Nowadays, heat waves are in rising trend and a large number of people are being exposed of the hazard as there is lack of knowledge of heat waves and its cascading effects. As a leading organization in managing the disaster risk, BDRCS is expanding its FbF/A arena to address the impacts of heat waves in Dhaka City.

This feasibility study will lead us to develop Early Action Protocol (EAP) and will ensure sustainable funding approach through FbF/A by the Disaster Relief Emergency Fund (DREF) of the International Federation of Red Cross and Red Crescent Societies (IFRC).

I extend my deepest appreciation to the FbF team of BDRCS, BMD, GRC and RCCC who worked and prepared this feasibility study report by collecting and researching background data, satellite data, climatic data and validated through consultation workshop. I would like to thank to the FbF team of disaster risk management department of BDRCS. The appreciation also goes to the FbF/A Technical Working Groups members for their time during the consultation workshop.

Major General (rtd.) ATM Abdul Wahab, Ex MP
Chairman, Bangladesh Red Crescent Society

FOREWORD

Heatwave is a meteorological phenomena, which is usually found to happen in Bangladesh during pre-monsoon season. But sometimes, it becomes unbearable, especially when it is coupled with high humidity. In the recent times, it is found to occur in Bangladesh in other times like- monsoon and post-monsoon seasons due to the changing behavior of climate. The heatwave is considered as one of the most dangerous hazards, because climate change is catalyzing the intensity and severity of the heatwave. It creates havoc with severe impact on human health such as heat stroke, heat exhaustion, and dehydration. It is also responsible for significant number of mortality at different parts of world. It has significant impact in Bangladesh also.

Bangladesh Meteorological Department (BMD) is the national forecasting agency in Bangladesh for issuing forecast and early warnings of meteorological hazards including heatwave. It has been affirmed through 'Meteorological Act', enacted on 29 July 2018. But to maximize the utility of this forecast, BMD need to collaborate with the agencies which are involved in disaster management, disseminating and translation forecast, guide and support to reduce the risk at local level. Consequently, BMD has signed an MOU with Bangladesh Red Crescent Society (BDRCS) for strengthening Forecast Based Financing (FbF) in Bangladesh in collaboration with BMD.

German Red Cross (GRC) is leading the piloting and scaling-up of Forecast-based Financing (FbF) globally. It is believed that the loss of lives and properties can be reduced significantly if humanitarian actions can be implemented prior to any disaster impact. FbF is such an anticipatory action for disaster risk reduction. FbF reduces the impact, human suffering and losses caused by extreme weather events. German Red Cross and Bangladesh Red Crescent Society with United Nations World Food Programme (WFP) introduced Forecast-based Financing (FbF) in Bangladesh in 2015.

At this situation, a joint initiatives has been taken to address the issues of Heatwave in Bangladesh. The most vulnerable locations of Dhaka North City area has been taken into consideration for managing heatwave related crisis. Accordingly, relevant activities has been conducted by the BDRCS volunteers based on the heatwave forecast issued by BMD and collaboration with Dhaka North City Corporation. As of my understanding, the piloting activities were successfully conducted. The relevant information has been incorporated in this Feasibility Study Report.

I hope the continuation of this activity in near future over heatwave vulnerable regions of Bangladesh.

Shamsuddin Ahmed
Director, Bangladesh Meteorological Department

FOREWORD

As we write this report many parts of the globe are witnessing record breaking temperatures. Increasing heat, because of climate change, is fueling record-breaking wildfires – current western United States, Canada and European wildfires to name but a few. As the climate crisis continues, such heatwaves are expected to be increasingly deadlier in its severity, intensity, and it will become more widespread particularly in urban centers. Almost every year the previous heat record is broken. Unlike many other disasters such as floods or cyclones, heatwaves do not have visible widespread destruction in the aftermath – hence many people do not recognize its deadly nature, it's a silent killer.

The concrete buildings and roof, asphalt street and concrete coverage absorb more heat making the cities warmer than rural areas by a few degrees. Further, because of 'heat island' effect, there are some areas in the cities that experience more temperature than other areas of the city. Hence, the heat related health impacts and deaths are more in cities.

The vulnerable population who are residing in the cities are disproportionately exposed to and impacted by excessive heat in urban pockets. The study has identified that in Dhaka the rickshaw/van pullers, the construction workers, migrant workers, pedestrians, street vendors/hawkers, people who work outdoor are some of the most vulnerable groups of people who are more exposed to heatwave. Because of their socioeconomic condition, they are not able to take adequate preventive measures to protect themselves from extreme heat.

The good news is that such heatwaves could be predicted. Under the Anticipatory Action approach, such heatwaves could be anticipated, and early actions could be implemented before the heatwaves to reduce their impact, human suffering, and losses.

This feasibility study is commissioned to identify impact of heatwaves and challenges faced by the city dwellers, available forecast and lead time and early actions that could be implemented to reduce the impact on the most vulnerable people of Dhaka city. This study gives us the possible windows to pilot heatwave early action in Dhaka city.

German Red Cross has technical expertise in anticipatory action along with its extensive global and regional experience of supporting host national societies to pilot forecast-based actions. In Bangladesh, since 2015 German Red Cross is supporting the Bangladesh Red Crescent Society to develop anticipatory action mechanism for extreme floods and cyclones. These Forecast-based Financing work is financially supported by German Federal Foreign Office. With the current study, we are looking forward to expanding this mechanism to heatwave too.

Anticipatory action requires engagement from the scientific community, government, donors, technical institutions, academicians, and private sectors. We look forward to working with all the stakeholders and through our collective action to better assist the vulnerable people and communities.

Gaurav Ray
Head of Office, German Red Cross

Contents

List of Abbreviation:

AA	Anticipatory Action
ABC	Awareness Raising and Behavior Change Communication
BBC	British Broadcasting Corporation
BBS	Bangladesh Bureau of Statistics
BDRCS	Bangladesh Red Crescent Society
BMD	Bangladesh Meteorological Organization
BT	Brightness Temperature
°C	Degree Celsius
EAP	Early Action Protocol
ECMWF	European Centre for Medium-Range Weather Forecasts
Em	Emissivity
ETM	Enhanced Thematic Mapper
°F	Degree Fahrenheit
FAR	False Alarm Ratio
FbF	Forecast-based Financing
FbA	Forecast-based Action
GFS	Global Forecast System
ICDDR,B	International Centre for Diarrheal Disease Research, Bangladesh
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
LST	Land Surface Temperature
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NWP	Numerical Weather Prediction
OLI-TIRS	Operational Land Imager Thermal Infrared Sensor
Pv	Percent of Vegetation
RCP	Representative Concentration Pathway
SVRS	Sample Vital Registration System
TM	Thematic Mapper
TOA	Top of Atmosphere
TW_{max}	Maximum Wet Bulb Temperature
UHI	Urban Heat Island
WHO	World Health Organization
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

1. Background

Heatwave is a meteorological phenomenon with a period of unusual excessively hot weather, often coupled with humidity. The heatwave is considered amongst one of the most dangerous hazards – climate change is catalyzing the increasing intensity and severity of the heatwave. It is already creating havoc with severe impact on human health (such as heat stroke, heat exhaustion, dehydration); increased number of heat-related mortality; the impact of daily activity, agriculture and goods and service output etc.

Global temperature is on the rise, and it has increased twice faster than in the previous centuries because of climate change (IPCC, 2013[1]). An analysis conducted by NASA reported that the earth's global surface temperature in 2019 was the second warmest on the record with the record 1.8 °F (0.98 °C) warmer than 1951 to 1980 mean[2][3]. The recent analysis by NASA shows that the global average surface temperature of 2020 tied 2016, with an average temperature 1.84 °F (1.02 °C), as the hottest year on the record. This rise in global temperature is expected to continue and therefore we will witness an increasing number of hot days will also continue increasing[4]. While the frequency, duration and magnitude of unusual extreme temperature events globally are on the rise, the densely inhabited agricultural regions of the Ganges and Indus basins are identified as the hotspots of life-threatening heatwaves in future[5]. As estimated by WHO, around 125 million people were exposed to heatwaves between 2000 and 2016.

German Red Cross is leading the piloting and scaling-up of Forecast-based Financing (FbF) globally. With the belief that many of the humanitarian actions could be implemented before any disaster and thus reduced humanitarian impact, FbF works in anticipation instead of reaction. Using the available forecast information and risk analysis, FbF reduces the impact, human suffering and losses caused by extreme weather events[6]. German Red Cross and Bangladesh Red Crescent Society with United Nations World Food Programme (WFP) introduced Forecast-based Financing (FbF) in Bangladesh in 2015. After successful implementation of FbF/A on extreme floods and cyclones, GRC and BDRCS are looking forward to deploying their knowledge and expertise to pilot FbF/A on the heatwave. Bangladesh Meteorological Department (BMD) is the key forecasting agency in Bangladesh. BDRCS has signed an MoU with the BMD for strengthening FbF/A in Bangladesh.

2. About the study

The current study is an attempt to analyze the [historical] forecast data, study the impact, identify the available sources of forecast and propose thresholds, triggers and early actions to pilot anticipatory action on the heatwave in Dhaka.

The first part of the report, sections three to eight investigate the secondary data on heatwave/stress and its impact, available forecast models, sources of the forecast. Based on the available data, models

[1] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
[2] https://climate.nasa.gov/climate_resources/139/video-global-warming-from-1880-to-2019/
[3] https://www.discovermagazine.com/environment/2019-enters-the-record-books-as-second-warmest-year
[4] https://climate.nasa.gov/effects/
[5] Im, E. S., Pal, J. S., & Eltahir, E. A. (2017). Deadly heatwaves projected in the densely populated agricultural regions of South Asia. Science advances, 3(8), e1603322
[6] https://www.forecast-based-financing.org/

and menu of the forecast, a heatwave trigger model is proposed based on the analysis of the available data and information.

The second part of the report, section nine analyses the findings from the field level assessment on impacts of heatwave and needs of the vulnerable community affected by heatwave/stress. This assessment aims to probe into key impacts of heatwaves on the slum populations, rickshaw/van pullers, hawkers, pedestrians of Dhaka and identify key measures/early actions. The findings are based on the response obtained from a survey of 400 respondents, Focus Group Discussions with slum dwellers, and Key Informant Interviews with Government officials, pharmacy owners, doctors, City Corporation officials, etc.

The proposed triggers, thresholds and early actions will be the base for piloting/simulating Forecast-based Action (FbA) on the heatwave in Dhaka city. Worth mentioning, the key outcomes of the study has been validated through consultations with key stakeholders.

3. Objective, Approach and Limitation

3.1 Objective of the study

The current study is designed to contribute to two core areas of the heatwave in Dhaka – a) develop triggers and threshold, b) identify the impacts of heatwave/stress, especially on the vulnerable population of Dhaka city and propose early actions to minimize the impacts. This can later be extrapolated to other urban areas of Bangladesh. The key objectives of the study are to:

- Identify credible sources of forecasts (temperature and humidity) on heatwaves at different timescales (lead-time) and resolution- *when*.
- Develop heat index and identify relevant thresholds to trigger early actions- *when.*
- Identify vulnerable areas to pilot heatwave early actions in Dhaka- *where.*
- Identify vulnerable groups and propose early actions – *what [for whom].*

3.2 Approach

The approach of the study is based on the two distinct areas of quest of the study. The secondary data is reviewed to design a model for the trigger, thresholds; whereas primary data has been collected through field survey using structured questionnaire in ODK form, Focus Group Discussion and Key Informant Interviews to identify the impacts on and early actions for the most vulnerable people in the Dhaka city area.

Key components of the approach of the study include:

- Reviews and analysis of secondary literature, climate data and satellite imageries.
- Heat index calculation and compare it with existing thresholds (e.g., ICDDR,B), Urban Heat Island (UHI) effect incorporation, and thresholds aligned with impact evidence determination.
- Identify the areas for intervention by superimposing slums over the urban heat islands, which are derived using the time-series satellite data.
- Trigger and thresholds have been proposed to activate forecast-based early actions.

- Impacts of heatwave and needs of the vulnerable groups have been identified by engaging with 400 respondents from the vulnerable communities.

3.3 Limitation

Due to the limitation of the available data related to satellite-based information and imagery for the heatwave and lack of comprehensive data on the impact of extreme heat, the study suffered from the following limitations:

- Data on the health impact of extreme temperate and/or heat stress in Bangladesh is limited.
- Due to the shortage of Satellite data during the heatwave days, the quality of analysis has been suffered to some extent.
- Satellite-based land surface temperature (LST) and observed air temperature always have some differences. Efforts have been given to minimize these errors.

4. Definition of heatwave

Globally, there is no formal, standardized definition and threshold for the heatwave that is applicable everywhere. Different counties and organizations define heatwave differently, but there is a unanimous agreement that it is characterized by overshooting the temperature above the normal range. World Meteorological Organization defines a heatwave as 5 or more consecutive days during which the daily maximum temperature surpasses the average maximum temperature by 5°C (9°F). While developing operational definitions, different countries have adopted their own standards with the variance of the temperature range, its duration and/or consideration/inclusion of different components of weather.

At the point while ambient air TW exceeds 35°C, the human body can no longer shed heat to the environment, rather start gaining heat from the air. Hence, 35°C is considered the threshold beyond which the human body stops cooling itself adequately which could be fatal even for healthy people.

The IPCC Glossary describes heatwave as “a period of abnormally and uncomfortably hot weather.” Based on this, the WMO Commission for Climatology Task Team on the Definition of Extreme Weather and Climate Events (2018) felt the need to adopt a standard approach that will allow database inter-operability and consistent analysis of heatwave at the global and regional level. Hence, the Task Team defined heatwave as “a period of marked unusual hot weather (maximum, minimum and daily average temperature) over a region persisting at least three consecutive days during the warm period of the year based on local (station-based) climatological conditions, with thermal conditions recorded above-given thresholds.”

A study conducted by Nissan et al. has tried to define heatwave 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."[7]

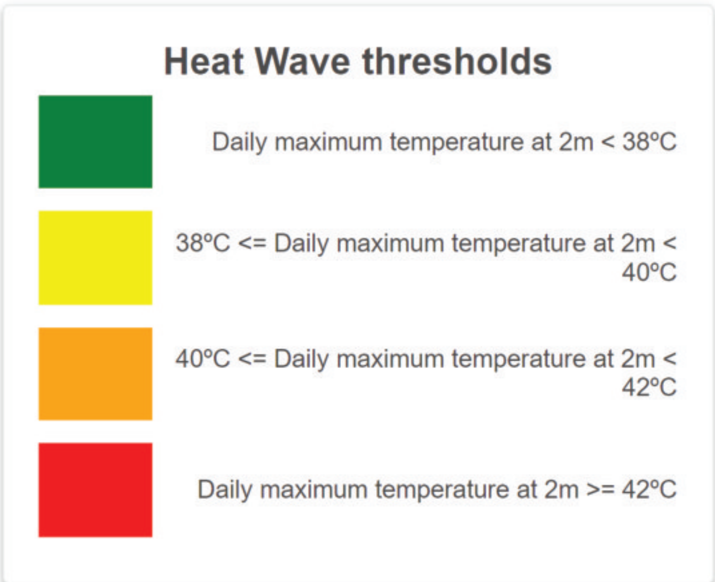
ICDDR,B has developed a heat index threshold using the formula by NOAA and proposed to use it for 2 consecutive days instead of 5 days defined by the WMO considering the context of Bangladesh. To develop the heat-health index ICDDR,B has used the formula developed by the NOAA.

Bangladesh Meteorological Department (BMD) has classified heatwaves into four categories based on maximum temperature – types of the heatwaves are captured in the table below:

Table 1: Heatwave classification by BMD[8]

Temperature range	*Type of heatwave*
36-38 °C	Mild heatwave
38-40 °C	Moderate heatwave
40-42 °C	Severe heatwave
> 42 °C	Extreme heatwave

As observed from the above analysis, in terms of the heatwave in Bangladesh, the threshold for heatwave starts at 36°C. This directly links with the adaptability of the human body to the temperature of ambient air, i.e., TW 35°C which is considered the threshold beyond which the human body stops cooling itself. For the purpose of piloting/simulating heatwave early action by BDRCS and GRC, we will consider 36°C as the reference point to start closely monitoring the event and send an alert to the internal team (please refer to the threshold section for further details).



5. Seasonal variation in temperature in Bangladesh

Bangladesh has a subtropical climate and has three distinct seasons with cool and dry winter from October to February, hot summer from March to May, and a monsoon season from June to October.

[7] Nissan, H., Burkart, K., Coughlan de Perez, E., Van Aalst, M., & Mason, S. (2017). Defining and predicting heatwaves in Bangladesh. Journal of Applied Meteorology and Climatology, 56(10), 2653-2670.
[8] Mallik, M. A. K., et al. (2020), Study on Heatwave and its Thermodynamic Features over Bangladesh using Numerical Weather Prediction Model, International Journal of Science and Business

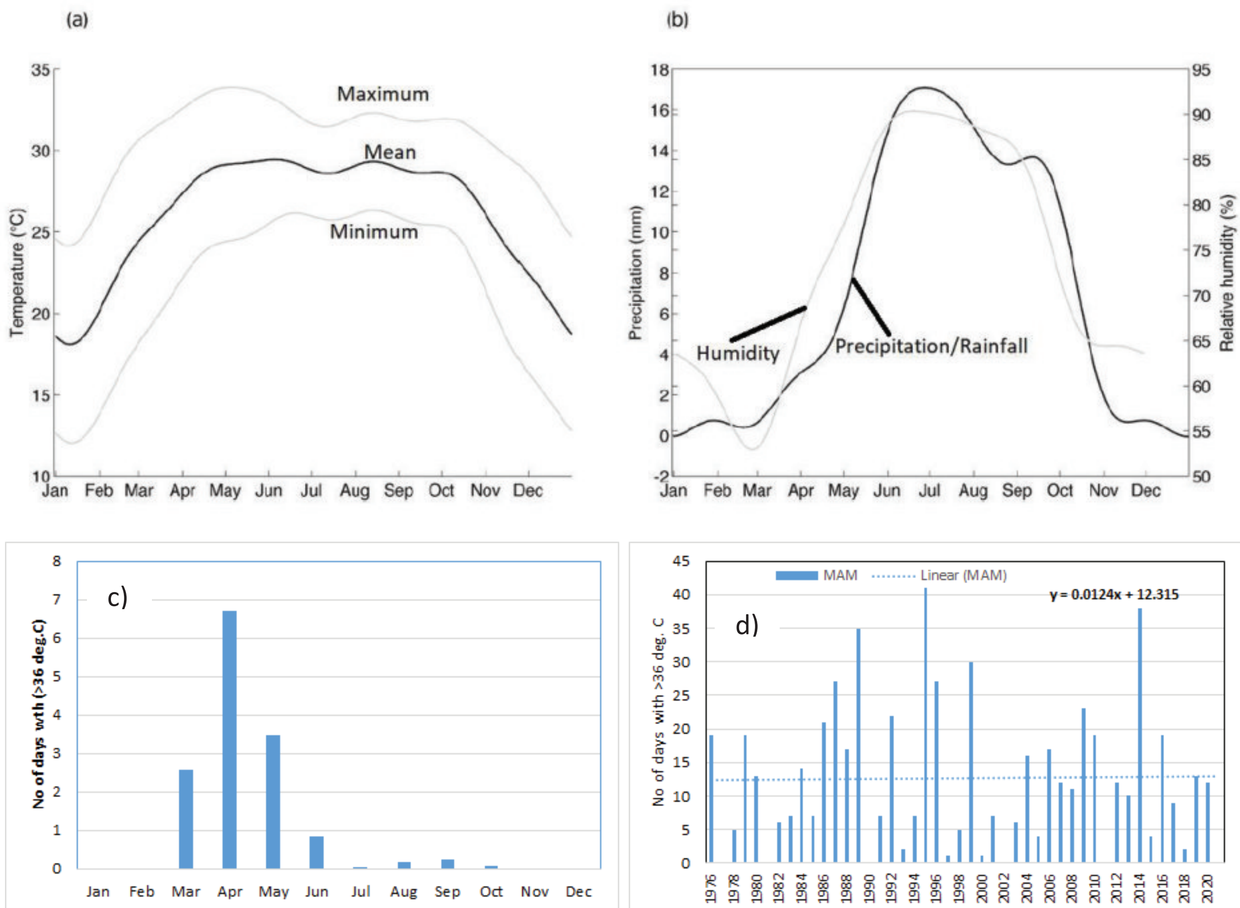


Figure 1: Smoothed seasonal cycle of country monthly (a) maximum average, minimum average, average temperature, (b) rainfall/precipitation and relative humidity, c) number of days crossed 36° Celsius in 2020 and d) number of days crossed 36 degree Celsius in March, April and May from 1976 to 2020[9]

As shown in figure 1 and based on our analysis of daily three hours' interval observed temperature for 44 years (from 1972 to 2016 for Dhaka station) we found that April, May and June are the hottest months in Dhaka when a heatwave is most likely to hit the city. Parts of the county may also experience higher temperatures in August, September and October, but it might not reach the level of a heatwave due to a higher amount of rainfall. A recent observation from BMD (figure 1c and 1d) shows that there is a growing trend of heat/temperature from mid-March to the end of September. However, the hot days are reducing in Dhaka after the month of June (figure 1c). For the initial piloting purpose, we are considering pre-monsoon season i.e., April to June to implement the heatwave early action.

6. Menu of Forecast

A heatwave is an extreme weather event, and its severity depends mainly on the level of temperature and humidity, while other factors might aggravate the condition. Forecast for temperature and humidity is available at both global and national level models with different lead times and resolutions. The below-mentioned section examines the forecast available at the global and national levels and their skills.

[9] Figure a & b from Nissan et al. and c & d from Bangladesh Meteorological Department

6.1 Forecast Available at Global Level

At the global level, forecast for temperature and humidity is available in ECMWF and GFS model at 9 to 27 km resolution. The following table shows the availability of weather forecasts at the global level, lead-time and resolution.

Table 2: Forecast available at global level with different lead time and resolution

Lead time	Forecast agencies	Model	Access Window	Resolution	Format	Downloadable
10 days	ECMWF	ECMWF	Windy	9 km[10]	Raster	No
10 days	NOAA	GFS	Windy, Ventusky	27 km[11]	Raster	No

* See annexure for forecast window

6.2 Forecast Available at Local/national Level

At the local/national level, Bangladesh Meteorological Department (BMD) provides temperature and humidity forecasts in NWP, WRF and GFS models at 3 to 27 km resolution. The following table summarizes the BMD forecasts in terms of scale, lead-time and resolution. Though the forecast from BMD is expected to be with a lead time of 5 days and 3 days, those forecast data are uploaded to the server about 10 hours later. In reality, for anticipatory action, the available lead time could be 4.5 and 2.5 days respectively.

Table 3: Forecast available at local/national scale in different lead time, resolution and available model by BMD

Lead time	Forecast agencies	Model	Access Window	Resolution	Format	Downloadable
10 days	BMD	GFS	BMD website	27 km[12]	Raster	No
5 days	BMD	WRF	BMD website	9 km[13]	Tabular	Copy-paste
3 days	BMD	WRF	BMD website	3 km[14]	Tabular	Copy-paste
2 days	BMD	WRF	BMD website	Upazila	Alert	No

*See annexure for forecast window

For the purpose of the pilot, we will use BMD's WRF model with 9 km resolution and lead time of 5 days (in reality 4 days) with skill described in the below section.

6.3 Skill of the Available Forecast

Forecasting skill for temperature has been calculated for BMD's tabular WRF model forecast data of Dhaka station at 3 KM and 9 KM resolution from the period of 1 March 2020 to 28 April 2020. Daily one-hour interval tabular forecast data was collected from the BMD website and the daily maximum temperature has been considered to assess the skill of the forecast. False Alarm Rate (FAR) has been calculated using threshold-based method where 37°C was set as the threshold.

[10] https://www.ecmwf.int/en/forecasts/documentation-and-support
[11] https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs
[12] https://blog.francis-fustier.fr/en/nouveau-modele-gfs-a-maille-025/
[13] http://123.49.38.4/forecasts
[14] http://123.49.38.4/forecasts

6.3.1 False Alarm Rate

In weather forecasting, the false alarm rate (FAR) is the fraction of false forecasts/warnings (to the total number of warnings). According to Barnes et al. FAR is the fraction of forecasted events that did not occur. FAR is one of the key metrics to verify weather forecasts/warnings, meaning how many weather forecasts/warnings did actually observed/reported to the total number of warnings/forecasts.

FAR helps to understand the skills of the available forecast and warning accuracy.

To calculate FAR, the below formula is widely used, and it is deployed to use in the current study:

Table 4: Forecast skill calculation model[15]

		Forecast	
		Yes	No
Observed event	Yes	X	Y
	No	Z	W

Where X is the number of times of weather event forecasted and the event actually occurred, Y is missed forecast, but weather event occurred, Z is the number of times the event forecasted but actually missed and W is the number of times forecasted the event will not occur and actually the event did not occur.

$$False\ Alarm\ Rate = \frac{Z}{(X + Z)}$$

Where Z is the number of weather events forecasted but actually missed, X is the number of events/times forecasted and happened.

The following table summarizes the skill of forecast provided by BMD. As shown in the table, FAR and lead-time has a positive relation - the longer the lead-time higher the FAR. The FAR has been calculated using a threshold method considering 36°C as the threshold.

Table 5: Forecast skill (FAR) of BMD in different resolution and lead-time

Lead-time (days)	Day 3 (actual 2)[16]	Day 4	Day 5 (actual 4)
FAR	0.58	0.62	0.67

*See annexure for details of the calculation

As we are proposing to implement early action 5 days ahead of the event, we will consider the FAR for the last 3 days i.e., day 3 to day 5.

The above table means that if the forecast from BMD shows that the temperature will cross 37°C on the third day, there is the possibility that 58 out of 100 forecasts will be false. For the fourth day, it will be 62 times and for the fifth day, there will be 67 times false out of 100 times forecast.

[15] https://journals.ametsoc.org/doi/pdf/10.1175/WAF1031.1

[16] Though, BMD has the system to give forecast with 5 days and 3 days lead time, but almost a day is lost to upload it on the server and make it available for the public. Hence, the actual lead-time is 4 and 2 days respectively.

7.0 Health impacts of high temperature

During a heatwave increases the health hazard. However, literature on the health and socio-economic impact of heatwaves and extreme temperature in the context of Bangladesh is very scant. Nissan et al., after analyzing the nationwide death counts collected from Sample Vital Registration System, concluded that during the heatwave season, the death rate increases by 20%. Moreover, there are some media reports that point out the adverse impacts of temperature and heatwaves on human health. For e.g., on 24 April 2014 Dhaka Tribune reported that about 786 patients were admitted to the International Centre for Diarrheal Disease Research, Bangladesh (ICDDR,B) hospital within 24 hours and about 60% of them were infants suffering from water-borne diarrheal diseases[17].

A video documentary prepared by BBC media action reported that nearly 3,500 people died in 2005 due to different heatwaves in Bangladesh[18].

In 2003, at least 62 people died due to heatwaves across Bangladesh[19].

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[17] https://www.dhakatribune.com/uncategorized/2014/04/24/capital-experiences-highest-temperature-in-54-years
[18] https://web.facebook.com/bbcamraipariofficial/videos/1909520232661607
[19] https://www.newagebd.net/article/84885/frequent-long-heat-waves-reduce-monsoon

Table 6: Impact analysis (temperature versus humidity) in different heatwaves

Humidity in % \ Temperature in °C	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5	28.3	29.1	29.9	30.7	31.5	32.3	33.1	33.9	34.7	35.5	36.3	37.1	37.9	38.7	39.5	40.2	41.0	41.8	42.6	43.3	44.1
10	28.1	28.9	29.8	30.6	31.5	32.3	33.2	34.1	35.1	36.0	37.0	38.0	39.0	40.0	41.1	42.1	43.2	44.3	45.4	46.6	47.7
15	28.1	28.9	29.8	30.7	31.6	32.6	33.6	34.6	35.7	36.8	38.0	39.2	40.5	41.8	43.1	44.5	45.9	47.3	48.8	50.3	51.9
20	28.2	29.1	30.0	30.9	32.0	33.0	34.2	35.4	36.7	38.0 786 patients admitted to ICDDR'B hospital (2014)	39.4	40.8	42.3	43.9	45.5	47.2	49.0	50.8	52.7	54.6	56.6
25	28.4	29.3	30.3	31.4	32.5	33.7	35.0	36.4	37.9	39.5	41.1	42.8	44.6	46.5	48.4	50.5	52.6	54.8	57.1	59.4	61.9
30	28.8	29.7	30.8	32.0	33.3	34.7	36.2	37.8	39.4	41.2	43.1	45.1	47.2	49.4	51.7	54.1	56.6	59.2	62.0	64.8	67.7
35	29.2	30.3	31.5	32.8	34.3	35.8	37.5	39.3	41.3	43.3	45.5	47.8	50.3	52.8	55.5	58.3	61.2	64.2	67.4	70.6	74.0
40	29.7	30.9	32.3	33.8	35.4	37.2	39.1	41.2	43.4	45.8	48.3	50.9	53.7	56.6	59.6	62.8	66.2	69.6	73.3	77.0	80.9
45	30.3	31.7	33.2	34.9	36.8	38.8	41.0	43.4	45.9	48.5	51.3	54.3	57.5	60.8	64.2	67.9	71.6	75.6	79.7	83.9	88.4
50	31.0	32.6	34.4	36.3	38.4	40.7 62 people died over the country (2003)	43.1	45.8	48.6	51.6	54.8	58.1	61.7	65.4	69.3	73.3	77.6	82.0	86.6	91.4	96.4
55	31.9	33.7	35.6	37.8	40.2	42.7	45.5 3500 people died all over the country (2005)	48.5	51.6	55.0	58.5	62.3	66.2	70.4	74.7	79.2	84.0	88.9	94.0	99.4	104.9
60	32.8	34.8	37.1	39.5	42.2	45.1	48.1	51.4	55.0	58.7	62.6	66.8	71.2	75.8	80.6	85.6	90.9	96.3	102.0	107.9	114.0
65	33.9	36.2	38.7	41.4	44.4	47.6	51.0	54.7	58.6	62.7	67.1	71.7	76.5	81.6	86.9	92.4	98.2	104.2	110.4	116.9	123.6
70	35.0	37.6	40.4	43.5	46.8	50.3	54.2	58.2	62.5	67.1	71.9	77.0	82.3	87.8	93.6	99.7	106.0	112.6	119.4	126.4	133.7
75	36.3	39.2	42.3	45.7	49.4	53.3	57.5	62.0	66.7	71.8	77.0	82.6	88.4	94.5	100.8	107.4	114.3	121.4	128.8	136.5	144.4
80	37.7	40.9	44.4	48.1	52.2	56.5	61.2	66.1	71.3	76.8	82.5	88.6	94.9	101.5	108.4	115.6	123.0	130.8	138.8	147.1	155.7
85	39.1	42.7	46.6	50.8	55.2	60.0	65.1	70.4	76.1	82.1	88.3	94.9	101.8	108.9	116.4	124.2	132.2	140.6	149.3	158.2	167.5
90	40.7	44.7	49.0	53.5	58.4	63.7	69.2	75.1	81.2	87.7	94.5	101.6	109.0	116.8	124.9	133.2	141.9	150.9	160.2	169.9	179.8
95	42.4	46.8	51.5	56.5	61.9	67.6	73.6	80.0	86.6	93.7	101.0	108.7	116.7	125.1	133.7	142.7	152.1	161.7	171.7	182.1	192.7
100	44.2	49.0	54.2	59.7	65.5	71.7	78.2	85.1	92.4	99.9	107.9	116.1	124.8	133.7	143.0	152.7	162.7	173.0	183.7	194.8	206.2

*Based on available impact and observed weather data

8. Trigger and Thresholds

8.1 Heat Index

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[20]. While analyzing heat index data and its impact, we observed that the proposed threshold of 95th percentile by Nissan et al.[21] is quite high considering the impacts observed at that level (e.g., table 6). We further analyzed the below heat index and thresholds proposed by the International Centre for Diarrheal Disease Research, Bangladesh (ICDDR,B) (Fig. 2) below. The thresholds (caution, low danger, high danger and extreme danger) proposed by ICDDR,B also didn't exactly correspond with the impacts that were available (bold faces index value in heat index and table 6). In fact, impacts appear much earlier- from 35 °C to 39.5 °C and corresponding heat index of 38 to 45.5 for Dhaka. However, BMD has not developed any heat index-based heatwave forecast.

Humidity in % \ Temperature in °C	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5	28.3	29.1	29.9	30.7	31.5	32.3	33.1	33.9	34.7	35.5	36.3	37.1	37.9	38.7	39.5	40.2	41.0	41.8	42.6	43.3	44.1
10	28.1	28.9	29.8	30.6	31.5	32.3	33.2	34.1	35.1	36.0	37.0	38.0	39.0	40.0	41.1	42.1	43.2	44.3	45.4	46.6	47.7
15	28.1	28.9	29.8	30.7	31.6	32.6	33.6	34.6	35.7	36.8	38.0	39.2	40.5	41.8	43.1	44.5	45.9	47.3	48.8	50.3	51.9
20	28.2	29.1	30.0	30.9	32.0	33.0	34.2	35.4	36.7	**38.0**	39.4	40.8	42.3	43.9	45.5	47.2	49.0	50.8	52.7	54.6	56.6
25	28.4	29.3	30.3	31.4	32.5	33.7	35.0	36.4	37.9	39.5	41.1	42.8	44.6	46.5	48.4	50.5	52.6	54.8	57.1	59.4	61.9
30	28.8	29.7	30.8	32.0	33.3	34.7	36.2	37.8	39.4	41.2	43.1	45.1	47.2	49.4	51.7	54.1	56.6	59.2	62.0	64.8	67.7
35	29.2	30.3	31.5	32.8	34.3	35.8	37.5	39.3	41.3	43.3	45.5	47.8	50.3	52.8	55.5	58.3	61.2	64.2	67.4	70.6	74.0
40	29.7	30.9	32.3	33.8	35.4	37.2	39.1	41.2	43.4	45.8	48.3	50.9	53.7	56.6	59.6	62.8	66.2	69.6	73.3	77.0	80.9
45	30.3	31.7	33.2	34.9	36.8	38.8	41.0	43.4	45.9	48.5	51.3	54.3	57.5	60.8	64.2	67.9	71.6	75.6	79.7	83.9	88.4
50	31.0	32.6	34.4	36.3	38.4	**40.7**	43.1	45.8	48.6	51.6	54.8	58.1	61.7	65.4	69.3	73.3	77.6	82.0	86.6	91.4	96.4
55	31.9	33.7	35.6	37.8	40.2	42.7	**45.5**	48.5	51.6	55.0	58.5	62.3	66.2	70.4	74.7	79.2	84.0	88.9	94.0	99.4	104.9
60	32.8	34.8	37.1	39.5	42.2	45.1	48.1	51.4	55.0	58.7	62.6	66.8	71.2	75.8	80.6	85.6	90.9	96.3	102.0	107.9	114.0
65	33.9	36.2	38.7	41.4	44.4	47.6	51.0	54.7	58.6	62.7	67.1	71.7	76.5	81.6	86.9	92.4	98.2	104.2	110.4	116.9	123.6
70	35.0	37.6	40.4	43.5	46.8	50.3	54.2	58.2	62.5	67.1	71.9	77.0	82.3	87.8	93.6	99.7	106.0	112.6	119.4	126.4	133.7
75	36.3	39.2	42.3	45.7	49.4	53.3	57.5	62.0	66.7	71.8	77.0	82.6	88.4	94.5	100.8	107.4	114.3	121.4	128.8	136.5	144.4
80	37.7	40.9	44.4	48.1	52.2	56.5	61.2	66.1	71.3	76.8	82.5	88.6	94.9	101.5	108.4	115.6	123.0	130.8	138.8	147.1	155.7
85	39.1	42.7	46.6	50.8	55.2	60.0	65.1	70.4	76.1	82.1	88.3	94.9	101.8	108.9	116.4	124.2	132.2	140.6	149.3	158.2	167.5
90	40.7	44.7	49.0	53.5	58.4	63.7	69.2	75.1	81.2	87.7	94.5	101.6	109.0	116.8	124.9	133.2	141.9	150.9	160.2	169.9	179.8
95	42.4	46.8	51.5	56.5	61.9	67.6	73.6	80.0	86.6	93.7	101.0	108.7	116.7	125.1	133.7	142.7	152.1	161.7	171.7	182.1	192.7
100	44.2	49.0	54.2	59.7	65.5	71.7	78.2	85.1	92.4	99.9	107.9	116.1	124.8	133.7	143.0	152.7	162.7	173.0	183.7	194.8	206.2

Symbol	Heat Index	Danger Level
(green)	<41	Caution
(yellow)	41-47.9	Low Danger
(orange)	48-53	High Danger
(red)	> 53	Extreme Danger

Figure 2: Proposed heat index threshold by ICDDR'B

The impact, considering the available source and matched with the proposed heat index proposed by ICDDR,B, it is found that the impact starts even below the low danger level. Then we tried to investigate the other factors which may govern the impact and we found urban heat islands may be one of the factors influencing the impact of the heatwave. Based on the hypothesis that heat island aggravates the

[20] https://www.weather.gov/safety/heat-index

[21] Nissan, H., Burkart, K., Coughlan de Perez, E., Van Aalst, M., & Mason, S. (2017). Defining and predicting heatwaves in Bangladesh. Journal of Applied Meteorology and Climatology, 56(10), 2653-2670.

heatwave situation, we tried to find out the impact of heat island on the heatwave. It is explained below.

8.2 Heat Island

Heat island also termed as Urban Heat Island (hereafter UHI) are the places or areas that have higher heat/temperature than surrounding areas. UHI generally occur in urban areas where heat is trapped because of lower transpiration[22]. To identify the urban heat islands, we first calculated the land surface temperature (LST) of Dhaka from satellite imageries (see annexure for details of LST calculation) and used the equation mentioned below.

$$UHI = LST > \mu + \frac{\sigma}{2}$$

Where, μ is the mean and σ is the standard deviation of LST.

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

$$UHI = LST > \mu + \sigma$$

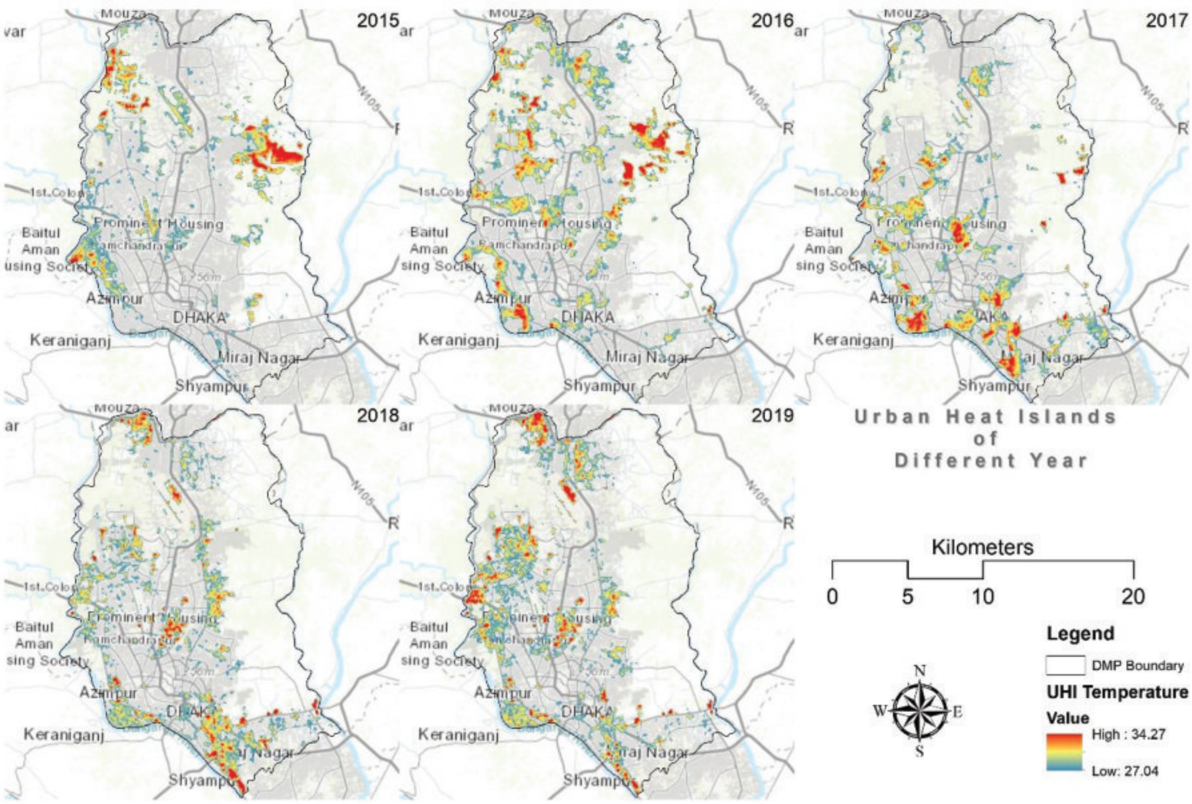


Figure 3: Spatio-temporal distribution of urban heat island (UHI)

[22] https://climatekids.nasa.gov/heat-islands/

From figure 4 below shows the aggregated heat islands of three years (2017-2019). Further, it is then superimposed with the slums in the city. The resultant figure, as shown in figure 4, is the distribution of slums in the aggregated Urban Heat Islands in Dhaka. The upcoming pilot on heatwave early action in Dhaka City will be selected amongst those areas.

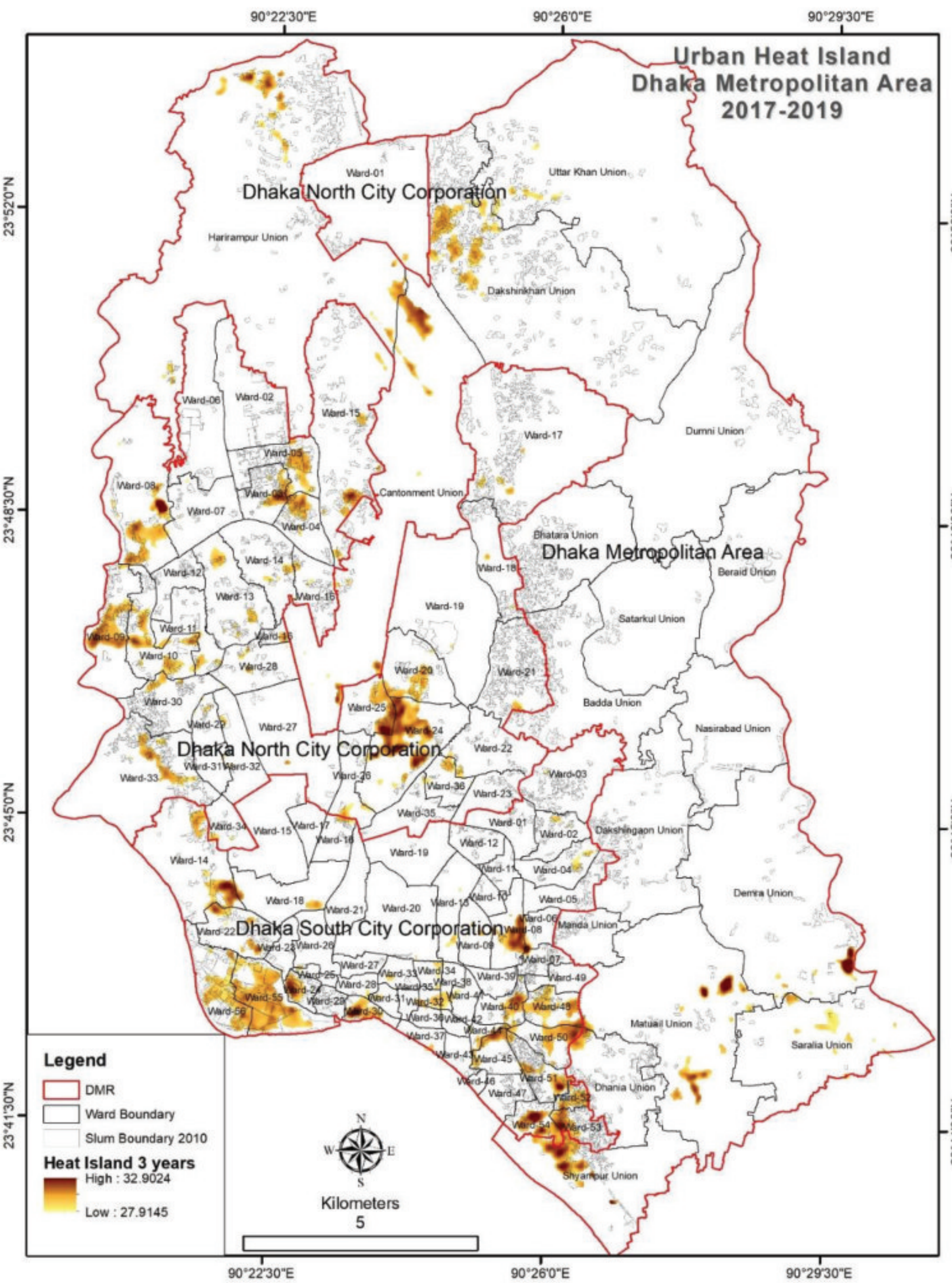


Figure 4: Heat Island with Ward Boundary in Dhaka Metropolitan Area

8.3 Heat Island Effect

It has been found from recent studies that surface temperature is 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 United States, the 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 higher temperature differences in humid regions and in cities with larger area and denser populations. The urban heat island effect is expected to aggravate in the future as the structure, spatial extent, and population density of urban areas is growing[23]. On a hot, sunny summer day, roof and pavement surface temperatures can be higher than the air[24]. Because of the impervious surface and/or higher reflection of the roof the temperature starts rising as it is trapped in those areas. So, people who work outdoor/on the ground, roof, or on the road and those groups of people who live in slums or on the street are most exposed to the UHI effects.

To calculate the UHI effect, we compared the difference in the ambient temperature (BMD observed data) and the land surface temperature (LST). For this purpose, we used the Landsat 5 TM sensor and Landsat 8 OLI-TIRS sensor imageries of 12 different dates from 1990 to 2016. All images were taken by the sensor around 10 AM of the respective day. We calculated the LST for each of the images. We also derived 3 hours interval air temperature from BMD data for the same dates and used the maximum observed temperature in those three hours (between 9 AM to 12 AM). Then we subtracted the air temperatures from LST and calculated the mean and standard deviation of the differences; as shown in table 7.

To get a higher level of accuracy we calculated UHI adding the full standard deviation with mean, and we subtracted half of the standard deviation from the mean of differences between LST and air temperature. The equation is as follows -

$$UHI\ Effect = \Delta\mu - \frac{\Delta\sigma}{2}$$

Here, $\Delta\mu$ is the mean of the differences and $\Delta\sigma$ is the standard deviation of the differences.

Table 7: Urban heat island (UHI) effect calculation

Year	Maximum LST	Air Temperature	Differences
04/29/1990	32.47	30.20	2.27
04/01/1995	31.25	32.40	-1.15
03/10/2001	35.66	30.40	5.26
03/02/2004	38.02	30.00	8.02
04/25/2006	37.24	32.80	4.44
03/27/2007	43.36	33.60	9.76
04/14/2008	33.27	31.90	1.37
04/01/2009	31.25	29.60	1.65
04/07/2011	37.63	32.20	5.43
03/30/2014	44.73	36.20	8.53
03/17/2015	34.27	32.10	2.17
04/20/2016	33.07	32.50	0.57
Average/Mean ($\Delta\mu$)			4.03
Standard Deviation ($\Delta\sigma$)			3.30
UHI Effect (To be added with air temperature)			2.38

*See annexure for LST map

[23] Hibbard, K.A., F.M. Hoffman, D. Huntzinger, and T.O. West. 2017. Changes in land cover and terrestrial biogeochemistry. In Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC. pp. 277–302. doi: 10.7930/J0416V6X

8.4 Impact Based Heat Index

As discussed in section 7, anecdotal evidence shows, health impacts of temperature starts much earlier than the thresholds proposed by Nissan et al and ICDDR,B. Moreover, these thresholds have not taken into account the UHI, which is one of the key aggravating factors. Hence, to activate heatwave early actions in Dhaka, we developed thresholds using the following method:

- Calculated the heat index with temperatures and humidity at which earlier impacts were observed. (Section 7, table 6) [without UHI effect]

- For the same impacts, we calculated the heat index by incorporating UHI effect on the air temperature. [With UHI effect]

- Calculated the difference in heat index with UHI effect and without UHI effect to calculate the mean of difference (table 8).

Table 8: Impact of UHI on heat index[25]

Parameter		Impact	
Temperature in ^{0}C	39	36	35
Humidity in %	20	55	50
Heat Index	37.99	45.51	40.68
Heat Index (with UHI effect)	41.39	52.88	46.83
Difference	3.4	7.37	6.15
Mean of Difference		5.64	

*Based on previous impact data

- Thereafter, we subtracted the mean of differences from ICDDR,B proposed thresholds (Fig. 2) to constitute the threshold for piloting forecast-based early action for the heatwave in Dhaka. The following figure is the heat index threshold that we are proposing for the pilot.

[25] This table is based on the three-impact data that was available to find out the impact of UHI on heatwaves

Humidity in %	Temperature in °C																				
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5	28.3	29.1	29.9	30.7	31.5	32.3	33.1	33.9	34.7	35.5	36.3	37.1	37.9	38.7	39.5	40.2	41.0	41.8	42.6	43.3	44.1
10	28.1	28.9	29.8	30.6	31.5	32.3	33.2	34.1	35.1	36.0	37.0	38.0	39.0	40.0	41.1	42.1	43.2	44.3	45.4	46.6	47.7
15	28.1	28.9	29.8	30.7	31.6	32.6	33.6	34.6	35.7	36.8	38.0	39.2	40.5	41.8	43.1	44.5	45.9	47.3	48.8	50.3	51.9
20	28.2	29.1	30.0	30.9	32.0	33.0	34.2	35.4	36.7	**38.0**	39.4	40.8	42.3	43.9	45.5	47.2	49.0	50.8	52.7	54.6	56.6
25	28.4	29.3	30.3	31.4	32.5	33.7	35.0	36.4	37.9	39.5	41.1	42.8	44.6	46.5	48.4	50.5	52.6	54.8	57.1	59.4	61.9
30	28.8	29.7	30.8	32.0	33.3	34.7	36.2	37.8	39.4	41.2	43.1	45.1	47.2	49.4	51.7	54.1	56.6	59.2	62.0	64.8	67.7
35	29.2	30.3	31.5	32.8	34.3	35.8	37.5	39.3	41.3	43.3	45.5	47.8	50.3	52.8	55.5	58.3	61.2	64.2	67.4	70.6	74.0
40	29.7	30.9	32.3	33.8	35.4	37.2	39.1	41.2	43.4	45.8	48.3	50.9	53.7	56.6	59.6	62.8	66.2	69.6	73.3	77.0	80.9
45	30.3	31.7	33.2	34.9	36.8	38.8	41.0	43.4	45.9	48.5	51.3	54.3	57.5	60.8	64.2	67.9	71.6	75.6	79.7	83.9	88.4
50	31.0	32.6	34.4	36.3	38.4	**40.7**	43.1	45.8	48.6	51.6	54.8	58.1	61.7	65.4	69.3	73.3	77.6	82.0	86.6	91.4	96.4
55	31.9	33.7	35.6	37.8	40.2	42.7	**45.5**	48.5	51.6	55.0	58.5	62.3	66.2	70.4	74.7	79.2	84.0	88.9	94.0	99.4	104.9
60	32.8	34.8	37.1	39.5	42.2	45.1	48.1	51.4	55.0	58.7	62.6	66.8	71.2	75.8	80.6	85.6	90.9	96.3	102.0	107.9	114.0
65	33.9	36.2	38.7	41.4	44.4	47.6	51.0	54.7	58.6	62.7	67.1	71.7	76.5	81.6	86.9	92.4	98.2	104.2	110.4	116.9	123.6
70	35.0	37.6	40.4	43.5	46.8	50.3	54.2	58.2	62.5	67.1	71.9	77.0	82.3	87.8	93.6	99.7	106.0	112.6	119.4	126.4	133.7
75	36.3	39.2	42.3	45.7	49.4	53.3	57.5	62.0	66.7	71.8	77.0	82.6	88.4	94.5	100.8	107.4	114.3	121.4	128.8	136.5	144.4
80	37.7	40.9	44.4	48.1	52.2	56.5	61.2	66.1	71.3	76.8	82.5	88.6	94.9	101.5	108.4	115.6	123.0	130.8	138.8	147.1	155.7
85	39.1	42.7	46.6	50.8	55.2	60.0	65.1	70.4	76.1	82.1	88.3	94.9	101.8	108.9	116.4	124.2	132.2	140.6	149.3	158.2	167.5
90	40.7	44.7	49.0	53.5	58.4	63.7	69.2	75.1	81.2	87.7	94.5	101.6	109.0	116.8	124.9	133.2	141.9	150.9	160.2	169.9	179.8
95	42.4	46.8	51.5	56.5	61.9	67.6	73.6	80.0	86.6	93.7	101.0	108.7	116.7	125.1	133.7	142.7	152.1	161.7	171.7	182.1	192.7
100	44.2	49.0	54.2	59.7	65.5	71.7	78.2	85.1	92.4	99.9	107.9	116.1	124.8	133.7	143.0	152.7	162.7	173.0	183.7	194.8	206.2

Symbol	Heat Index	Danger Level
	<35	Caution
	35 - 38	Low Danger
	>38 - 42	Medium Danger
	> 42 - 47	High Danger
	> 47	Extreme Danger

Figure 5: Proposed heat index thresholds (with UHI effect)

8.5 Stages of Triger for Activation of Early Action

We have identified three heat index thresholds- 38, 42, and 47 for medium, high and extreme heatwaves respectively. As shown in table 6, the health impacts of heatwaves start at a heat index of 38°C. Therefore, we have chosen this particular threshold to pilot forecast-based early actions in Dhaka. However, temperature below 36 degrees centigrade will not be considered (even if the heat index reaches 38°C or higher).

Two stages of trigger have been proposed here: (i) Pre-activation – targeted behavioural change communication and readiness for field intervention; and (ii) activation – activate EAP. The criteria and lead time of each stage of triggers are described in table 9.

Table 9: Stage of Trigger for activate EAP

	Pre-activation/Readiness	Activation
Lead time	10 days	5 days (actual 4 days)
Criteria	Source: ECMWF and GFS global model Forecast: Temperature will cross 37^o Celsius and heat index will cross 38 and remain for 2 or more consecutive days.	Source: BMD WRF model 9 km resolution Forecast: Temperature will cross 37^{o}C or heat index will cross 38. For both cases, the condition will remain for 2 or more consecutive days.
Activities	Mobilize resources and proceed with procurements, Awareness Raising and Behavior Change Communication (ABC), volunteer training	Implementation of Early Actions (for pilot phase - 50 hawkers in 1 or 2 spots, 100 rickshaw pullers and 300 students)

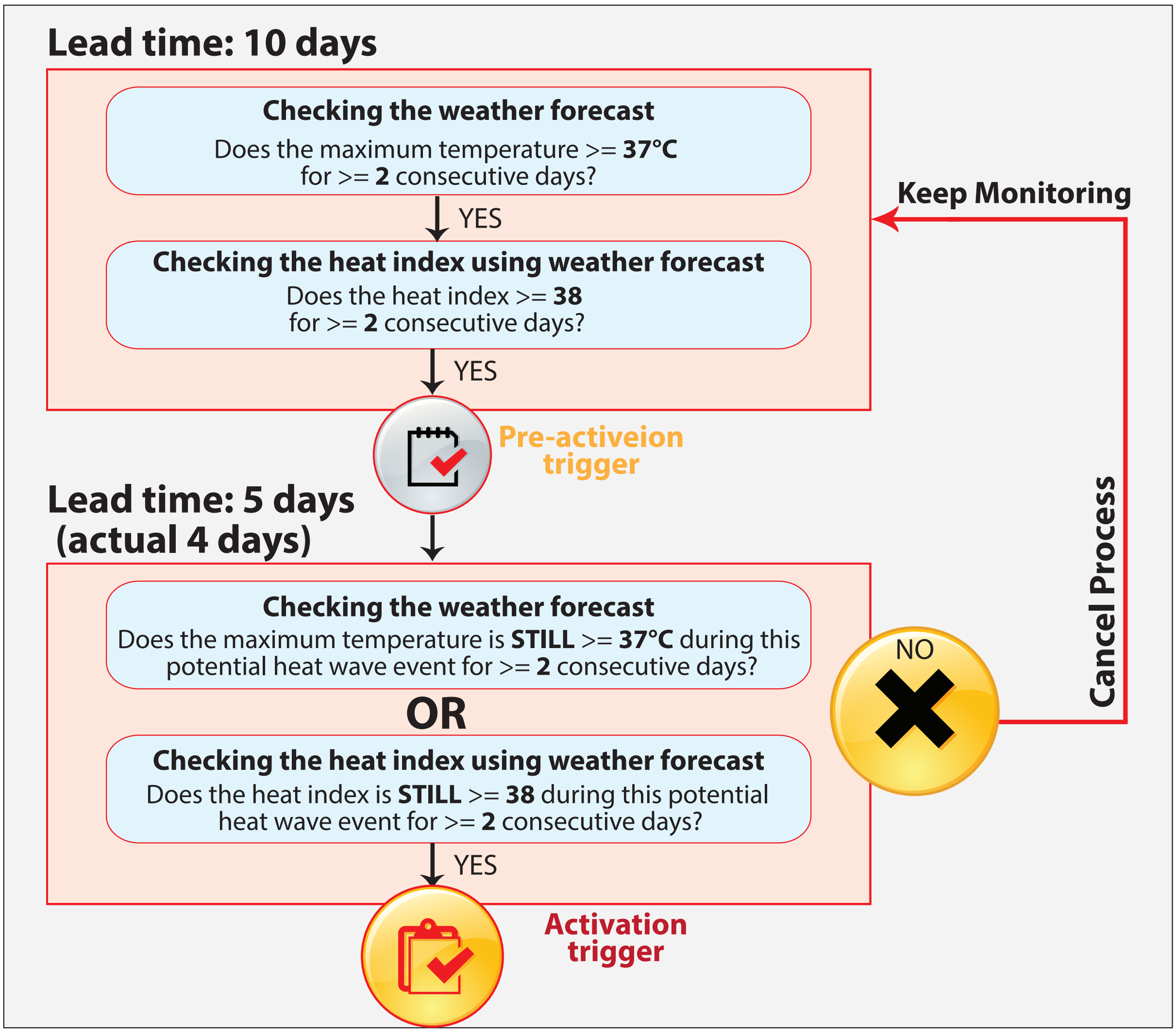


Figure 6: Proposed trigger protocol for heatwave

9.0 Impacts of heatwave and needs of most vulnerable communities

This part of the report analyses the data on the impacts of heatwaves and the needs of the vulnerable community that was collected from Dhaka city. It proposes early actions to support the vulnerable families reduce the impact of the heatwave. The data was collected through Focus Group Discussions (FGD), Key Informant Interviews (KIIs), survey with 400 respondents, including rickshaw pullers, pedestrians, hawkers, slum dwellers, Government officials, pharmacy owners, doctors.

9.1 Data Collection Methods

A total of 20 BDRCS RCY volunteers were trained on data collection through KoBo using mobile to collect survey data. A total of 400 respondents were interviewed (100 representing each group-rickshaw/van puller, hawker, construction worker and pedestrian). For each group, 80 respondents were interviewed on their experience with heatwaves whereas 20 respondents with general information for comparison. This survey helped to gather some data on heatwaves and analyze the data to find out information on heatwave impact on the community, life and livelihood of people due to heatwaves and to identify possible interventions to reduce their vulnerability.

9.2 People who are disproportionately affected by heatwave

Heatwaves are most likely to affect people who work or live outdoors. The heatwave affects people especially who work outside (rickshaw puller, van puller, street hawkers, construction workers, agriculture labourers), children and elderly people because of their age and dependency and slum dwellers as slum area are overpopulated and congested.

Being under the sun or in an area with little air movement, can increase the apparent temperature, and thus increase the risk for adverse effects from the heat and humidity.

With the same temperature and humidity, people from the same town might get affected disproportionately depending on various factors. Some of the reasons for being affected disproportionately are -

- Financial capacity
- Occupational pattern
- Living condition
- Age & Dependency

9.3 Heat islands in Dhaka City

The Land Surface Temperature (LST) maps show that there are a few pockets where the calculated LST is higher than the surrounding areas. The comparison between the LST maps and earth imagery shows higher temperatures in the areas with high built-ups. Badda, Gulshan, Kamrangirchar, Mirpur, Gabtoli, Goran, Bashabo, Tongi, Sahid Nagar, Babubazar, Postogola, Zurain, Hazaribagh, Jatrabari, Saydabad, Kurmitola, Azampur, Uttara, Kamarpara, Mohammadia housing area, Adabar, Farmgate, Tejkunipara, Nakhalpara, Mohakhali, etc. areas show high-temperature value (29-34.5˚C) on average. Through the analysis, the identified average urban heat island (UHI) effect for Dhaka city is 2.38 ˚C. This is to consider that the satellite image was from 2015 to 2019 and was not representing the exact time of the heatwave as the satellite passed over Bangladesh a few days ahead of the heatwave.

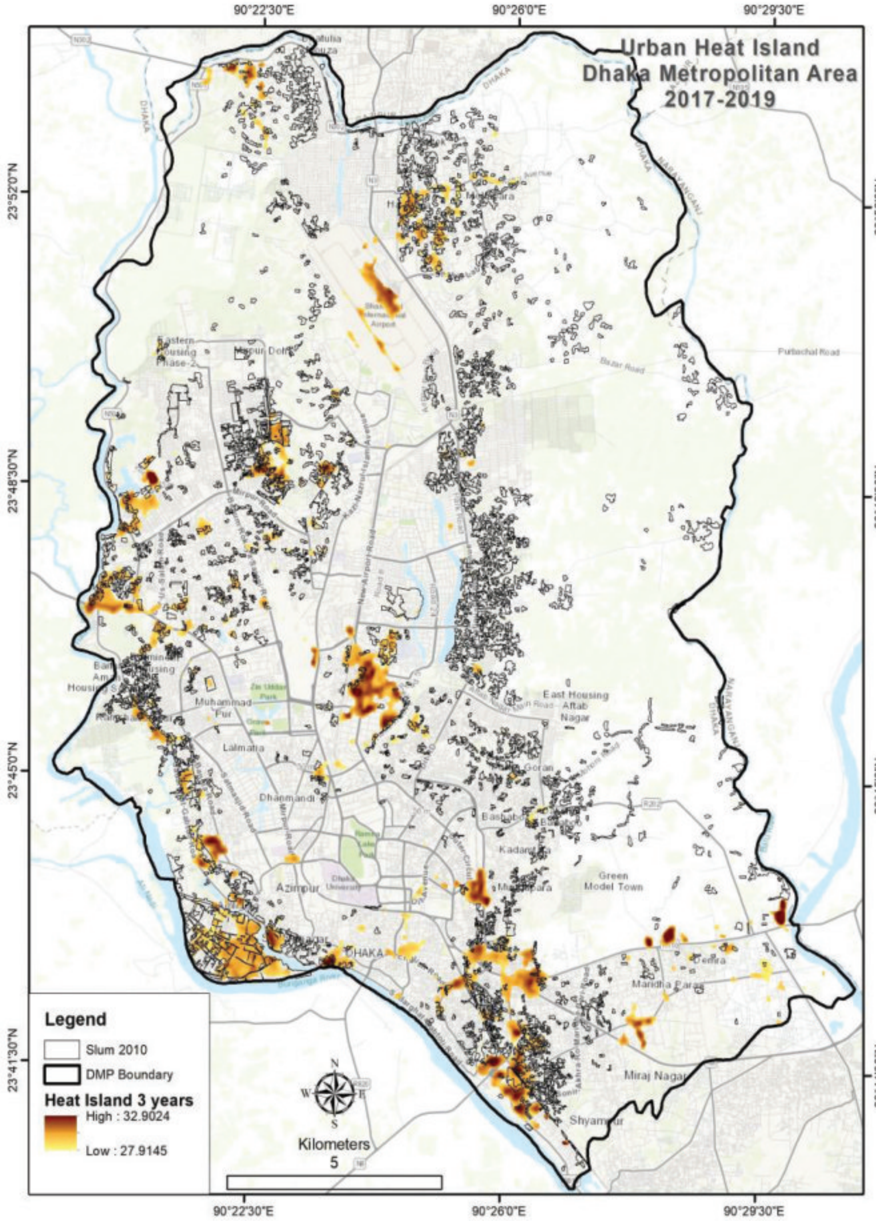


Figure 7: Urban heat island intersect of Dhaka city in 2015 - 2019

9.4 Exposed and vulnerable population- interaction between exposed and vulnerable elements/ population/ segment

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, low height of the roof, housing material, increased load shedding, lack of accessibility to the proper health care system, lack of greenery, low income, the unhygienic living condition makes them most vulnerable to heatwaves.

In the FGD, people mentioned how they try to cope with excessive heat or heatwaves. 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, often wipe their body with wet cloths. Some of them take showers several times a day. Those who have shops, close their shop between 12:00 pm to 3:00 pm due to extreme heat. Rickshaw and van pullers also avoid working during these hours.

While interacting with the community people, some of the major findings are-

- Health impact: People in the community mentioned skin disease, fever, cold, heat stroke, fatigue, an increase of water-borne diseases (diarrhoea, cholera etc.), dehydration, respiratory problems during
- Impact on working hours and income: Impacting daily income of labourer/rickshaw/van puller group due to loss of working hours. Most of the respondents of this group mentioned that they are forced to skip work between 12:00 pm to 3:00 pm due to excessive heat outside
- Increase in 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 get highly vulnerable to catch fire and it increases fire incidence in slum areas. Excessive temperature helps the fire get spread rapidly 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 heatwaves their sell of IV saline and oral saline increases by almost three times than the regular sell which verify the statement of the community people of getting affected by diarrhoea/cholera during heatwaves and increased health expenditure.

According to doctors on duty at the emergency wing/department from different hospitals, during heatwaves, they mostly receive adult patients from the streets as parents are protective about kids going out during excessive heat. Most of the heatwave related patients belong to lower-income groups of the society. Usually, the patients came to the hospitals with symptoms of heat exhaustion and dehydration. The number of patients with heat stroke is low.

9.5 Heat stress vis-à-vis livelihoods and other aspects of social life

Heatwaves have different types of impacts on the human body and mind. This can adversely impact the life and livelihood of people who are exposed to heatwaves. Heat stroke, for example, affects not only health but also economic productivity at the individual level, particularly in low-income groups who are daily labourers. 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.[26]

Heat stress-induced severe health related issues have been increasing. School going children have reported cases of fainting, vomiting, fatigue. The spreading of Diarrhea and Cholera increases due to the

[26] Rabbani, GOLAM & Rahman, Atiq & Islam, Nazria. (2011). Climate Change Implications for Dhaka City: A Need for Immediate Measures to Reduce Vulnerability. Resilient Cities: Cities and Adaptation to Climate Change - Proceedings of the Global Forum 2010. Local Sustainability.

consumption of unhygienic drinks while the heatwave is spurring on the heat islands. Though heat stress does not directly cause Diarrhea and Cholera, these are the consequence of extreme heat that people are suffering. Another most common heat-related disease is skin disease. During summer the outbreak of skin diseases is another most common heat-related problem.

9.6 Survey Analysis Output

The survey data were analyzed to develop a baseline of FbF response for heatwaves. Key findings are:

- 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 'heatwave' refers to.
- The rickshaw/van pullers travel 7-8 km of distance on an average from their garage (surveyed rickshaw/van pullers are working on an average of 8.5 years).
- The average working hours for a rickshaw puller is 10 hours/day and their average income is BDT 650 – 700 per day.
- During the heatwave of a particular year, people fell sick and couldn't go to work for about 3.27 days on average.
- Around 3.12 Hours have been lost due to heat exhaustion.
- Around 82.81% of respondents said that their healthcare expenses increase by BDT 535 on an average.

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. About 81% of the respondents said that their healthcare expenditure increases in summer due to more frequent illnesses.

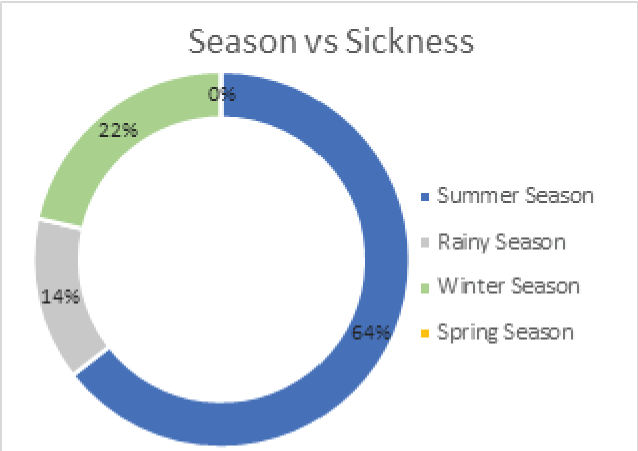


Figure 8: Season wise sickness percentage for the respondents

All these respondents were asked general questions not specified to the heatwave. 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 heatwave and their income and health expenditure. We also tried to find out if any early action could reduce the impact on their livelihood and health during the heatwave. According to the respondents, they lose about 2.87 hours (average) daily in the summer season from their working hours due to heatwave which led to the losses of their income, or they had to work additional hours to make up for their daily loss of income. The following figure shows the reduction of income due to work hours loss for those respondents (n=105, of the total 320 respondents) who reported the loss of their daily income during the heatwave in the survey.

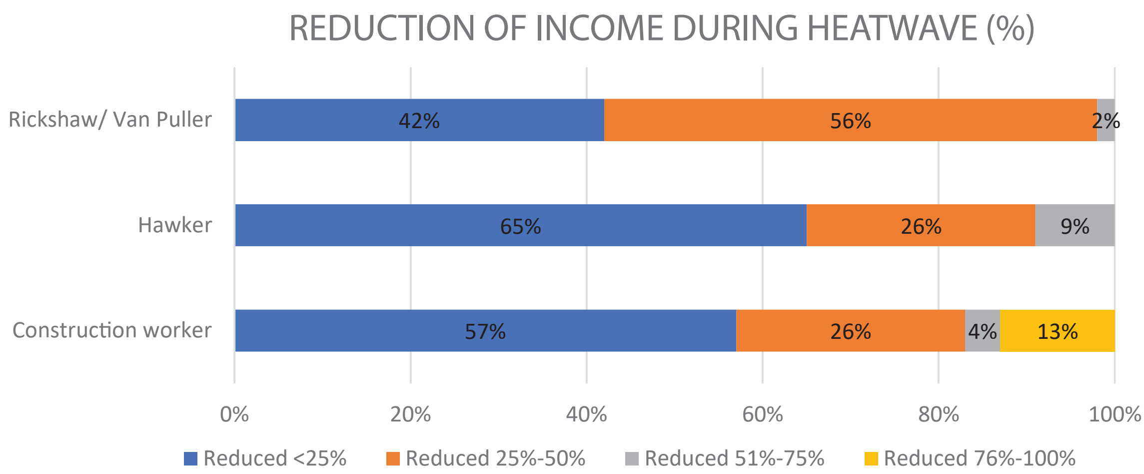


Figure 9: Percentage of reduction of income of different respondent group during heatwave

The figure shows that among the rickshaw pullers who reported a loss of their daily income, 42% of them lost less than 25 %, 56% lost 25-50% and 2% lost 51-75% of their daily income. Similarly, Hawkers and Construction workers also reported about the percentage of daily income losses during the summer season due to heat stress. For construction workers, 13 % of them sometimes had to face a total of 76-100% loss of their daily income.

The construction workers are mostly paid daily based on their regular attendance and assigned tasks. They also need to work extra hours to cover the task that they missed during noon or while resting to save themselves from the heatwave. Working extra hours to cover their daily income takes a toll on different working groups by impacting their health due to workload. Among the 320 respondents, 216 people said that they face health problems during heatwave/summertime. People mentioned cold, fever-induced from heat and excessive sweating and dehydration. The following chart gives an overview of health-related problems mentioned by respondents from different occupational groups.

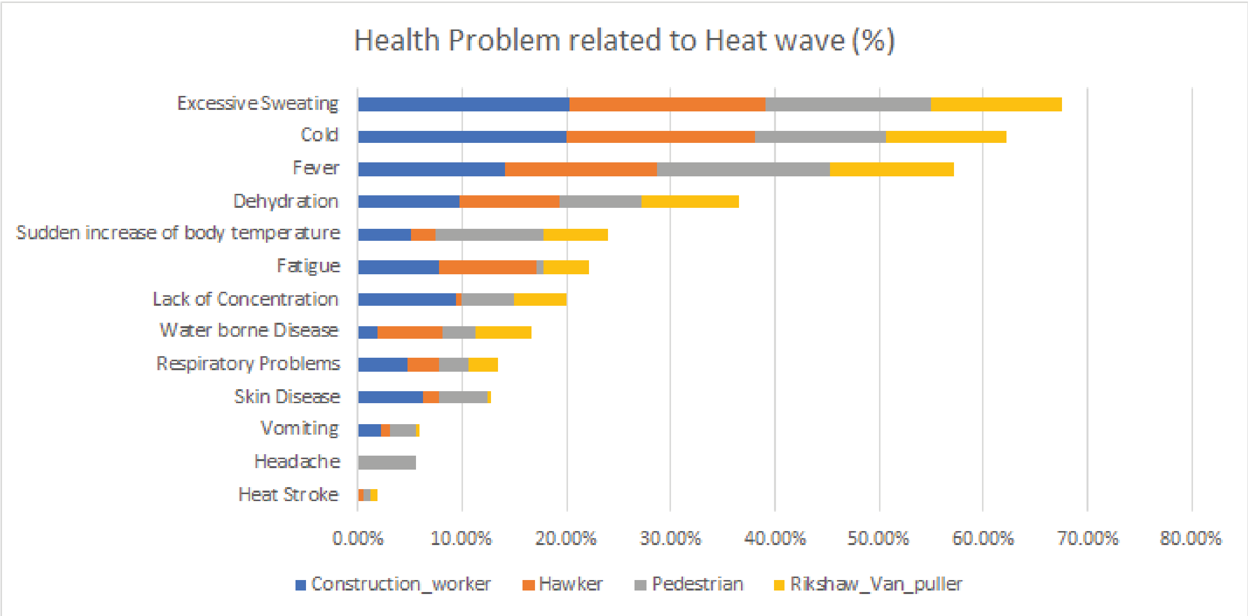


Figure 10: Health problem related to heatwave (%)

About 83% of the total respondents (n=320) from the study group said that their expenditure for healthcare increases during the summer season for different health issues. The following diagram shows the percentage of respondents who have said that their medical expenditure for themselves and for their family has increased (for both visiting doctors and purchasing medicine) who are using different means to cover that additional expenditure which includes loan, reduction of other family expenditure, spending their savings, increasing working hours for additional income, getting involved with other income generation activities etc. Most of the respondents spend the little savings that took them months to save.

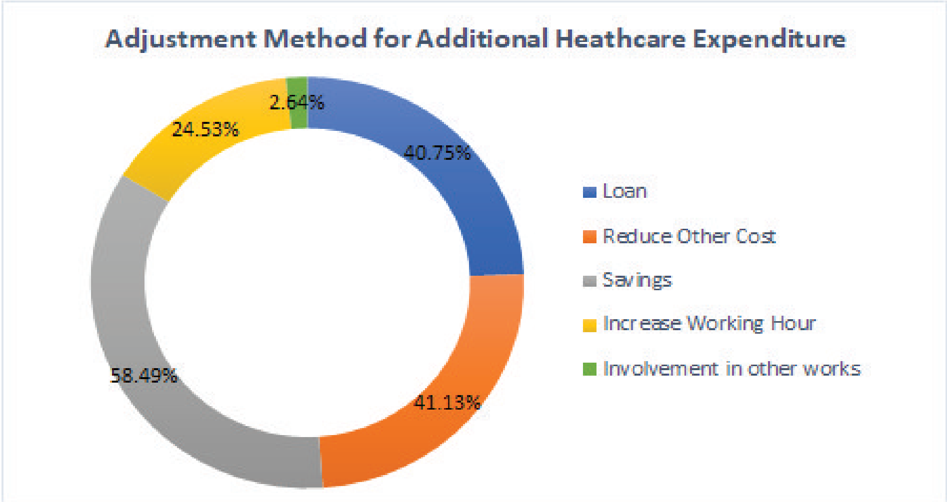


Figure 11: Way to adjust additional healthcare expenditure

Most of the respondents do take some initiative by themselves to protect themselves during hot summer. Most of the respondents from all groups do prefer drinking water and taking rest in areas with shades or under trees. They do use their Gamcha (locally made towel) to cover their head and wipe themselves when sweating. In the analysis, it was found that most of the respondents who mentioned visiting doctors/taking medicine during a heatwave are the ones not taking any or most of those above-mentioned initiatives. Only 9.26% of respondents who are visiting the doctor/taking medicine drink water and take rest but none of them use umbrellas or caps to protect them from the scorching sun while working. Around 26% of the respondents among the same group drink water but they do not take rest or use anything to cover their head. Which can prove that drinking more water, resting in a shed, using an umbrella/cap to cover their head etc. helps them protect themselves from the direct health impact of heatwaves and which could lead to less sickness, less health expense and less loss of income due to work hour loss.

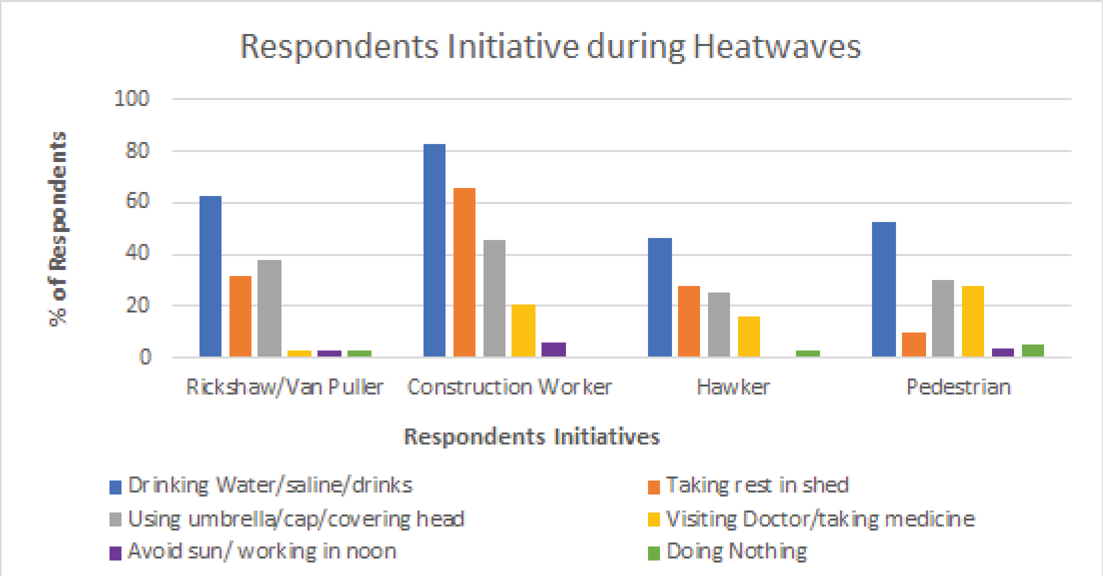


Figure 12: Respondents personal initiatives to protect themselves during heatwaves

In the survey the respondents of different groups also identified the assistance they require to overcome the additional cost and the burden incurred because of their additional expenditure. Around 64% of the total respondents (n=320) require assistance to access pure drinking water during heatwaves. Around 51.25% of total respondents mentioned that they require umbrella, cap and towel to cover their heads and protect them from direct sunlight while working. Apart from this assistance, some of the respondents also mentioned opportunities for alternate livelihood and options to return back to their village with some source of income. The below chart gives an overview of assistance required by different working groups and pedestrians.

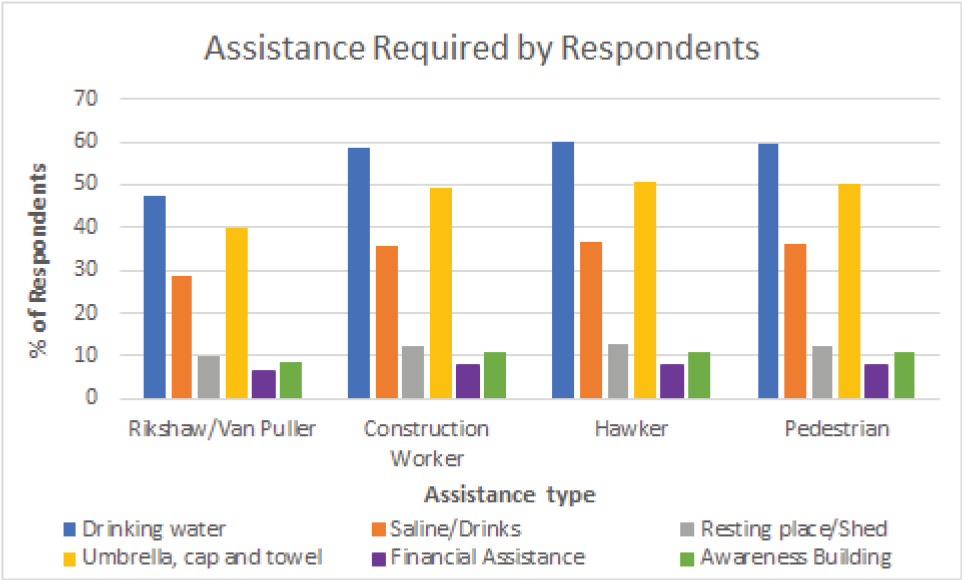


Figure 13: Type and percentage of assistance required by different groups

The respondents from different groups provided information on what they require if they want to reduce the loss of income due to work hour loss, sickness and cover additional expenditure on health services. Their response on required items identified early action interventions for different working groups and pedestrians as part of FbF intervention. Based on their response FbF proposed certain early actions for a heatwave.

9.7 Proposed Early Actions for Heatwave

Considering the health and other social and financial impact people are facing in areas affected by heatwaves and the recommendation made by the respondents during the survey, FbF team came up with possible early actions for a heatwave. Early actions could be taken in two stages – pre-activation and activation.

9.7.1 Pre-activation Stage and Preparedness Action

Volunteer Orientation: Around 50 RCY volunteers will be oriented just after receiving the pre-activation alert. After the orientation, the volunteer will support the FbF team for beneficiary and implementation of early action etc.

Beneficiary Selection: For the piloting of FbF in a heatwave the beneficiary will be selected based on identified intervention areas of Dhaka South City Corporation (DSCC) to ensure the effectiveness of selected early actions in the community during a heatwave. For rickshaw/van pullers, the beneficiary will be from a selected garage of Dhaka South City Corporation (DSCC). Another intervention group will be hawkers and the identified hawkers for the interventions are those in the temporary marketplaces approved by the DSCC in the context of COVID-19.

Awareness: Awareness will ensure the effective implementation of the pilot. Awareness activities will include-

- Orientation for the RCY volunteers
- Orientation for the beneficiaries
- Distribution of communication materials with heatwave awareness information

Resource Need: Considering the intervention area and size, the number of distribution materials and human resources will be finalized.

9.8 Activation Stage and Early Action

Resource Allocation and Distribution: Based on budget and pre-selected areas, resources will be allocated to ensure proper and timely implementation of early actions. On reaching the triggers, distributions will be made and/or cooling facilities will be installed in agreed locations.

Post Distribution Monitoring (PDM): After the completion of early actions, a PDM will be conducted to identify the effectiveness of FbF early actions in the communities. Based on the findings of the PDM, BDRCS/GRC will develop the EAP and other related documents and plans for further scale-up and implementation.

Table : Heatwave Early Action Plan

Where	Who	Interventions		Partner	Selection Logic	Remarks
		Preparedness	Activation			
Slum (Tentatively Wared no. 40, 45, 50-55 and 58 of DSCC)	Rickshaw/ Van puller (Garage based)	Beneficiary selection, Awareness building, preparing health care workers and facilities, Resource allocation	Awareness building, Distribution (drinking water, Saline, Cap, Umbrella, Portable fan) Provisioning cash grants (MPCG) for the rickshaw/Van puller	Local NGO, BRAC, Dhaka North City Corporation, Slum Association, Forecasting Agencies, Ministry of Public Health, BDRCS (Health, Y&V, DR), Media	Suggested by FbF team and DSCC. (According to Slum List Provided by DSCC).	• We can take two different garages with two different intervention packages to identify the differences in impacts. • We can select one control group and one experimental group (intervention area) for comparison. • Need to identify criteria's for rikshaw/van puller who will be eligible for a cash grant
	Students (School-based)	Beneficiary selection, Awareness building, preparing health care workers and facilities, Resource allocation, ventilation/air cooler (in a specific room)	Awareness building, painting the roof, Distribution (drinking water, saline, cap, umbrella),	Students, teachers, School Management Committee, Department of Education, BRAC	Identify the schools/education centres at the most vulnerable/slums locations	• We can take two different schools with two different intervention packages to identify the differences in impacts. • We can select one control group and one experimental group (intervention area) for comparison. • Need to consider gender perspective where possible

Market Place	Hawkers	Beneficiary selection, Awareness building, preparing health care workers and facilities, Resource allocation, cooling corner (in a specific room)	Awareness building, Distribution (drinking water, Saline, Cap, Umbrella, Portable fan), Waterpoint, Jerry Can be supplied water, Shed	Forecasting Agencies, Hawkers association, Dhaka Medical College Hospital, DSCC, BDRCS (Health, Y&V, DR), Ministry of Public Health, Media etc.	Many people visit this area, different hawkers, crowd, open street market	We won't go for random people as we need feedback from them after completion of the piloting to analyze the feasibility.
Open Street	Pedestrian, Rickshaw/ van Puller, Hawkers	Beneficiary selection, Awareness building, preparing health care workers and facilities, Resource allocation	Awareness building, Distribution (drinking water, Saline, Cap, Umbrella, Portable fan), Waterpoint, Jerry Can be supplied water, shed (Using Gas/Fuel pumps)	Forecasting Agencies, City Corporation Authority, BDRCS (Health, Y&V, DR), Ministry of Public Health, Media etc.		• Advocating WASA for safe drinking water, especially ensuring the quality of supply water or installation of drinking water substitutions for the street people • We can go for random beneficiaries here but getting feedback from them after completion of the piloting to analyze the feasibility will be challenging here.

Table : Timeline for FbF Early Action on Heatwave

Sl No	Activities	Timeline (Day)																				
		-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
1	Preparedness Alert																					
1.1	General Alert	■																				
1.2	Alert sharing						■															
1.3	Coordination within BDRCS	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.4	Communication with relevant vendor and stakeholders		■	■	■	■	■	■	■	■	■											
1.5	Volunteer Orientation						■	■														
1.6	Beneficiary Selection/communication with selected beneficiary							■	■													
1.7	Awareness building								■	■												
1.8	Initiate Procurement procedure		■																			
1.9	Procurement completed and item received									■	■											
1.10	Awareness building							■	■	■	■											
2	Activation of Early Action																					
2.1	Activation and coordination									■												
2.2	Distribution for Pedestrian (drinking water, Saline, Cap, Umbrella, Portable fan)											■	■	■	■	■						
2.3	Distribution for pre-selected community (drinking water, Saline, Cap, Umbrella, Portable fan)											■										
2.4.	Setting up cooling centers, water distribution points etc.											■										

10. Annex

10.1 Menu of Forecast

10.1.1 Global Level

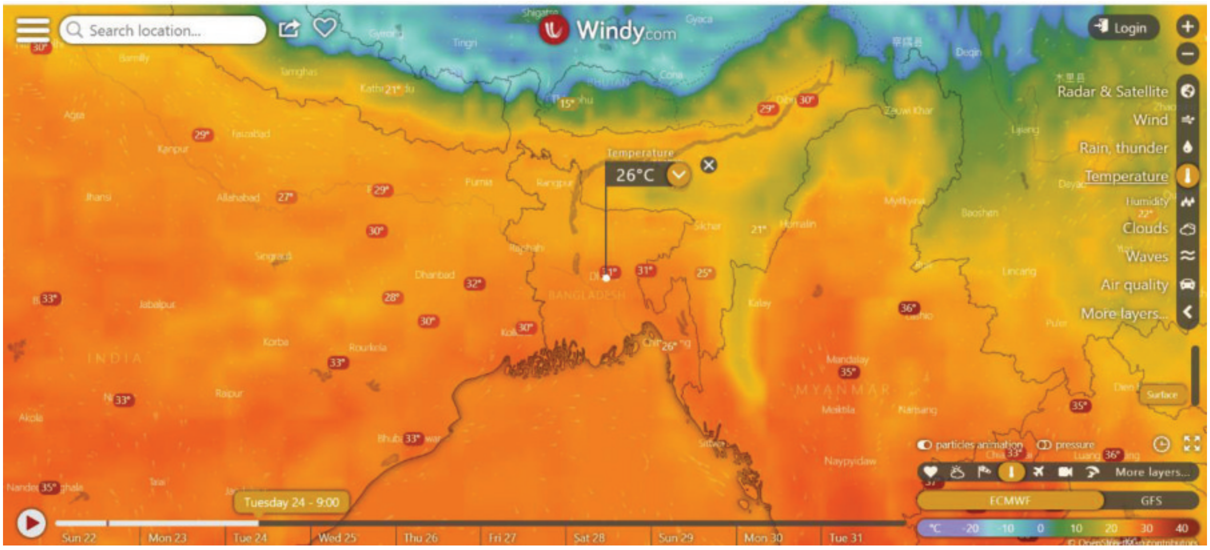


Figure 14: Temperature forecast at global level in ECMWF model

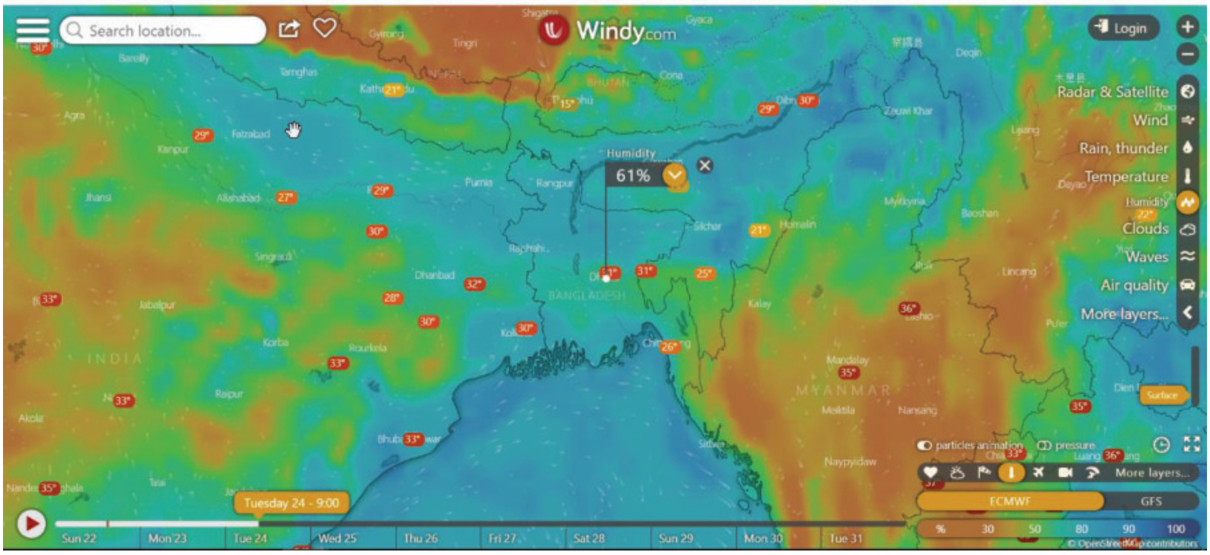


Figure 15: Humidity forecast at global level in ECMWF model

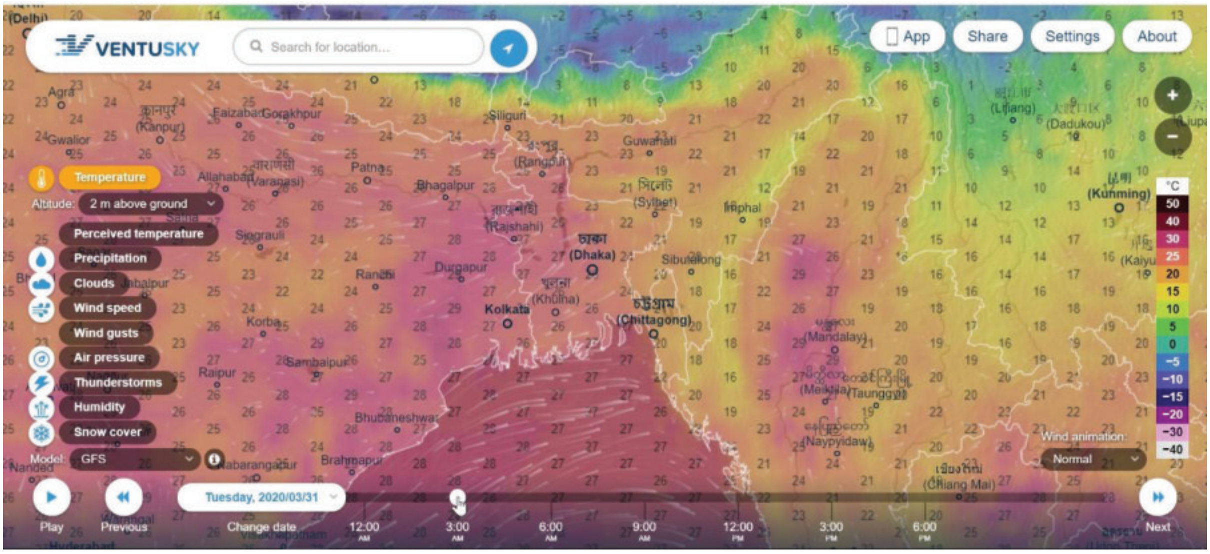


Figure 16: Temperature forecast at global level in GFS model

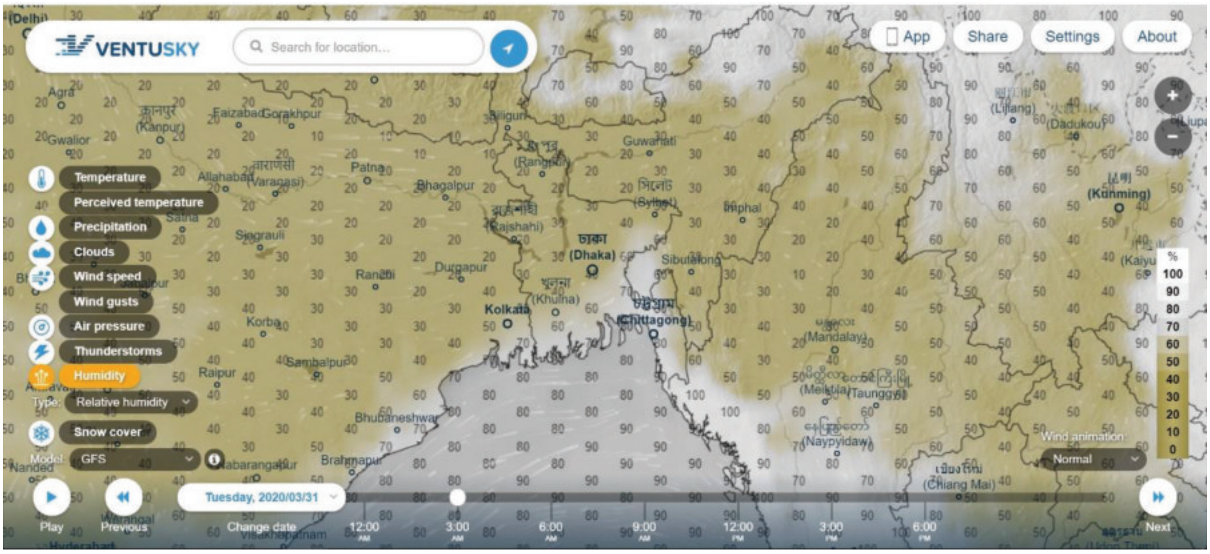


Figure 17: Humidity forecast at global level in GFS model

10.1.2 Local/national level

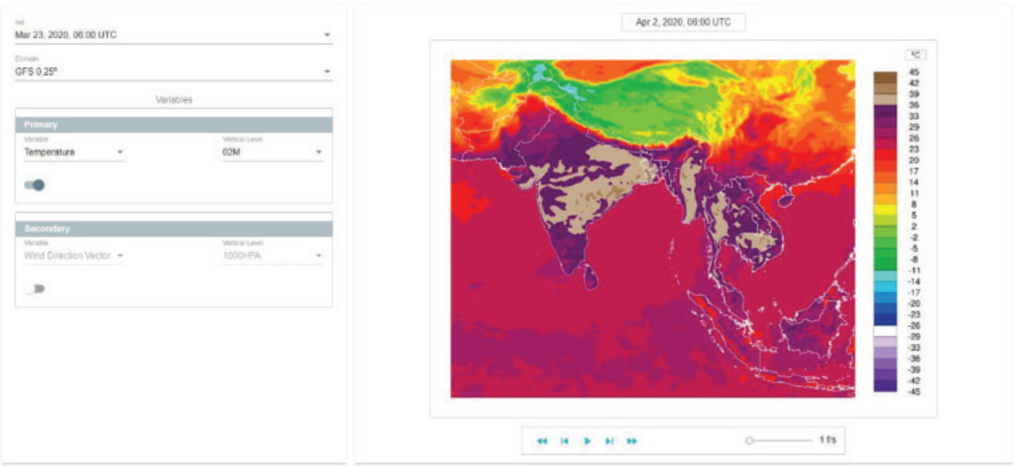


Figure 18: Temperature forecast at local/national level in GFS model by BMD

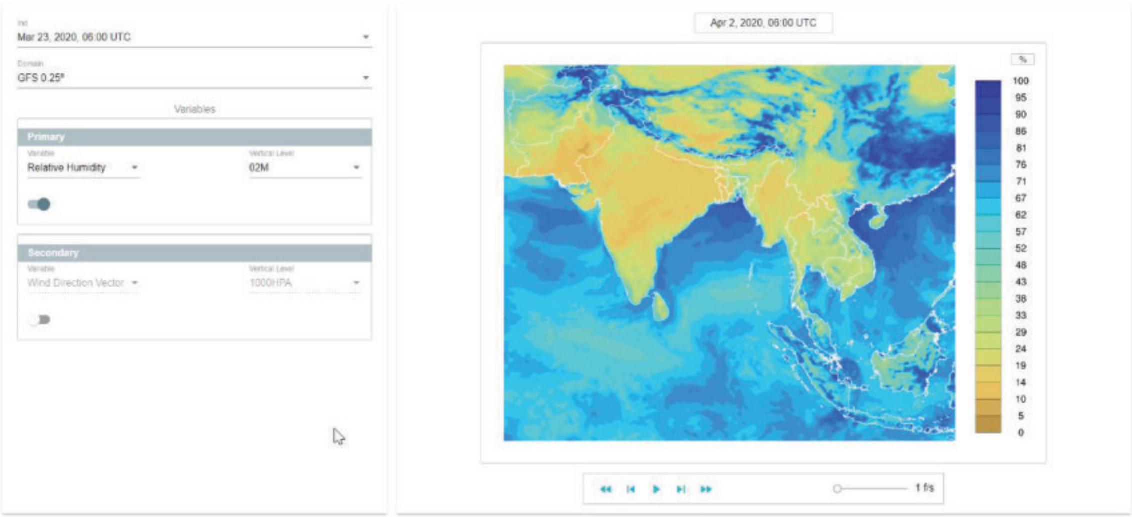
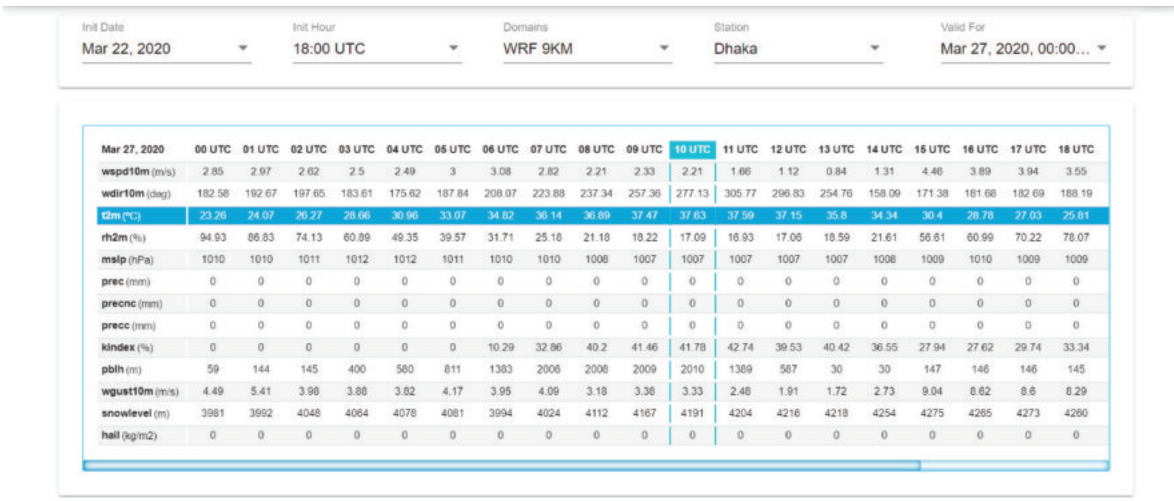


Figure 19: Humidity forecast at local/national level in GFS model by BMD ahead of 10 days



Mar 27, 2020	00 UTC	01 UTC	02 UTC	03 UTC	04 UTC	05 UTC	06 UTC	07 UTC	08 UTC	09 UTC
wspd10m (m/s)	2.85	2.97	2.62	2.5	2.49	3	3.08	2.82	2.21	2.33
wdir10m (deg)	182.58	192.67	197.65	183.61	175.62	187.84	208.07	223.88	237.34	257.36
t2m (°C)	23.26	24.07	26.27	28.66	30.96	33.07	34.82	36.14	36.89	37.47
rh2m (%)	94.93	86.83	74.13	60.89	49.35	39.57	31.71	25.18	21.18	18.22
mslp (hPa)	1010	1010	1011	1012	1012	1011	1010	1010	1008	1007
prec (mm)	0	0	0	0	0	0	0	0	0	0
precnc (mm)	0	0	0	0	0	0	0	0	0	0
precc (mm)	0	0	0	0	0	0	0	0	0	0
kindex (%)	0	0	0	0	0	0	10.29	32.86	40.2	41.46
pblh (m)	59	144	145	400	580	811	1383	2006	2008	2009
wgust10m (m/s)	4.49	5.41	3.98	3.88	3.82	4.17	3.95	4.09	3.18	3.38
snowlevel (m)	3981	3992	4048	4064	4078	4081	3994	4024	4112	4167
hail (kg/m2)	0	0	0	0	0	0	0	0	0	0

Mar 27, 2020	10 UTC	11 UTC	12 UTC	13 UTC	14 UTC	15 UTC	16 UTC	17 UTC	18 UTC
wspd10m (m/s)	2.21	1.66	1.12	0.84	1.31	4.46	3.89	3.94	3.55
wdir10m (deg)	277.13	305.77	296.83	254.76	158.09	171.38	181.68	182.69	188.19
t2m (°C)	37.63	37.59	37.15	35.8	34.34	30.4	28.78	27.03	25.81
rh2m (%)	17.09	16.93	17.06	18.59	21.61	56.61	60.99	70.22	78.07
mslp (hPa)	1007	1007	1007	1007	1008	1009	1010	1009	1009
prec (mm)	0	0	0	0	0	0	0	0	0
precnc (mm)	0	0	0	0	0	0	0	0	0
precc (mm)	0	0	0	0	0	0	0	0	0
kindex (%)	41.78	42.74	39.53	40.42	36.55	27.94	27.62	29.74	33.34
pblh (m)	2010	1389	587	30	30	147	146	146	145
wgust10m (m/s)	3.33	2.48	1.91	1.72	2.73	9.04	8.62	8.6	8.29
snowlevel (m)	4191	4204	4216	4218	4254	4275	4265	4273	4260
hail (kg/m2)	0	0	0	0	0	0	0	0	0

Figure 20: Numerical weather forecast (temperature and humidity) forecast at local/national level in GFS model by BMD ahead of 4 days at 9 km resolution

10.1.3 False Alarm Rate Calculation

Table 10: Forecast skill calculation (FAR) of BMD forecast data in different lead time and resolution

Lead time 1 day

		Forecast	
		Yes	No
Observed	Yes	9	1
	No	15	34

Lead time 2 days

		Forecast	
		Yes	No
Observed	Yes	10	0
	No	15	35

Lead time 3 days

Lead time 4 days

	Forecast	
	Yes	No
Observed Yes	10	0
Observed No	14	37

	Forecast	
	Yes	No
Observed Yes	10	0
Observed No	16	36

Lead time 5 days

	Forecast	
	Yes	No
Observed Yes	9	1
Observed No	18	35

10.2 Heat Index Calculation

NOAA has prepared heat index for US based on air temperature and relative humidity in Fahrenheit scale. The NOAA formula is widely used to heat index calculation globally[27]. To calculate the heat index, we use the following NOAA equation.

$$\begin{aligned} Heat\ Index = & -42.379 + (2.04901523 \times T) + (10.14333127 \times rh) - (0.22475541 \times T \times rh) \\ & - (6.83783 \times 10^{-3} \times T^2) - (5.481717 \times 10^{-2} \times rh^2) + (1.22874 \times 10^{-3} \times T^2 \times rh) \\ & + (8.5282 \times 10^{-4} \times T \times rh^2) - (1.99 \times 10^{-6} \times T^2 \times rh^2) \end{aligned}$$

Where, T represents temperature in °F and *rh* refers to the relative humidity in percent.

We converted the degree Celsius temperature to degree Fahrenheit using the following equation given by NOAA.

$$°F = \left(°C \times \frac{9}{5}\right) + 32$$

After calculating the heat index in degree Fahrenheit scale, we then reconvert the heat index in degree Celsius using following equation given by NOAA.

$$°C = (°F - 32) \times \frac{5}{9}$$

Nissan et al. (2017) calculated heat index using daily three-hour interval temperature and humidity and proposed to use above 95th percentile for daytime and nighttime separately. Here we have calculated the heat index based on Nissan et al.'s definition; as shown in figure 6 below. The category was taken as percentile of maximum temperature and percentile of minimum humidity as when maximum temperature arrives the humidity always fall down i.e., daytime only. And we come up with the categories as 75th, 85th and 95th percentile. The bold faces value indicates impact.

[27] https://www.weather.gov/ama/heatindex

Humidity	Temperature in °C 30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5	28.26	29.08	29.89	30.70	31.51	32.32	33.12	33.93	34.72	35.52	36.31	37.10	37.89	38.68	39.46	40.24	41.02	41.79	42.56	43.33	44.10
10	28.15	28.95	29.77	30.60	31.46	32.33	33.23	34.14	35.07	36.02	36.99	37.98	38.99	40.01	41.06	42.12	43.20	44.31	45.43	46.57	47.72
15	28.14	28.95	29.79	30.68	31.61	32.57	33.58	34.63	35.72	36.84	38.01	39.22	40.47	41.76	43.08	44.45	45.86	47.31	48.80	50.33	51.90
20	28.24	29.08	29.98	30.94	31.96	33.05	34.19	35.39	36.66	**37.99**	39.38	40.83	42.34	43.91	45.54	47.23	48.99	50.80	52.68	54.62	56.61
25	28.44	29.34	30.32	31.38	32.52	33.74	35.05	36.44	37.90	39.45	41.08	42.80	44.59	46.47	48.42	50.46	52.58	54.78	57.06	59.43	61.87
30	28.75	29.73	30.82	32.00	33.29	34.67	36.16	37.75	39.45	41.24	43.13	45.13	47.23	49.43	51.73	54.14	56.64	59.25	61.96	64.77	67.68
35	29.17	30.26	31.47	32.80	34.25	35.83	37.53	39.35	41.28	43.35	45.53	47.83	50.26	52.80	55.47	58.26	61.17	64.21	67.36	70.63	74.03
40	29.69	30.91	32.28	33.78	35.43	37.22	39.14	41.21	43.42	45.77	48.27	50.90	53.67	56.58	59.64	62.84	66.17	69.65	73.27	77.03	80.93
45	30.32	31.70	33.24	34.95	36.81	38.83	41.01	43.36	45.86	48.52	51.34	54.33	57.47	60.77	64.23	67.86	71.64	75.58	79.68	83.94	88.37
50	31.05	32.62	34.36	36.29	38.39	**40.68**	43.14	45.78	48.60	51.59	54.77	58.12	61.66	65.37	69.26	73.33	77.57	82.00	86.61	91.39	96.35
55	31.89	33.67	35.64	37.81	40.18	42.75	**45.51**	48.47	51.63	54.98	58.53	62.28	66.23	70.37	74.71	79.24	83.98	88.91	94.04	99.36	104.88
60	32.83	34.85	37.07	39.52	42.18	45.05	48.14	51.44	54.96	58.69	62.64	66.81	71.19	75.78	80.59	85.61	90.85	96.30	101.97	107.86	113.95
65	33.88	36.16	38.66	41.40	44.38	47.58	51.02	54.69	58.59	62.73	67.10	71.70	76.53	81.60	86.90	92.43	98.19	104.19	110.42	116.88	123.57
70	35.04	37.60	40.41	43.47	46.78	50.34	54.15	58.21	62.52	67.08	71.89	76.95	82.26	87.82	93.63	99.69	106.00	112.56	119.37	126.43	133.74
75	36.30	39.17	42.31	45.72	49.39	53.33	57.54	62.01	66.75	71.76	77.03	82.57	88.38	94.45	100.79	107.40	114.28	121.42	128.83	136.50	144.44
80	37.67	40.88	44.37	48.14	52.20	56.55	61.17	66.08	71.28	76.75	82.51	88.55	94.88	101.49	108.38	115.56	123.02	130.77	138.79	147.10	155.70
85	39.14	42.71	46.58	50.75	55.22	59.99	65.06	70.43	76.10	82.07	88.34	94.90	101.77	108.94	116.40	124.17	132.24	140.60	149.27	158.23	167.49
90	40.72	44.68	48.95	53.54	58.45	63.67	69.20	75.06	81.22	87.71	94.50	101.62	109.05	116.79	124.85	133.23	141.92	150.92	160.25	169.88	179.84
95	42.40	46.78	51.48	56.51	61.88	67.57	73.60	79.96	86.65	93.66	101.02	108.70	116.71	125.05	133.73	142.73	152.07	161.74	171.73	182.06	192.72
100	44.19	49.00	54.16	59.66	65.51	71.71	78.25	85.13	92.37	99.94	107.87	116.14	124.76	133.72	143.03	152.69	162.69	173.03	183.73	194.77	206.15

Symbol	Percentile	Danger Level
(green)	<75th	Caution
(yellow)	75th-85th	Low Danger
(orange)	85th-95th	High Danger
(red)	>95th	Extreme Danger

		Temperature celcius 75th	85th	95th	99th
		34.80	35.90	36.40	38.00
Humidity 75th	68.00	48.51	52.49	54.40	60.91
85th	74.00	51.92	56.41	58.56	65.88
95th	85.00	59.02	64.54	67.17	76.10
99th	92.00	64.10	70.34	73.31	83.36

Figure 21: Heat index calculated defined by Nissan et al. (2017)[28]

10.3 Heat Island Calculation

10.3.1 Land Surface Temperature Map

Land Surface Temperature (LST) is the radiative temperature of the land derived from sun or solar radiation. A simplified definition would be how warm the "surface" of the Earth would feel to touch in a particular location. Land surface temperature is not the same as air temperature that is included in the daily weather report[29]. To calculate LST from satellite imageries Landsat 8 OLI-TIRS (Operational Land Imager and Thermal Infrared Sensor) sensor imageries were used. LST has been calculated using different formula in different stages. We have prepared a model in ArcGIS model builder to calculate the LST combining different tools from ArcToolbox. The formula used to calculate LST was adopted from Orhan et al. (2014)[30] and Avdan and Jovanovska (2016)[31]. Using the following model, the LST has been calculated. LST is important to identify the urban heat island (UHI).

[28] Nissan, H., Burkart, K., Coughlan de Perez, E., Van Aalst, M., & Mason, S. (2017). Defining and predicting heatwaves in Bangladesh. Journal of Applied Meteorology and Climatology, 56(10), 2653-2670.
[29] https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/overview/geophysical-measurements/land-surface-temperature
[30] https://www.hindawi.com/journals/tswj/2014/142939/
[31] https://www.hindawi.com/journals/js/2016/1480307/

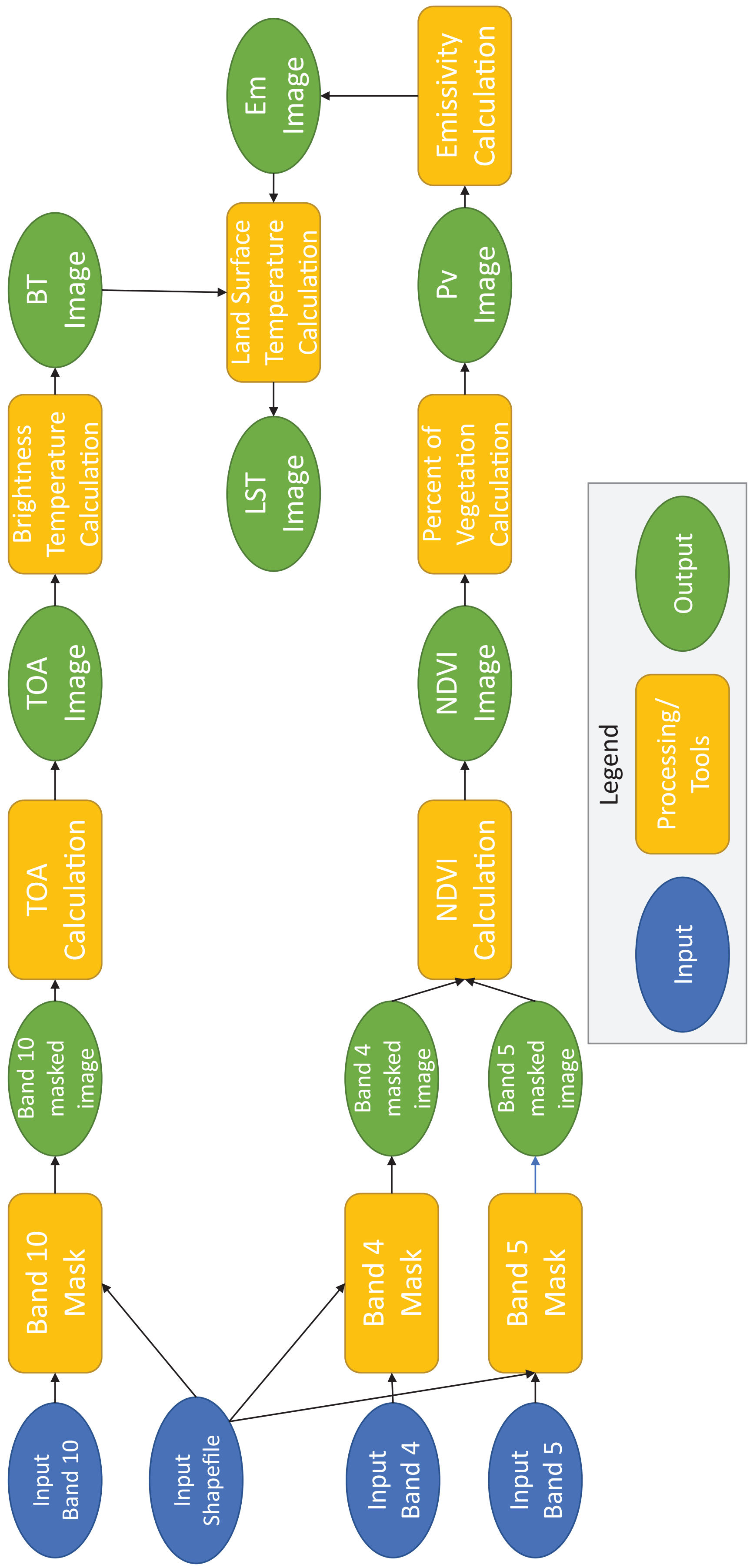


Figure 22: Land surface temperature (LST) calculation model

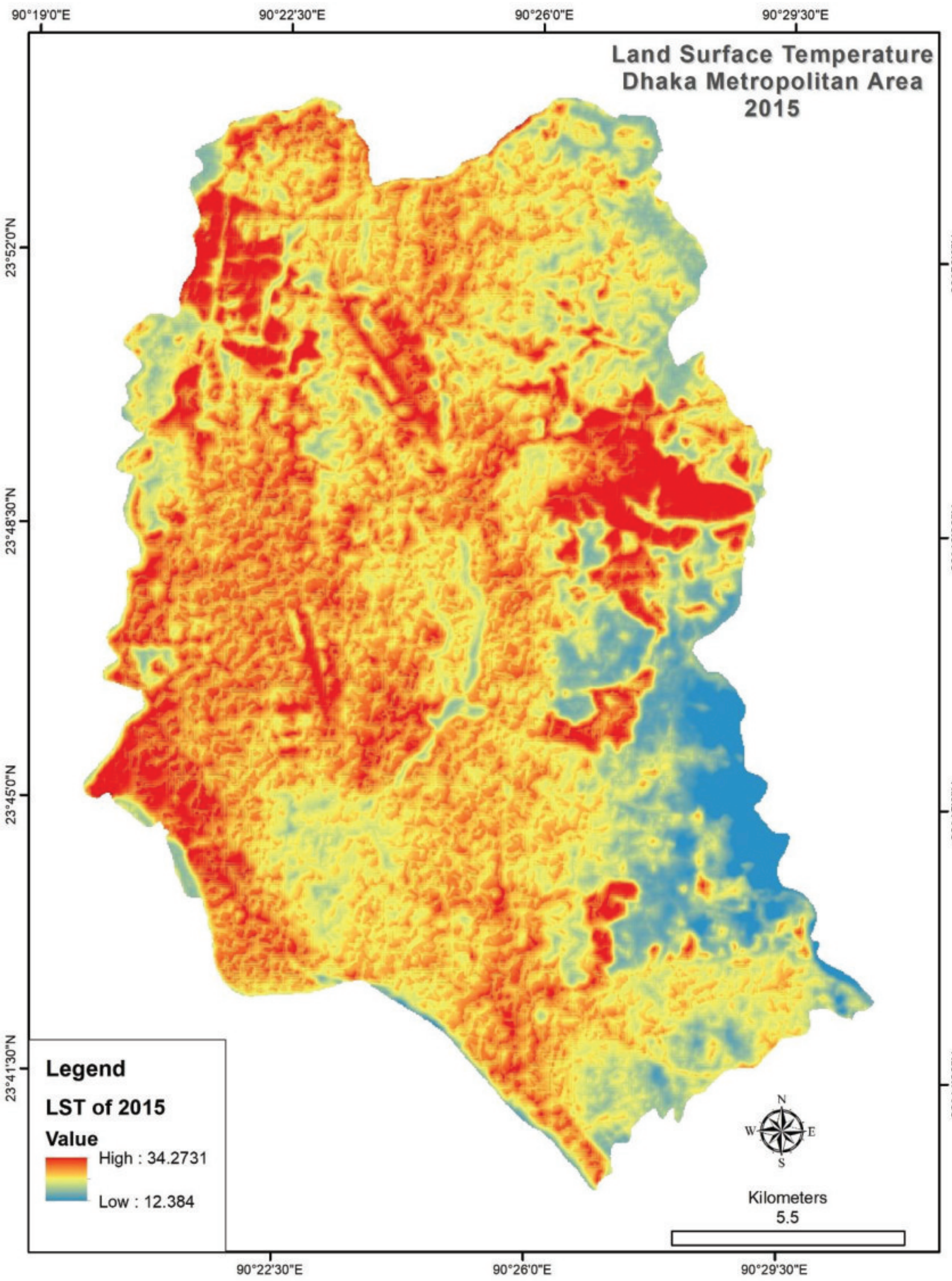


Figure 23: LST map of 2015

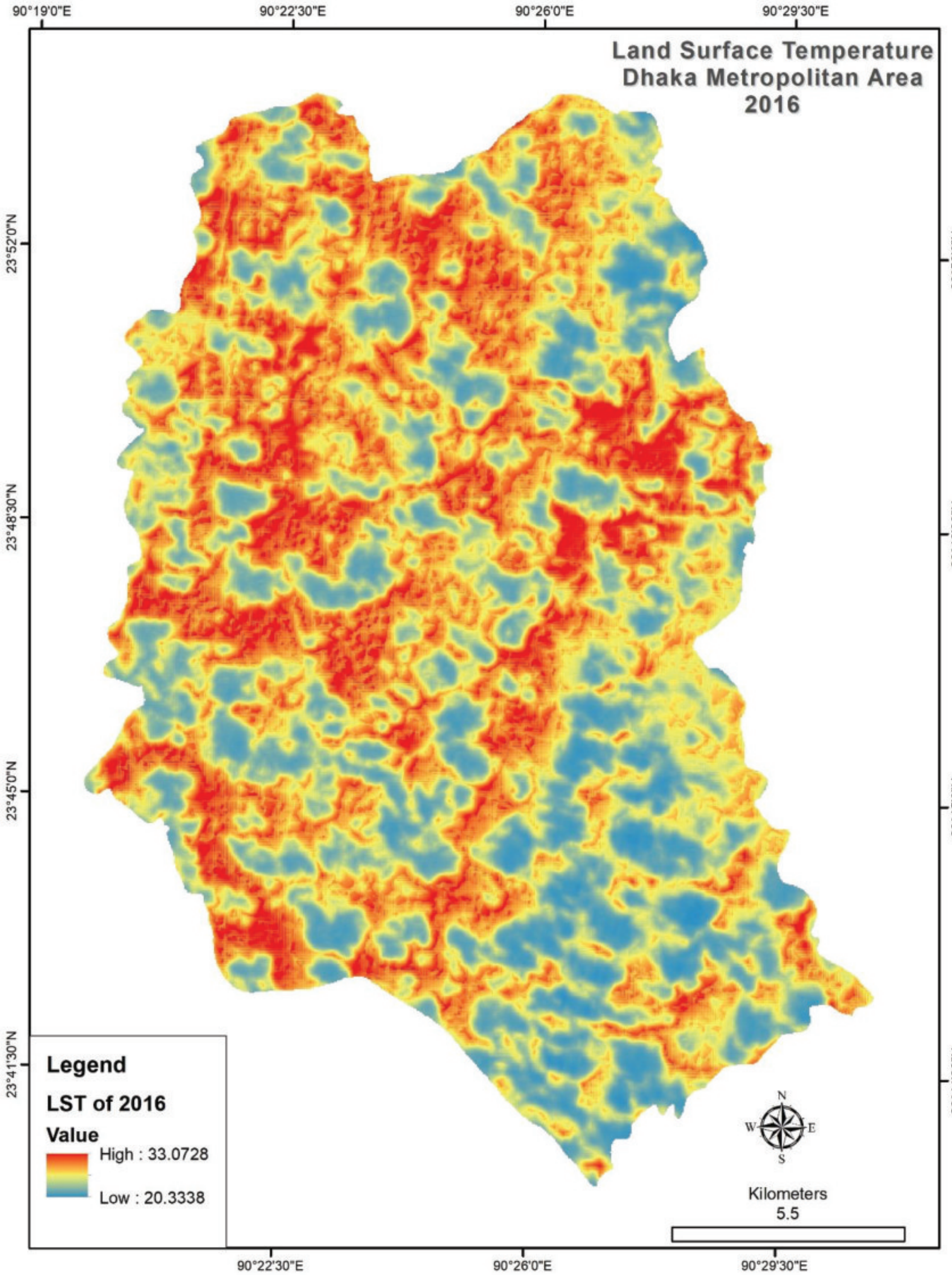


Figure 24: LST map of 2016

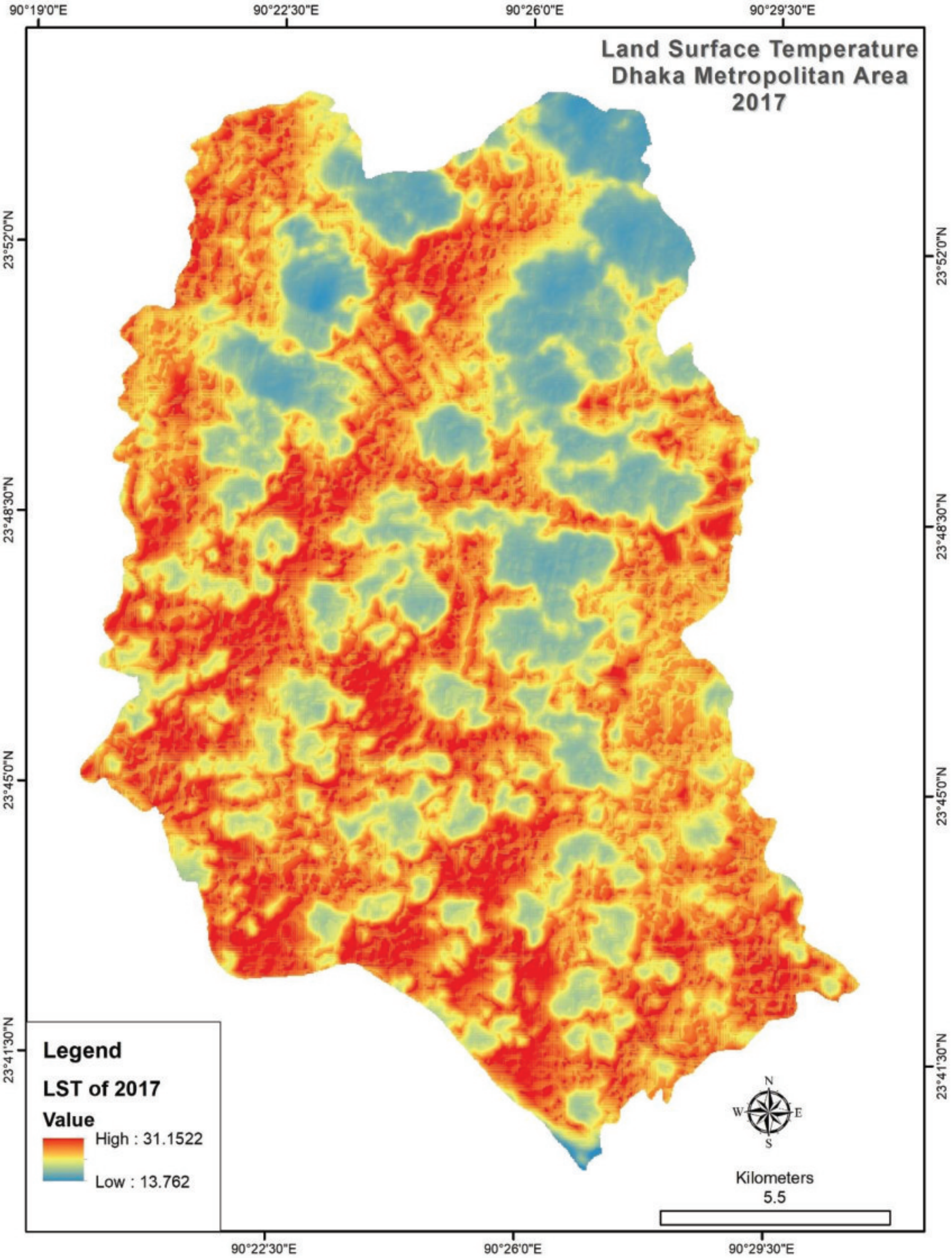


Figure 25: LST map of 2017

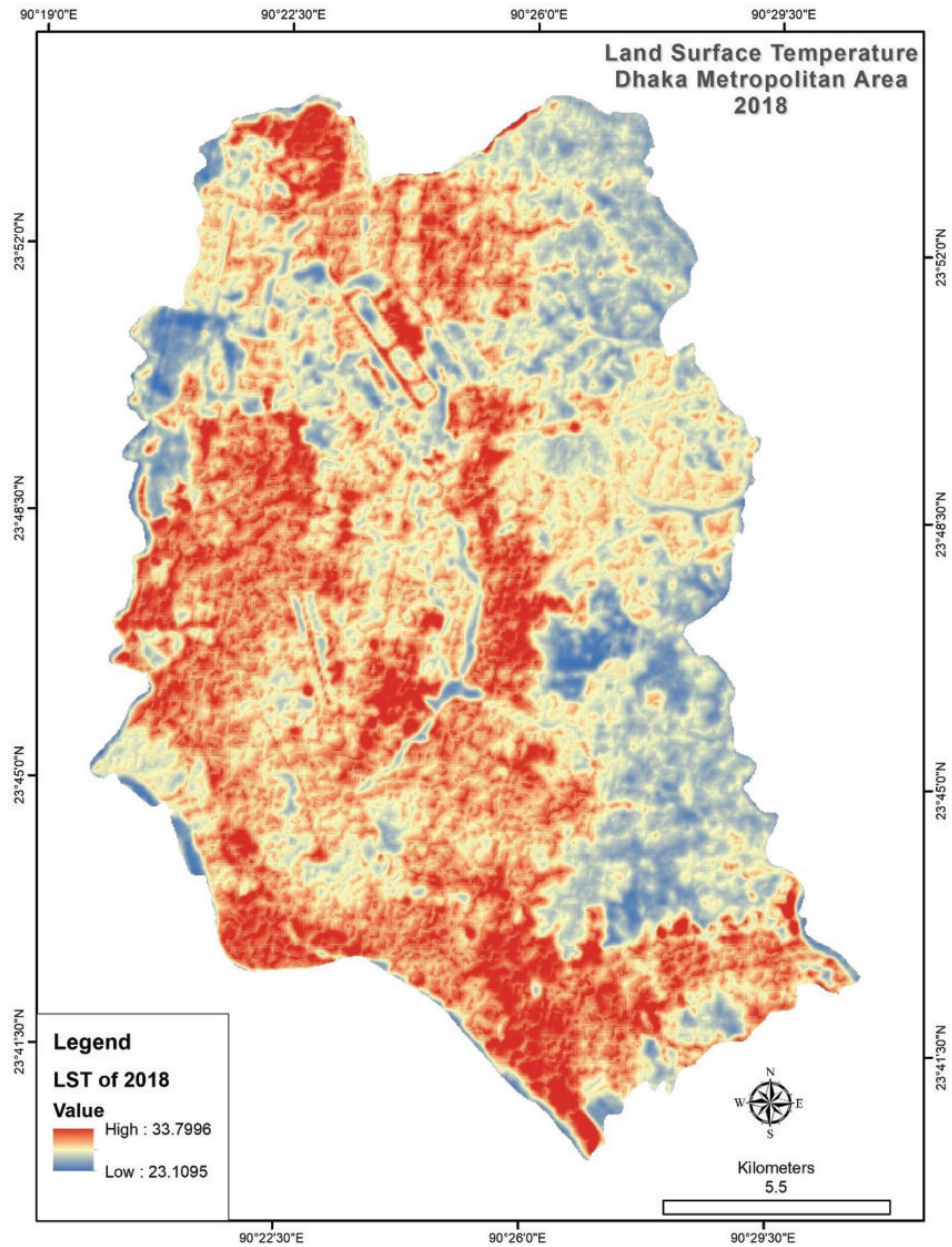


Figure 26: LST map of 2018

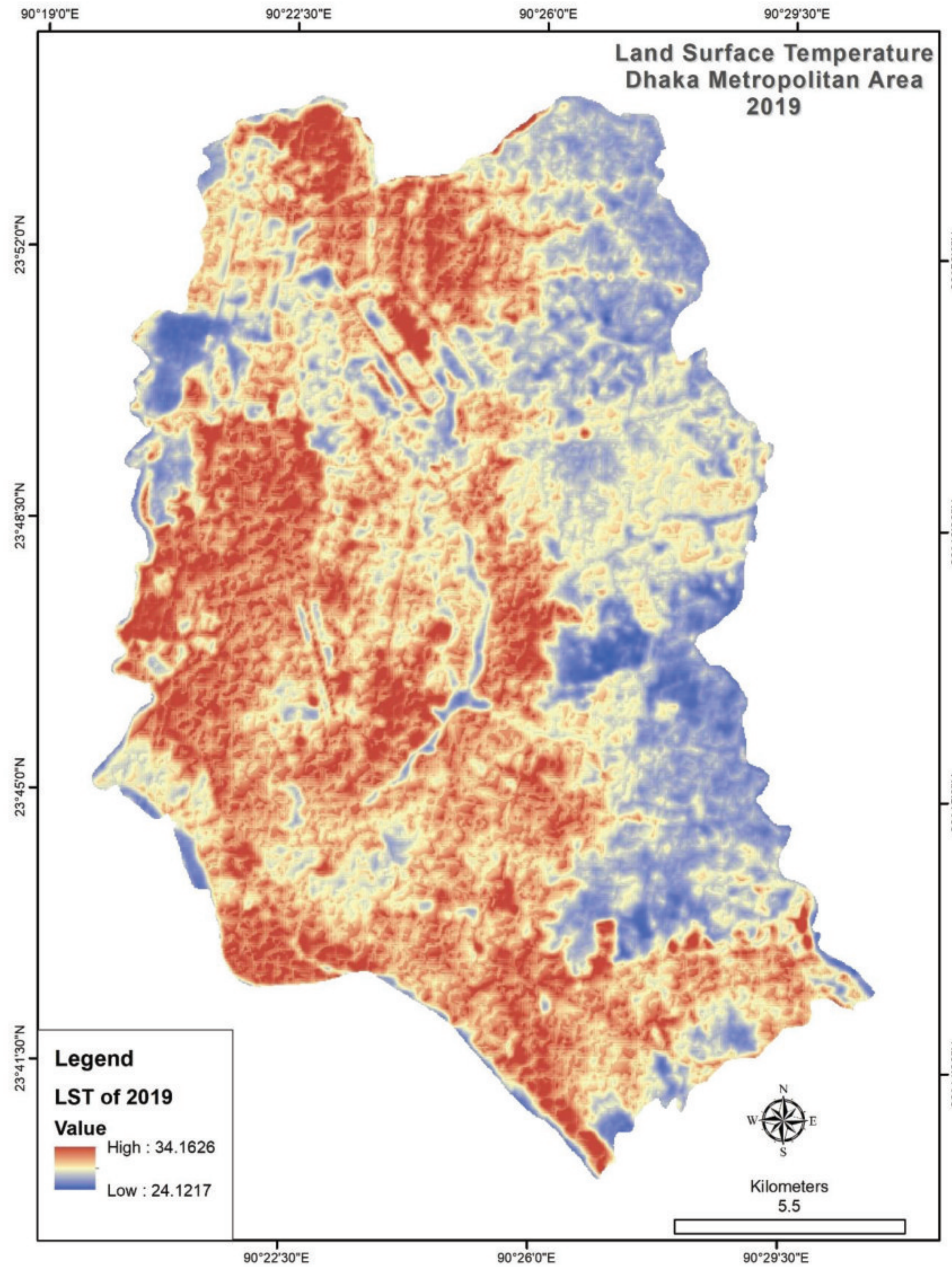


Figure 27: LST map of 2019

10.3.2 Urban Heat Island Map

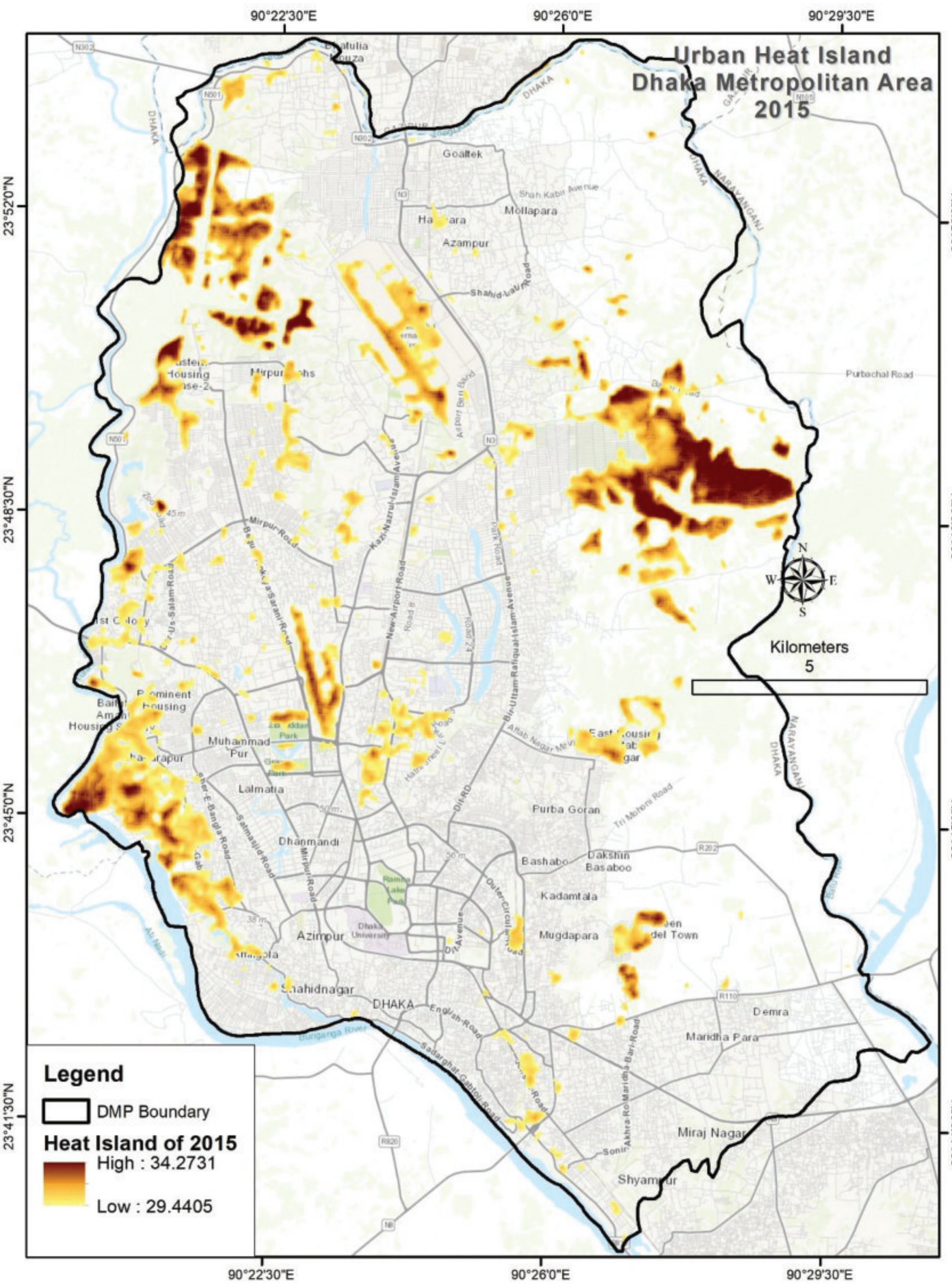


Figure 28: Spatial distribution of UHI in 2015

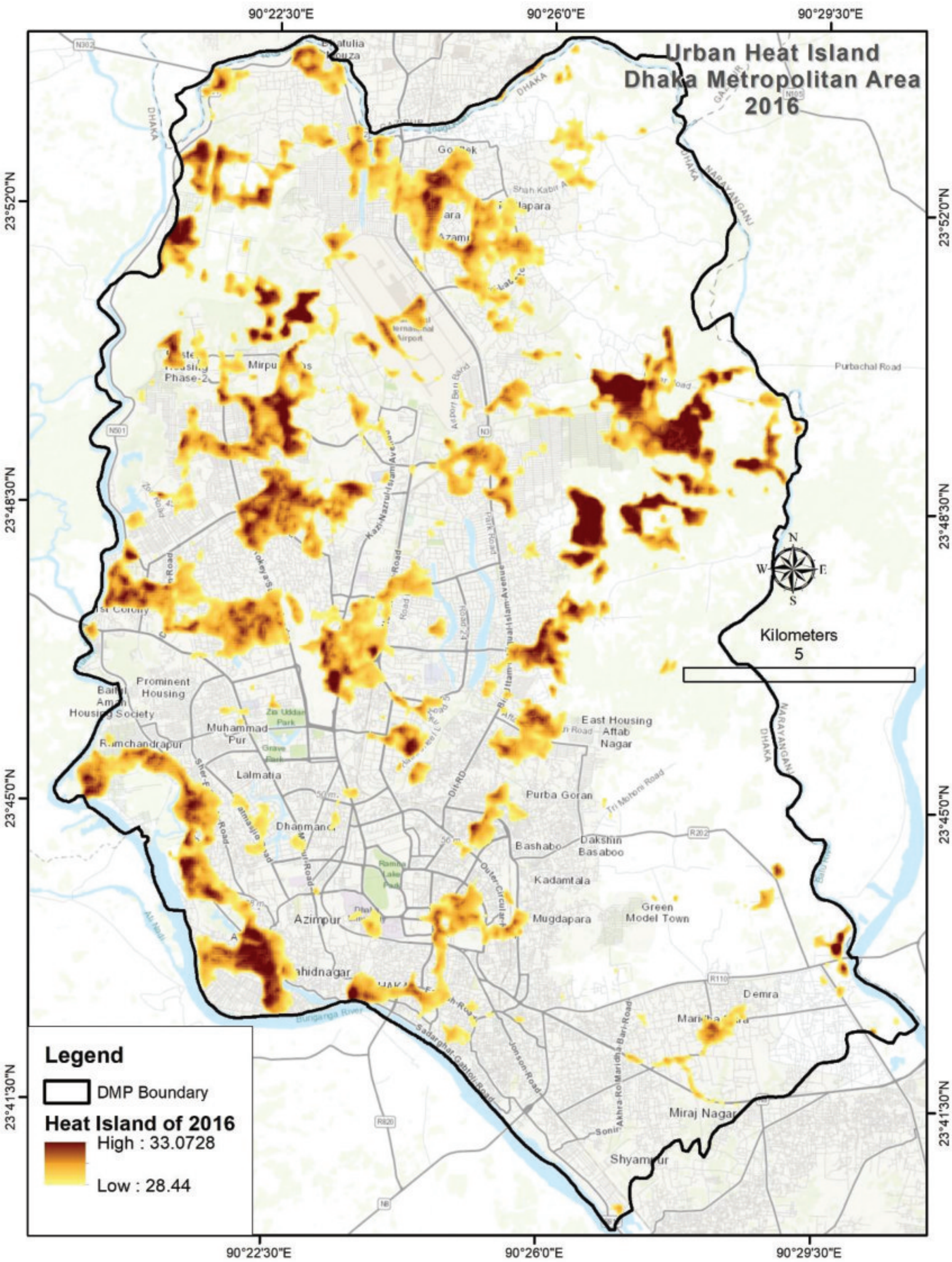


Figure 29: Spatial distribution of UHI in 2016

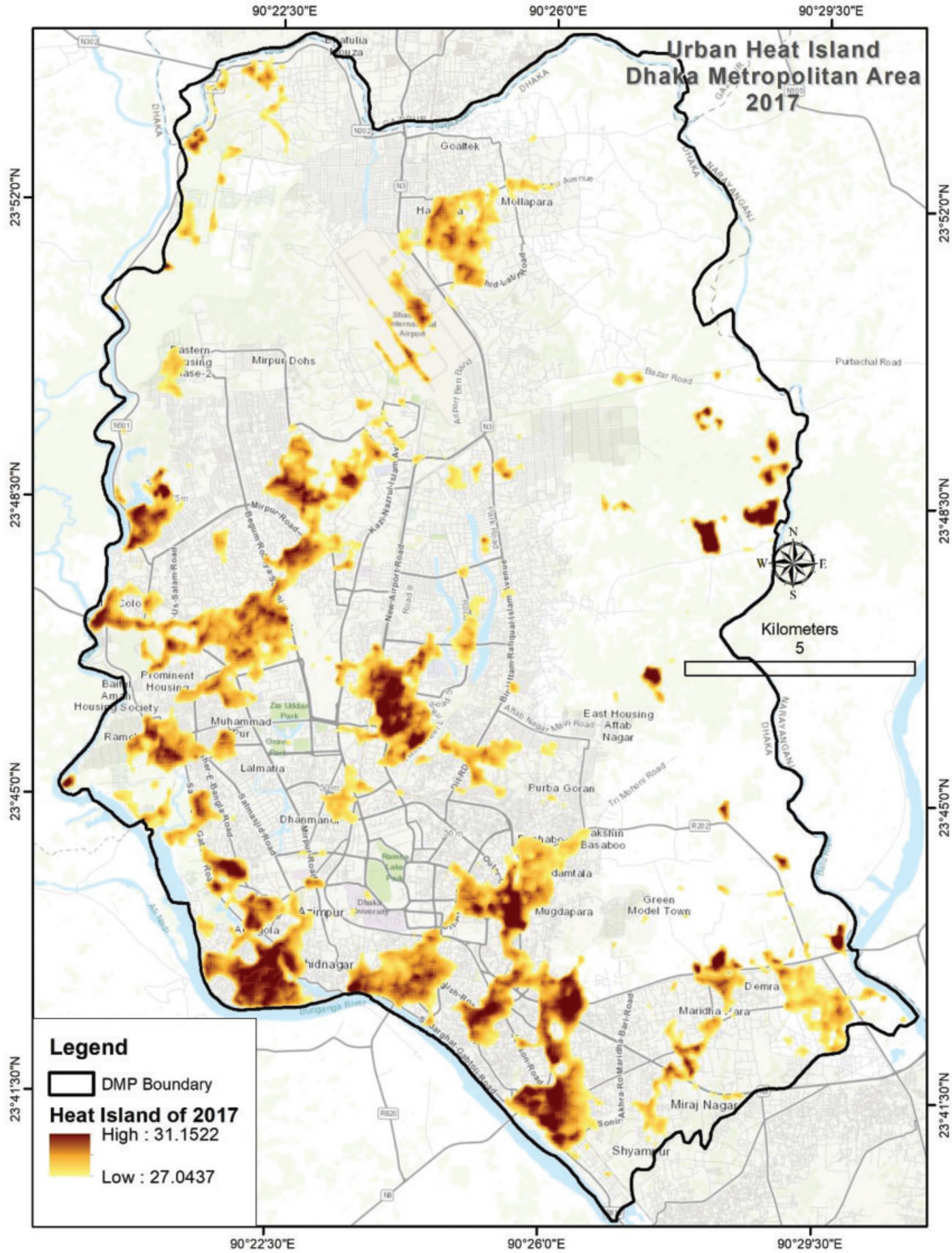


Figure 30: Spatial distribution of UHI in 2017

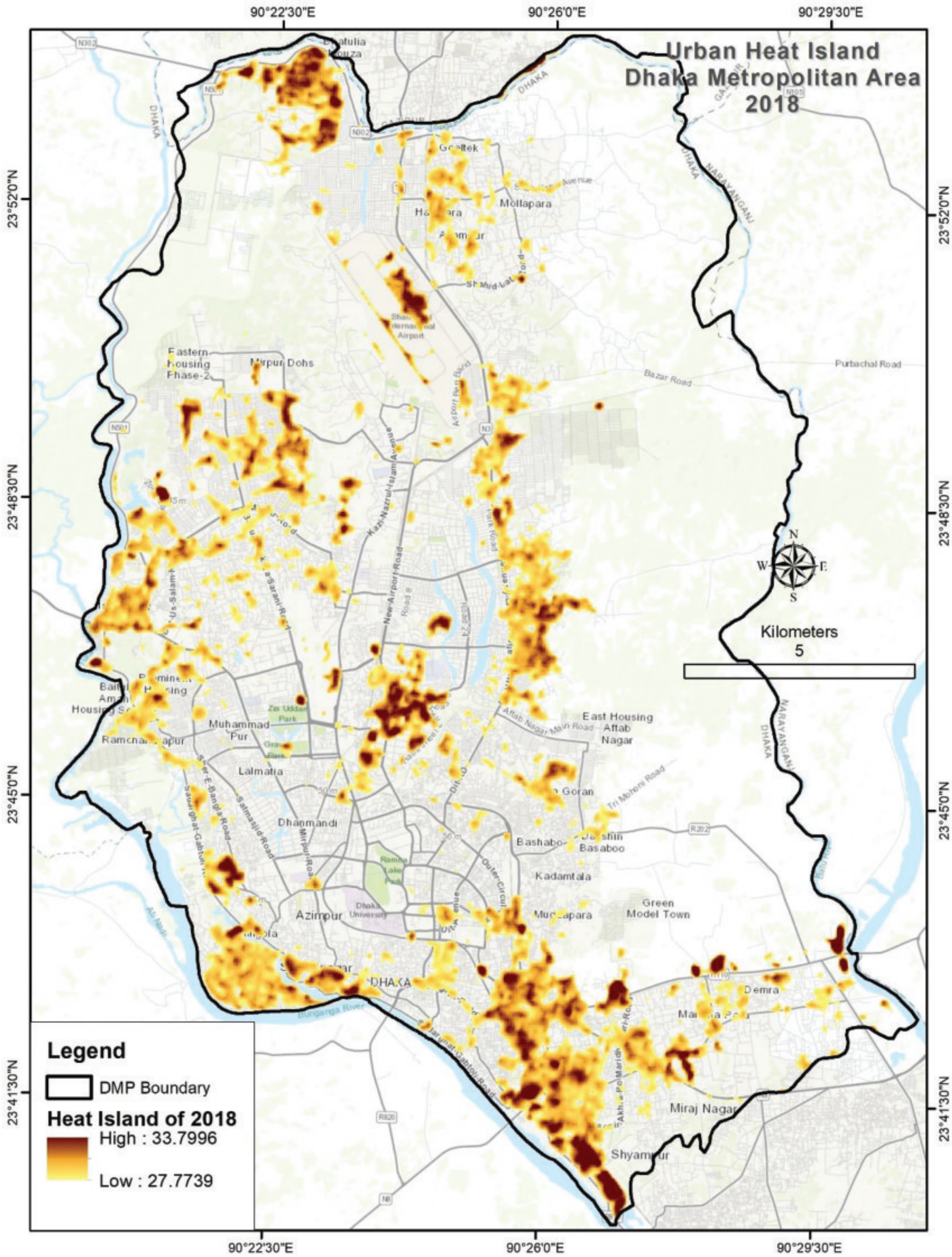


Figure 31: Spatial distribution of UHI in 2018

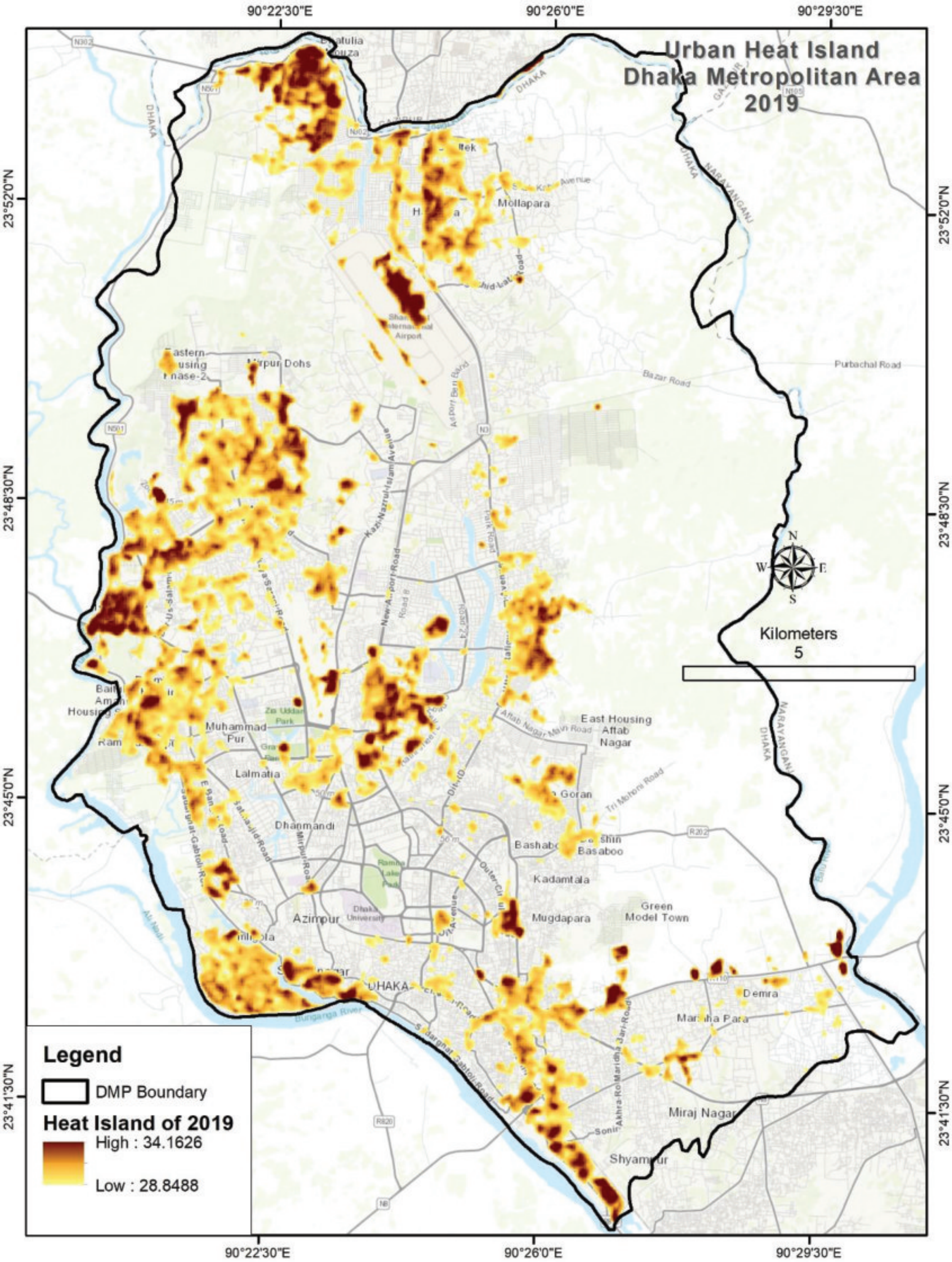


Figure 32: Spatial distribution of UHI in 2019

FEASIBILITY STUDY ON HEATWAVE
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Published : September 2021