



Nexus between heat wave, food security and human health (HFH): Developing a framework for livelihood resilience in Bangladesh

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ABSTRACT

Bangladesh has been severely affected by the extreme heatwave that is affecting most of Asia. Extreme climate events, particularly heatwave impacts on the food system, pose risks to human health in Bangladesh, explicitly in the north-west part of the country. The association between the heatwave, food security and health are narrowly described in the existing literature, resulting in a research lacuna related diverse component of food system that are particularly vulnerable to the heatwave. The current study therefore aims to develop a framework for understanding the nexus between heatwave, food security, and human health, which will ultimately help to improve livelihood resilience in Bangladesh. A comprehensive literature review was conducted to examine the link between heat waves, food security including human health (HFH) to explore the vulnerabilities in the food system in Rajshahi, Bangladesh. Additionally, the current study conducted a case study on the tribal community (e.g., Santals) of Rajshahi to understand heatwave, food security and health nexus. There is evidence that critical activities in the food system are prone to risk to heat waves. It is complex how heatwaves propagate along the food system and impact elucidative dimensions of food security to impact human health impacts. Different types of disruption related to heatwave can indirectly affect human health by compromising food security, a critical factor of health. The case study of the current investigation reveals that human health can also be affected by the physical impact of the heat wave on the food system, particularly with regard to diet-related impacts and food-borne diseases within the tribal community. In the study, we propose to offer a novel analytical framework to examine and respond to the relationship between heat waves, food security and human health. The investigation provide a benchmark to policymakers, academia, and relevant stakeholders to examine and understand current and future heatwave risks and to develop adaptation strategies to build livelihood resilience in Bangladesh explicitly for tribal community.

1. Introduction

Many studies have shown that both the slow and fast effects of climate change will be detrimental to human and environmental systems. Human health risks related to severe weather and climate events have been explored and are rapidly enhancing worldwide (Nissan et al., 2020). In literature, it is substantially noted that heat waves are the most alarming and noticeable indicator of climate change (Masson-Delmotte et al., 2021; Kim et al., 2016). Though heat waves have been the most urgent topic in recent years, the affected community still has limited knowledge about the estimation, prediction, and forecast of heat waves with spatial variation (Tawsif et al., 2022; Chowdhury et al., 2012). The

overall impact of a heatwave and its potentially disastrous repercussions in the long term are well documented, even though some countries are struggling with the heatwave (Luber and McGeehin, 2008). High temperatures are associated with relative humidity, which leads to heat waves that affect the lives of thousands of people, destroy crops, and damage infrastructure (Lee et al., 2019). Rising temperatures create the demand for water and electricity and also increase the various health difficulties of people, which later result in hospital admissions and often overburden hospital capacity (Lee et al., 2019). While climate change is occurring in such a manner, more heat waves will be recorded every decade, boosting the risk to human health, particularly for the elderly, infants, pregnant women, people with chronic health challenges, and

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those who work outside without cover (Åström et al., 2011; Lee et al., 2019). Due to its link to heat-related morbidity and mortality, heat waves—which are defined by warm air masses that are stagnant and successive nights with high temperatures—are regarded as a public health concern (Kovats and Hajat, 2008). If a heat wave stays for a longer duration with high intensity, then it could have the highest impact on mortality (Arifuzzaman et al., 2019; Toloo et al., 2014).

Heat waves have increased in frequency in developing places, particularly in the previous century (IPCC, 2021). Because of the rising trend in Asia, the year 2020 was dubbed the warmest year on record, with a mean temperature 1.39 °C higher than the average from 1981 to 2010 (WMO, 2021). The surface temperature in Asian nations has increased significantly in comparison to the mean of air temperatures worldwide (IPCC, 2021). Furthermore, future projections under the climate-sensitive scenario suggest that annual average temperatures in South Asia will increase by 1.6 °C (2.9°F) by 2050 (Mani et al., 2018).

According to Karmakar et al. (2019), Bangladesh is among the nation's most susceptible to climatic extremes, particularly heatwaves, in which the country's temperature has been rising rapidly since the 1960s. The heatwave has also been closely linked to an increase in infectious disease outbreaks. The capital of Bangladesh, Dhaka, recorded a temperature of 40.6 °C (105.1°F) on April 16, 2023, according to the Bangladesh Meteorological Department (BMD, 2023). The lowest air humidity for over a week made life unbearable for people, and this temperature record, which peaked in 1965 at 42 °C, is the highest to date. The World Bank indicated in a report from 2021 that Bangladesh's average temperature increases are generally in line with the world average (World Bank, 2021). Bangladesh often has some of the warmest day highs in all of Asia, with an average monthly high of roughly 30 °C (86°F) and an average April high of 33 °C (91°F), according to the UNISDR technical report (2015). The report stated that Bangladesh would soon face "emerging hot and humid seasons, in which the heat index exceeds 35 °C (95°F)". In the last six decades, the average temperature has risen by 0.7–1 °Celsius in Bangladesh. It may rise by 1.4 °Celsius in the next three decades, warned the experts. (Islam et al., 2021).

Food production will be temperature-sensitive and may decrease by up to a third in the tropics and subtropics due to the direct influence of climatic conditions (such as temperature, soil moisture, etc.) on crop yields. Upcoming tropical storms, on the other hand, will become more powerful as their destructive force grows due to increased wind speeds. There will be thus more regular flooding due to changing patterns of precipitation and midsummer glacier melt (Cremona et al., 2022). Sea level rise might submerge significant portions of low-lying countries, and by raising the frequency of illness and violence, climate change can indirectly cause different livelihood sufferings (Arifuzzaman et al., 2019). The way heatwaves affect the food system and pose an analytical threat to food security that later leads to human health problems is quite complex to explain. The relationships between heat waves and food system, food systems and food security food systems and human health, and the impact of heat waves on health and livelihoods are sometimes well understood, however, sometimes there are certain research gaps to understand explicitly among the nexus of heat waves, food, and health. Disruptions associated with heat waves can indirectly affect the food system by reducing food security, which is critical to human health. The heat wave can directly affect human health by causing changes in the food system, mainly through food security and malnutrition (Sharma et al., 2022). Despite Bangladesh's notable advancements in risk mitigation, particularly in relation to cyclones and floods, the relationship between heat waves, food security, and risks pertaining to human health remains poorly understood (Islam et al., 2022). The current work creates an analytical framework to investigate and address the relationship between heat waves, food security, and human health in Bangladesh in order to close this research gap. Bangladesh's current food security issues are discussed, along with any signs of potential health effects and appropriate mitigation strategies. The complex and dynamic links and

connections between the heatwave, food security, and human health are represented and illuminated by this research. For instance, high temperatures can interfere with the production of food, and it has been determined what factors lead to susceptibility and can affect human health and food security (Wu et al., 2018). Several frameworks highlight the linkages between food security, food systems, and, to some extent, health or nutrition, and climate change on a micro level (e.g., household or community). Nevertheless, there are limited studies that provide a comprehensive framework for heatwaves and conceptualize how heatwaves, food security, and human health are related considering northern part of Bangladesh. Apart from academia, policymakers, and important stakeholders, this is what the current study aims to build as a framework for investigating and analyzing present and future concerns to food security and health from the heat wave. Based on existing literature, interviews with various stakeholders and a case study, the overarching questions of the current study are: i) What is the status of the heat wave in the study area? ii) What are the relationships between heatwaves, food security and health? and iii) How can a comprehensive framework be developed to address the nexus between heatwave, food security and health?

2. The nexus among the heat wave, food security and human health (HFH): Bangladesh context

Bangladesh is particularly vulnerable to heatwaves and other environmental pressures. The country experienced 22 % higher mortality rates on days when it was hot outside (Nissan et al., 2017). Heatwaves are anticipated to become more often and powerful in the future in Bangladesh, a nation that constantly suffers natural calamities. According to Uddin and Suravi (2019), tropical storms, storm surges, coastal flooding, river erosion, floods, and droughts cause a considerable number of deaths and property losses nearly annually. The country is also quite susceptible to temperature fluctuation (Masud et al., 2023). Though temperatures will rise more quickly than they do now, information of long-term climate patterns is limited and weak in Bangladesh (Parker et al., 2019). Bangladesh has reportedly witnessed an average temperature increase of 0.5 °C during the last 100 years, according to numerous additional studies (Fahad et al., 2015). According to another study, Bangladesh's yearly average temperature rose by 0.3 °C between 1895 and 1980. A "urban heat island" has already developed in Bangladesh's capital, Dhaka, with symptoms increasing worse every year (Adnan et al., 2023; Kelbaugh, 2019; Raja et al., 2021). Rising temperatures of Rajshahi would significantly affect both agriculture and daily life (Esha and Rahman, 2021). The study also shows that rainfall is declining, which contributes to Rajshahi's shifting climate (Kong et al., 2020). According to BBS (2019), April and May are the hottest months in Rajshahi City Corporation (RCC). Nevertheless, Rajshahi had an increase in the number of days with a high temperature of over 36 °C each year between 1981 and 2016, according to a study by Karmakar (2019). Heatwaves will have a major effect on livelihoods at community level if the frequency of days in the future with a maximum temperature of more than 36 °C increases at the current rate. Numerous studies (Al-Maruf et al., 2021; Sharma et al., 2022; Rahman et al., 2022) examined the definition, prognosis, and measurement of heat wave severity while taking megacities into consideration. However, few studies have examined how residents of Bangladesh's medium-sized cities have adapted to the severe effects of the heat wave on overall livelihoods.

The Bangladeshi Constitution lists food security as one of the fundamental rights of its citizens (Islam et al., 2022). Food insecurity at the national and household levels worries the government, even though food grain output has more than doubled since the country's independence in 1971 (Begum et al., 2013). Almost 25 % of the population subsists on fewer than 1800 kcal per day due to severe energy shortages (GOB, 2000). With 2122 kcal/capita/day as the minimum dietary energy requirement, about half of the population cannot achieve this need.

In addition to the existing deficit in overall calorie consumption, the usual diet of Bangladeshi people is seriously out of balance, with insufficient amounts of fat, oil, and protein (GOB, 2000). Due to their limited access to food, women and children are particularly at risk (Begum et al., 2013). In 2010, there was a decline in the total amount of food consumed in rural and urban areas. According to FAOSTAT (2010), the intake was 12 % below the minimum required nationwide and roughly 11 % and 15 % lower in rural and urban areas, respectively (Ahmed et al., 2021; Begum et al., 2013). A comparison between pre-pandemic and post-pandemic food insecurity in Bangladesh has been studied by IFPRI in 2021, which will elicit explicative findings (IFPRI, 2021).

Certain meteorological factors (such as rainfall, temperature, solar radiation, relative humidity, heat balance, and energy balance) are necessary for Bangladesh's food crops (e.g., rice, corn, wheat, vegetables, mangoes, etc.) to grow more profitably. A heat wave causes a major drop in agricultural productivity, despite the fact that climate change can affect crops in both positive and negative ways (Amin et al., 2014; Islam et al., 2022).

Numerous studies invested the association between health and food security. Families experiencing food insecurity may encounter issues related to pregnancy outcomes, maternal health, infant development, chronic illnesses, mental and emotional wellness, and increased health care costs, among other things (Hanmer et al., 2021). Maintaining one's health and wellbeing depends on eating a healthy diet, which is essential for food security (McGregor et al., 2015). This is because eating poorly is considered to be a primary cause of death and disability. Bangladesh's self-reported prevalence of heart disease, asthma, kidney disease, diabetes, stroke, cancer, and mental health disorders was 16 %, 14 %, 3 %, 9 %, 7.5 %, and 1 %, respectively, since the country does not have a diet high in nutrients (Ahmed and Eklund, 2021).

3. Methods and materials

In order to explore the research questions and, in particular, to understand the relationships between heat wave, food security and health, two subjective data were essential for the analysis, namely the status and trends of the heat wave in the study area and its impact on food security (e.g. food production), processing, distribution and consumption) and human health (e.g. skin and heart problems). With this respect, this study used a multi-method approach (literature review, interviews and case study) to collect and organize the data necessary to examine the research questions. As McKendrick (2009) noted, multimethod involves the independent use of more than one method in a research design. This method includes a wide range of investigative strategies (McKendrick, 2009). A group of researchers (Creswell, 2009) pointed out that researchers can improve the ability to understand the analytical features by combining more than one research method in a single design. Furthermore, this method allows not only to provide more detailed data but also to validate results, thus increasing study reliability (Yin, 2009).

3.1. Systematic literature review

To develop a framework to address heatwave, food security and health nexus, key literature from previous studies, gray literature, and news stories, a systematic literature review was used. The four steps of the PRISMA strategic technique, which stands for Preferred Reporting Items for Systematic Reviews and Meta-Analyses, are as follows: Identification, Filtering, Eligibility, and Inclusion are the four categories. Using Google and Google Scholar, a search was run to locate pertinent materials for the study with an emphasis on the heatwave, food security, and health status. Five search algorithms were devised in order to uncover potential effects of heatwaves on food security and health, as well as their implications for human health. Consider the following examples: (1) heatwave + food security + Bangladesh; (2) heatwave + human health + Bangladesh; and (3) heatwave + food security + Bangladesh.

Four) food security plus human health plus Bangladesh; Five) food security plus Bangladesh plus resilience to human health plus Bangladesh.

3.2. Interviews

The current study conducted this investigation in two Upazila under districts of Rajshahi and Nwabganj (Fig. 1). Eight villages from Godagari and Nachol Upazilas were selected for the this investigation which provided primary data (Table 2), through informal discussions, focus groups, in-depth interviews and key informant interviews with local farmers. Both male and female farmers were collected. We also conducted qualitative interviews with representatives of the Bangladesh Meteorological Department (BMD), the Upazila Department of Food, local NGO activists, and household heads. In essence, key informants are specialists with substantial involvement in and a distinct understanding of the severity and consequences of heat waves, food shortages, and health issues brought on by heatwaves. We employ semi-structured interviews that are targeted at the suspected knowledge domain and skill of the individual informants and are directed by a list of subjects. We target each informant's likely breadth of knowledge and experience through semi-structured interviews that follow a list of subjects. The following were some of the interview topics: a) How is the heat wave currently perceived around the world? b) Where do the heat wave's detrimental effects stand? c) How are the heat wave, food security, and human health related in ways that are multiple? and d) what health issues are brought on by the heatwave and what qualifies as essential to enhancing human health's heatwave resilience. The officials from BMD, SBC, the Upazila-level food office and agricultural advisory officials, the two local NGOs, and community leaders at the research locations were also the subjects of two in-depth interviews and five crucial key informants' interviews (Table 1).

3.3. Understanding heatwave, food security and health nexus on Santals: a case of tribal community of Rajshahi

The Santal are a large ethnic community in Bangladesh and practice wild animal hunting as part of their traditions (Roy et al., 2023). Their socio-economic and cultural tradition is old but not comparable to that of the majority population in Bangladesh (Ahmed et al., 2023). Their socio-economic status is usually shaped by the combination of different indicators of their daily life, such as population, education, gender, occupation, income, land ownership, housing habits, living conditions, health care system, food system, communication system, etc. There is a limited evidence that a significant number of people from this community to improve their economic, social and financial conditions. Traditionally, Santals are mainly engaged in agriculture, while about 95 % of Santals engage in agricultural activities (Ahmed et al., 2019). In the past, the majority of Santals were landowners, but due to population growth, exploitation by moneylenders and landowners, poverty and illiteracy, and natural disasters, the vast majority of Bangladesh Santals have lost their land. Currently, nearly 80 % of the Santals are landless, forcing them to make their living at the mercy of large farm owners and the availability of field work from their Muslim or Hindu neighbors for their very survival. This tribal community was severely affected by heatwave in terms of household economy, food, and health. To formulate and assess the validation of the framework for understanding HFH nexus, this study conducted a case study on Godagari and Nachol Upazila of Rajshahi (Table 2).

4. Results and discussions

4.1. Status of heatwave in Bangladesh

To analyze the current situation of heatwaves in Bangladesh, it is crucial to understand the various types of heatwaves that occur there and how often they occur countrywide. In order to explore the state of

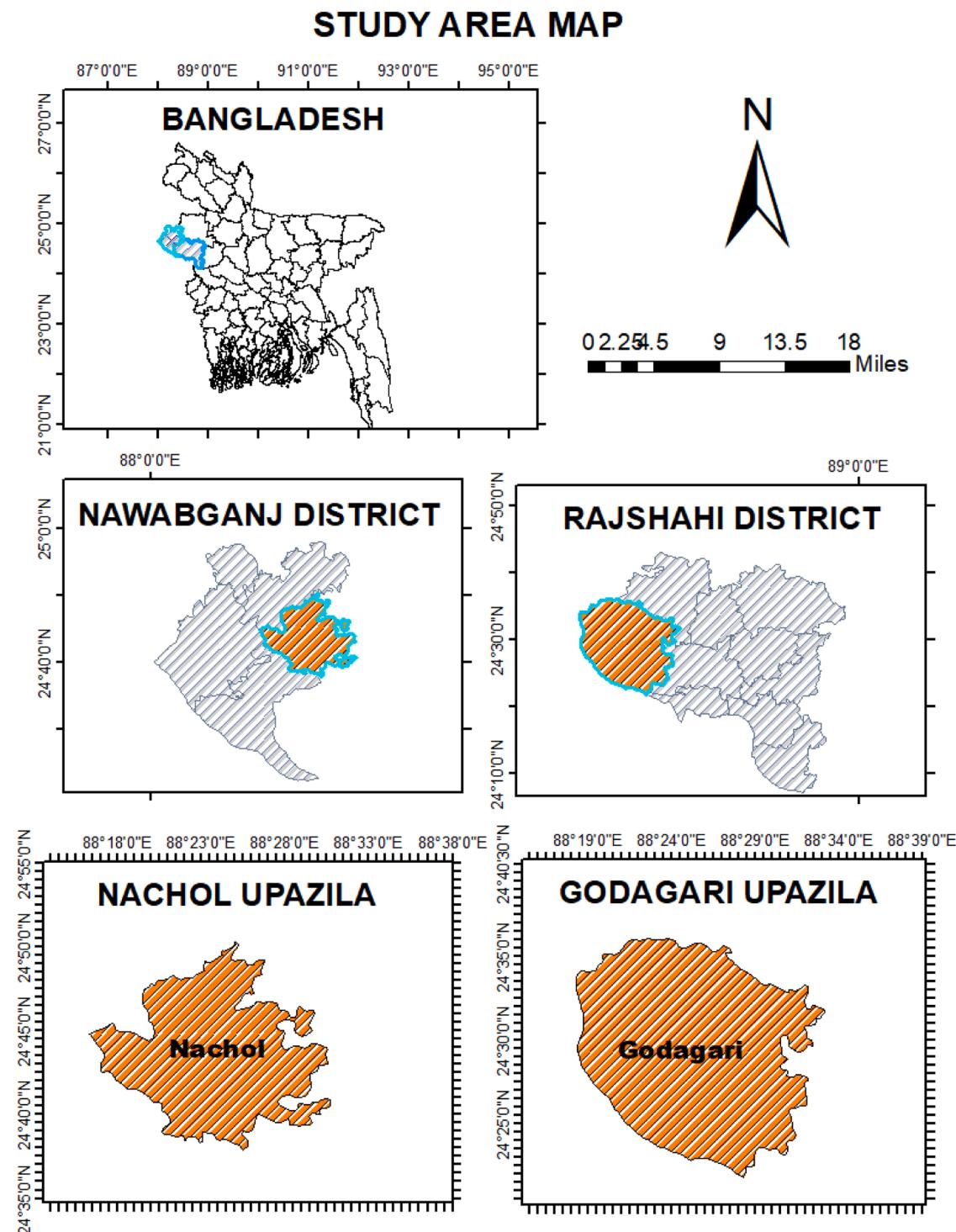


Fig. 1. Study areas.

heat waves across the Rajshahi district, the time series data of temperature from 1984 to 2018 were examined with consideration for their variability, patterns, and statistical metrics (Fig. 2). A linear trend model that was applied to all of the temperature data in Minitab was used to conduct trend analysis. We perform a trend analysis of heat wave periods, which are defined as multiple three-day periods with a threshold temperature of 35 °Celsius, since numerous studies have shown that a heat wave is present when the daily maximum temperature exceeds the average temperature by 35 °Celsius for more than three to four consecutive days (Tawsif et al., 2022). Additionally, we examined the

standard deviation and mean of the periods of heatwave to assess the severity of the heatwaves in the study area (Fig. 3). Since March through July are normally the warmest months in the research area, the current study conducted a trend analysis of heat wave durations throughout those times (Fig. 2). Concurrently, as April is when most heat waves happen, we ran a trend analysis of the heat wave times, focusing only on April over the years 1984–2018 (Fig. 4). The result of the trend analysis clearly shows that the longer hot periods are occurring over time.

To understand the status of the heat wave in Bangladesh, it is necessary to understand the climatology of Bangladesh. Generally, pre-

Table 1

Data collection locations, methods and sources.

Districts	Upazilas/Villages	Villages	Data collection methods	Respondents	No. of participants
Rajshahi	Godagari	Godagari	FGD (Focus group discussion)	Farmers	7
		Matikata	FGD	Farmers	11
		Dewrapara	Informal discussion	Farmers, community leaders, school teachers	13
		Bashudevpur	FGD	Farmers	12
		Pakri	KII (Key informants interview)	Officials of the Department of Food, Agriculture Extension official	3
		Rishikul	FGD	Households	8
		Gogram	FGD	Farmers	7
Chapai Nwabganj	Nachol	Fatehpur	Informal discussion	Farmers	8
		Nazimpur	FGD	Farmers	10
		Kashba	KII	Officials of BMDA and Uddipan	2
		Nachol	FGD	Farmers, households' heads	9
		Kendua	KII	Officials Agriculture Extension	7
		Bakoil Hut	FGD	Farmers	7
		Shanpur	Informal discussion	Farmers, community leaders, school teachers, shop keepers	6
		Mirzapur	FGD	Farmers	5
		Nasirabad	Informal discussion	Farmers, community leaders, school teachers, shop keepers	9
		Rajshahi	KII	BMD	1
		Rajshahi	KII	Official of BMDA	1
		Godagari, Nachol	In-depth interview	Dept of Food	1
		Rajshahi, Godagari, Nachol, Chapanwabganj	In-depth interview	Bangladesh Meteorological Department (BMD)	1

monsoon heat waves are found in the pre-monsoon season in Bangladesh, which specifically starts in March or April (Karmakar et al., 2019). Bangladesh's weather is remarkably seasonally dependent, with the hottest months being April and May. Averaged over the nation, the yearly cycle of the highest (daytime) temperature reaches near to 30 °C, with mostly lower temperatures during the monsoon season. Average temperature trends in Bangladesh are 1–3 °Celsius between 1950 and 2010 (Mani et al., 2018). June marks a less pronounced peak in minimum (night time) temperatures, with mild nights lasting for multiple months. The hottest days can occur as early as March or as late as the end of May, whereas the warmest nights occur between mid-May and mid-July (Nissan et al., 2017). However, recent sources claim that Bangladesh has been experiencing a heat wave since April 2021, with temperatures reaching as high as 40 °Celsius in some areas. Fig. 5 also shows that, when taking into account every year from 1984 to 2018, the frequency of heatwave periods is higher in April, which eventually results in an increase in heatwave severity in the research area.

Heat-related ailments like heatstroke, heat exhaustion, and dehydration have resulted from this. The government has released advisories and urged citizens to take preventative measures, like drinking enough of water, avoiding the outdoors during the hottest parts of the day, and dressing in lighter clothing (The Guardian, 2023; Dimitrova et al., 2021).

In pre-monsoon season, Bangladesh is attained by heat waves literally every year, and sometimes this condition persists even up to the first week of June when the monsoon is delayed (Rajib et al., 2011) (see Fig. 6). The monthly mean maximum temperature has increased by 1.1 °C/year, 1.2 °C/year, and 1.3 °C/year in March, April, and May, respectively, whereas the seasonal mean maximum temperature has increased by 1.2 °C/year in 36 years during the pre-monsoon season of 1981–2016 over Bangladesh (Karmakar et al., 2019). The country is suffering mild to severe heat waves as the maximum temperature from March through May 2014 has been over 4 °C to roughly 12–14 °C above normal for multiple days.

The hottest temperature in Bangladesh was recorded at Chuadanga on April 21, when it was 42.2 °C. According to Molla (2023), Dhaka recorded a temperature of 40.6 °Celsius on April 16, which was the

highest in 58 years. With an average temperature of 19.4 °Celsius, Rangpur and Syedpur had the lowest April temperatures. Because Chuadanga is located in the western part of Bangladesh, it experiences higher temperatures than other parts of the country (BMD, 2023). The global and Bangladeshi climates are predicted to change, resulting in an increase in heat waves (Raja et al., 2021). In reaction to climate change, it has become increasingly common and catastrophic in recent years. Heat waves typically affect the north-western portion of the nation, but this year (2023) they have also reached the south-west (Molla, 2023). The report also suggested that the average temperature will rise by 1.4 °Celsius by 2050 (World Bank, 2021).

4.2. Heat wave and food security

Heat waves affect Bangladesh's food security and agriculture over the long run, and they increase the nation's susceptibility to natural calamities (Ruane et al., 2013). Heatwaves and food security are closely related because excessive heat can lead to large agricultural losses and increased food costs, which can eventually impact vulnerable populations' access to enough nourishing food (Yadav et al., 2019; Kirtman et al., 2013). The United Nations study indicates that the frequency and intensity of extreme heat events are increasing, which is causing crop yields to decline and food insecurity to rise globally (UN, 2021). Severe heat can cause crops to experience heat stress, increased water stress, and decreased soil moisture, which can all have an impact on crop development, yields, and growth (Lobell and Gourdji, 2012; Golechha et al., 2021). In the upcoming years, extreme temperatures might significantly decrease food accessibility (Kroeger and Reeves, 2022). Farmers find it challenging to produce food in these conditions, and individuals in need find it challenging to obtain it (Farooq et al., 2022). In the upcoming years, it is anticipated that extreme weather events will become more common and intense, leading to a rise in natural disasters that may have an impact on food security both directly and indirectly. The extreme heat will cause problems with food security, placing farmers and other significant individuals in risk (NPR, 2018). By June 2022, there were 345 million people living from acute food insecurity across 82 countries, compared to 135 million in 2019 (World Bank,

Table 2

Insights from case study on heatwave, food security and health nexus on Santal community of Bangladesh.

No.	Dimensions of HFH nexus	Descriptions
1.	Geographical context	<ul style="list-style-type: none"> Bangladesh is frequently affected by different types of climate-induced disasters, e.g., floods, cyclone, storm surges, and heatwave Rajshahi and Nawabganj district severely affected by heatwave and drought particularly on tribal community The Santals are one of the oldest ethnic minority groups in Bangladesh. Drought is a major climatic shock in the northern part of Bangladesh. Seasonal floods and flash floods are common in the northern, northwestern and northeastern regions of Bangladesh.
2.	Impacts analysis of heatwave	<ul style="list-style-type: none"> Climate-induced disasters explicitly heatwave affect croplands and accelerate the vulnerability of smallholder farmers. Small and marginal farmers are often excluded from the mechanism of heatwave induced risk-sharing. Local community are facing health complexity due to heatwave, e.g., breathing complexity, skin related diseases Different traditional financial instrument, for example, microcredit, and relief programs, are continuing. However, how heatwave can be tackled with the particular focus of marginal farmers is a crucial question. Tribal community (e.g., <i>Santal</i>) are relatively less aware and knowledgeable about impact of heatwave on health
3.	Innovation	<ul style="list-style-type: none"> Household level adaptation measures such as yard plantation/gardening, preservation of water bodies, changes of behaviour pattern. For ensuring food security, performing weather-index-based crop insurance (WIBCI) was innovative for adapting to climate risk for the large, smallholder, and marginal farmers, however, interest of microlevel farmers is still big question.
4.	Key objectives	<ul style="list-style-type: none"> Understanding the relationship among the heatwave, food security, and health Building health resilience to heatwave and food security
5.	Location of case study	<ul style="list-style-type: none"> Godagari, Nachol
6.	Addressed risk events	<ul style="list-style-type: none"> Heatwave, drought, food insecurity, health risk
7.	Financial risk	<ul style="list-style-type: none"> The Santal community does not have the opportunity to obtain credit from various banks and does not meet the conditions for obtaining credit The highest number of households (43.4 %) earn Tk. 8000–16,000 per year (Haider, 2022).
8.	Heatwave and food	<ul style="list-style-type: none"> Santals are mainly involved in farming work while about 95 % of the Santals are involved in agricultural activities Therefore heatwave affects this community during production, food process, and harvesting In the past, the majority of Santals were landowners, but due to population growth, exploitation by moneylenders and landowners, poverty and illiteracy, and natural disasters, the vast majority of Bangladesh Santals have lost their land. Almost 80 % of the Santals are landless, forcing them to make their living at the mercy of large farm owners and the availability of field work from their Muslim or Hindu neighbors for their very survival (Haider, 2022).
9.	Results of others aspects	<ul style="list-style-type: none"> Santal women are more likely to assume leadership roles in subsistence or agricultural activities

Table 2 (continued)

No.	Dimensions of HFH nexus	Descriptions
		<ul style="list-style-type: none"> Almost all respondents from the community of Santal ate once a day, and this ratio for this community also applied to eating three times a day. A large number of Santal respondents (78.0 %) had collected water near their homes. Chronologically the local communities are facing health difficulties such as heatstroke, difficulties in respiratory system. Health and hygiene are an important factor in social life. According to the result, less than half of the respondents (40.6 %) used a half-brick toilet. On the other hand, some of the interviewees used toilets in barracks. About 90.0 % of those surveyed used a bar of soap after going to the toilet (Households survey, 2023).

Sources: Based on FGD, KII, Household's survey, and informal discussion (2023).

2023). In 2018, a heat wave in Europe resulted in poor crop yields, with some crops reducing by up to 50 % (NPR, 2018; Miraglia et al., 2009). This resulted in increased food prices and reduced food availability for vulnerable communities, exacerbating food insecurity. In the United States, extreme heat events in the Midwest have led to a reduction in corn and soybean yields, contributing to higher food prices and reduced availability of affordable food (NPR, 2019; Lake et al., 2012). The impact of heat waves on food security is particularly severe in low-income countries, which are more vulnerable to extreme weather events due to limited resources and infrastructure to cope with their impacts (UN, 2021). Climate change is predicted to exacerbate the frequency and intensity of heat waves, further threatening global food security (Fig. 7) and exacerbating inequalities in access to food (Schnitter and Berry, 2019).

The rise in global food insecurity was mostly caused by alterations in the climate. Weather patterns are being affected by global warming, resulting in heat waves, flooding, and droughts (World Bank, 2023). In Bangladesh, heat waves soaring temperatures in agricultural productivity. Several studies found that crops may experience heat stress during the growing season, which will lower their yields and quality (Hossain and Noor, 2016; Fonta et al., 2011). Long heat waves may also disrupt with flowering and pollination processes, which can cause crop failure (Shukla et al., 2019). Rice, the staple food of Bangladesh, is especially sensitive to high temperatures (Chowdhury and Khan, 2015). As a consequence, farmers have fewer earnings and find it difficult to supply the demand for food, which drives up the price of food. In Bangladesh, heat waves can make it difficult to store and preserve food. Fig. 8 illustrates how heatwaves and food insecurity differ geographically.

High temperatures raise the possibility of post-harvest losses brought on by spoilage, pest infestations, and fungus growth. Significant amounts of food might be lost due to improper storage and preservation methods, which increases the nation's food insecurity as also assessed by Karim et al. (1996) and Al Mamun et al. (2021). Farmers in Bangladesh had to harvest their grain before their usual time of harvesting due to excessive heat impacts on agricultural production as local house noted during the case study. For instance, the people of the northwestern part of Bangladesh harvest mangoes earlier due to changes in the harvest cycle and excessive mangoes ripening over a short period of time (Hossain and Noor, 2016; KII, 2022). According to Dewan et al. (2021), heat shocks destroyed 21,000 hectares of rice crops in Bangladesh in 2021, while Billah (2023) found that heat waves had already destroyed 141 hectares of rice crops. Agricultural extension professionals are working to protect the harvest from heat shocks. For every 2 °C increase in temperature, the yields decrease many times, for example, Bangladesh has a 13.5 % decrease in Boro rice output as a result of a 2 °C temperature increase (World Bank, 2020). Bangladesh's domestic food production plays a major role in the country's food supply chain, which

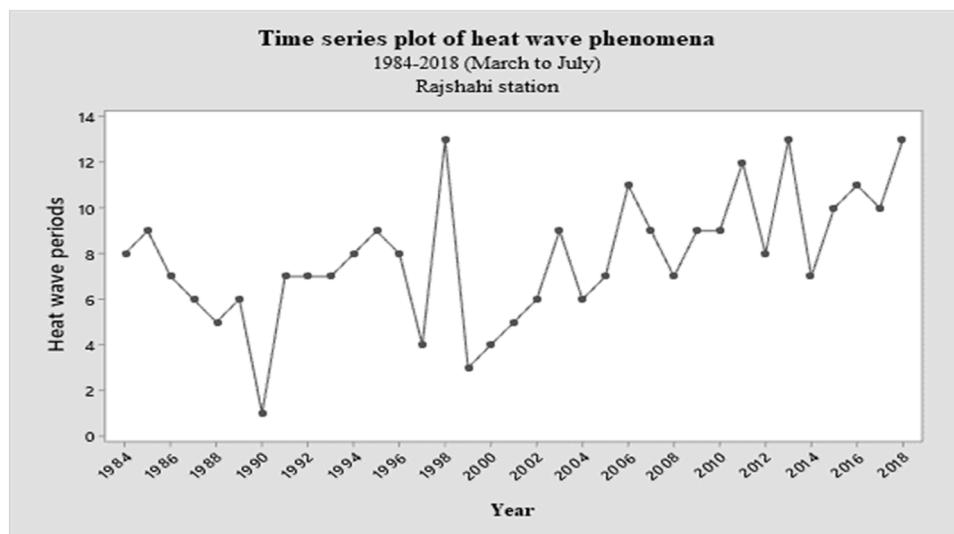


Fig. 2. Heat wave periods over the Rajshahi city, 1984–2018. Adopted from Tawsif et al. (2022).

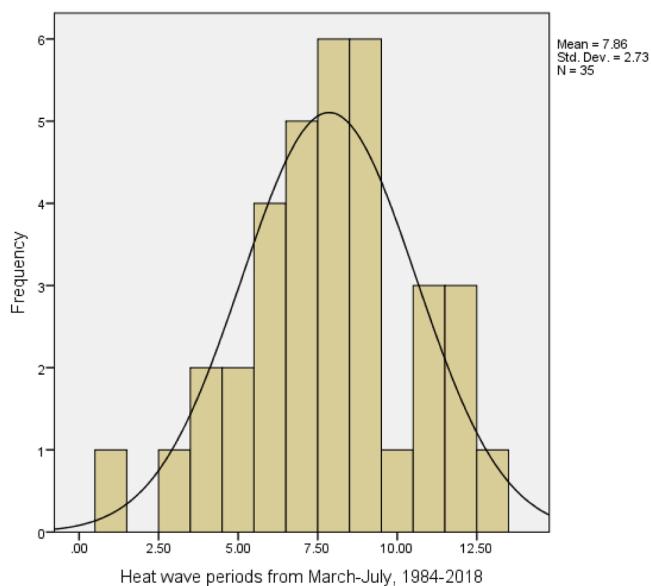


Fig. 3. The value of standard deviation (SD) and mean for the number heat wave periods from March to July 1984–2018.

maintains national food security (Wassmann et al., 2009) (Fig. 6). Heatwaves negatively impact food production and availability, which makes the most vulnerable populations more susceptible to food insecurity (Ara Parvin and Reazul Ahsan, 2013). Additionally, it also increased the risk level of food availability in Bangladesh too. Food is easily accessible to everyone at this level of availability. However, the heat wave reduces productivity, which has an impact on the food supply as indicated by the cases study on tribal community. In later years, a scarcity of food caused food prices to rise, which made food insecurity worse in developing nations like Bangladesh.

4.3. Heat wave and human health

Heat waves and human health are closely related because intense heat can have a variety of negative impacts on health, such as heat exhaustion, heat stroke, and even mortality. Extended episodes of intense heat, or heat waves, can have a detrimental effect on society and raise the death rate from heat-related causes (Wu et al., 2018; Drake

et al., 2018). One of the most destructive natural disasters are heat waves since it is often difficult to predict how many people will die and how much damage they will cause (Campbell et al., 2018). Heat wave claimed the lives of approximately 166,000 individuals between 1998 and 2017, with over 70,000 of those deaths occurring in Europe in 2003 (WHO, 2011). The World Health Organization (WHO) found that elevated temperatures cause an estimated 2500 fatalities globally per day in a research conducted in 2018 (WHO, 2011 ;Mahfuzur et al., 2022). According to a 2011 research by the Centers for Disease Control and Prevention (CDC), heat waves can cause dehydration, heat cramps, and heat exhaustion in addition to aggravating pre-existing medical issues like cardiac and respiratory disorders. Wu et al. (2018) study found no significant correlation between the risk of cholera and heatwaves with a 2-day lag in households with greater medium-dense tree cover. These results imply that heatwaves may encourage the spread of cholera, however, rainfall and tree cover may have an impact on this association. Severe heat waves can affect people's physiological responses and functioning directly, as well as indirectly through effects on food security and other activities that support health systems generally and jeopardize hard-won gains in nutrition and health (Lee et al., 2019). Heat exhaustion, heat cramps, dehydration, and hyperthermia can all result from high temperatures. Additionally, it can make pre-existing medical disorders like respiratory and cardiac disorders worse (CDC, 2011).

Heat waves may have a number of harmful effects on people's health, especially in developing nations like Bangladesh where the infrastructure and medical systems may not be prepared to handle such intense weather conditions (Alam et al., 2012). The biggest health risk during heat waves comes from heat-related disorders such heat exhaustion and heat stroke as pointed also in the case study and key informants interview (KII). These conditions can lead to dehydration, heat cramps, organ failure, and even death.

Children and the elderly are particularly susceptible to heat waves. According to Raja et al. (2021), heat wave frequency and intensity are expected to rise in Bangladesh; the most susceptible populations are those over 65 and younger than nine years old (Haines et al., 2006). People who lack literacy are also susceptible to heat-related incidents since they are unaware of the possibility of harm. According to Uejio et al. (2011), the number of heat-related mortality among Bangladesh's uneducated population is thus high. However, several studies from Bangladesh indicated that cold spells increase all-cause mortality but heat waves do not because of stronger population adaptation response (Alam et al., 2012). Additionally, almost all the heat-wave related

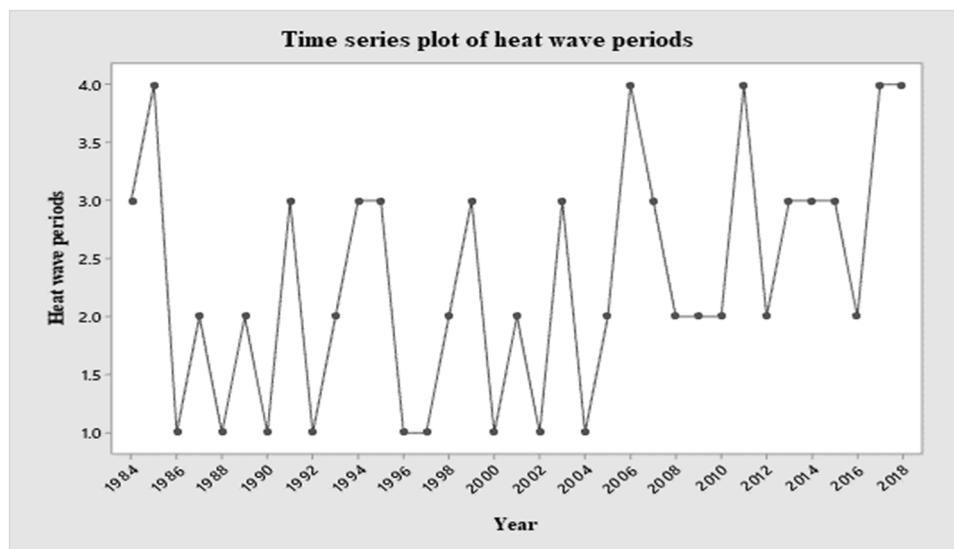


Fig. 4. Heat wave periods in April 1984–2018. Adopted from Tawsif et al. (2022).

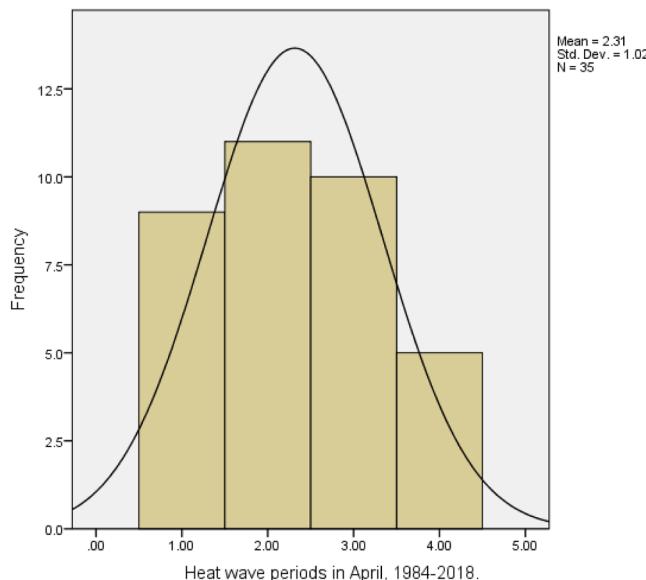


Fig. 5. The value of standard deviation (SD) and mean for the number heat wave periods from only in April 1984–2018.

studies have identified heat-wave related mortality, however rarely some regions consider heat-associated morbidity. With an increase of temperature, Bangladesh have seen higher rates of contracted illness like Cholera and Diarrhea (Corner et al., 2013).

Furthermore, heatwave frequency and intensity are expected to rise due to climate change, worsening the health effects on the nation's most vulnerable people particularly tribal community (Case study, 2022; Fig. 9). Strategies for reducing the harmful effects of extreme heat events on people's health, especially those who are more vulnerable, must be developed. Therefore, it's critical to take preventative measures against heatstroke, such as drinking enough of water and refraining from physically demanding activities while the temperature is at its peak.

4.4. Heat wave, and food security and human health nexus

Heatwaves, food security, and human health are intricately related and can have a big influence on global South particularly in Bangladesh. It poses a severe threat to human health as well as the safety of food

supply. Temperature increases, changing weather patterns, and extreme weather events are affecting crop yields, agribusiness operations, and food production respectively (Burke and Lobell, 2010). In addition, there has been a rise in heat-related illnesses and deaths, particularly in Bangladesh and other vulnerable groups including the elderly, kids, and those with underlying medical conditions. This essay emphasizes the connection between the heat wave, public health, and food security.

Extreme weather conditions, such as heatwaves and prolonged droughts, have a significant impact on crop yields and food production. Studies suggest that high temperature increases crop transpiration rates and decreases photosynthesis and dry matter production, leading to lower yields in many crops (Wahid et al., 2007). Heat waves and other extreme weather events are also causing an increase in food loss and waste, which can raise food prices, particularly for low-income families, as similar findings found in the case study (2022). Systems associated to food and agriculture are similarly susceptible to heat waves and other climate-related phenomena. About 80 % of agricultural land worldwide is rain-fed, making it vulnerable to droughts and other extreme weather conditions, according to the Food and Agriculture Organization (FAO, 2020). In addition, the heat wave can increase the demand for water resources, making it more challenging to maintain water availability for agriculture and other purposes. In some areas, water scarcity may lead to conflicts over water resources, leading to food insecurity and social unrest.

Heatwaves pose a direct risk to food security and human health, while they may cause harm indirectly to human health by reducing crop production, storage, and transportation, which affects food availability, accessibility, and utility. Furthermore, heatwaves can indirectly impact human health by disrupting food availability and quality. Reduced crop yields and food shortages can lead to malnutrition and related health problems, especially among low-income and marginalized communities of the country. Heatwaves can also exacerbate the spread of waterborne diseases and vector-borne illnesses as they contribute to water scarcity and alter disease transmission patterns. Heat waves have noticeable impacts on population nutrition and food security, which also supports the connection between heat waves, food security and health (Lake et al., 2012). Taking everything into account, the heat wave poses a major threat to public health and food security. Particularly vulnerable groups will be affected, such as residents of low-income areas or developing nations like Bangladesh. In conclusion, the extended heat wave presents a severe environmental risk to public health and food security.

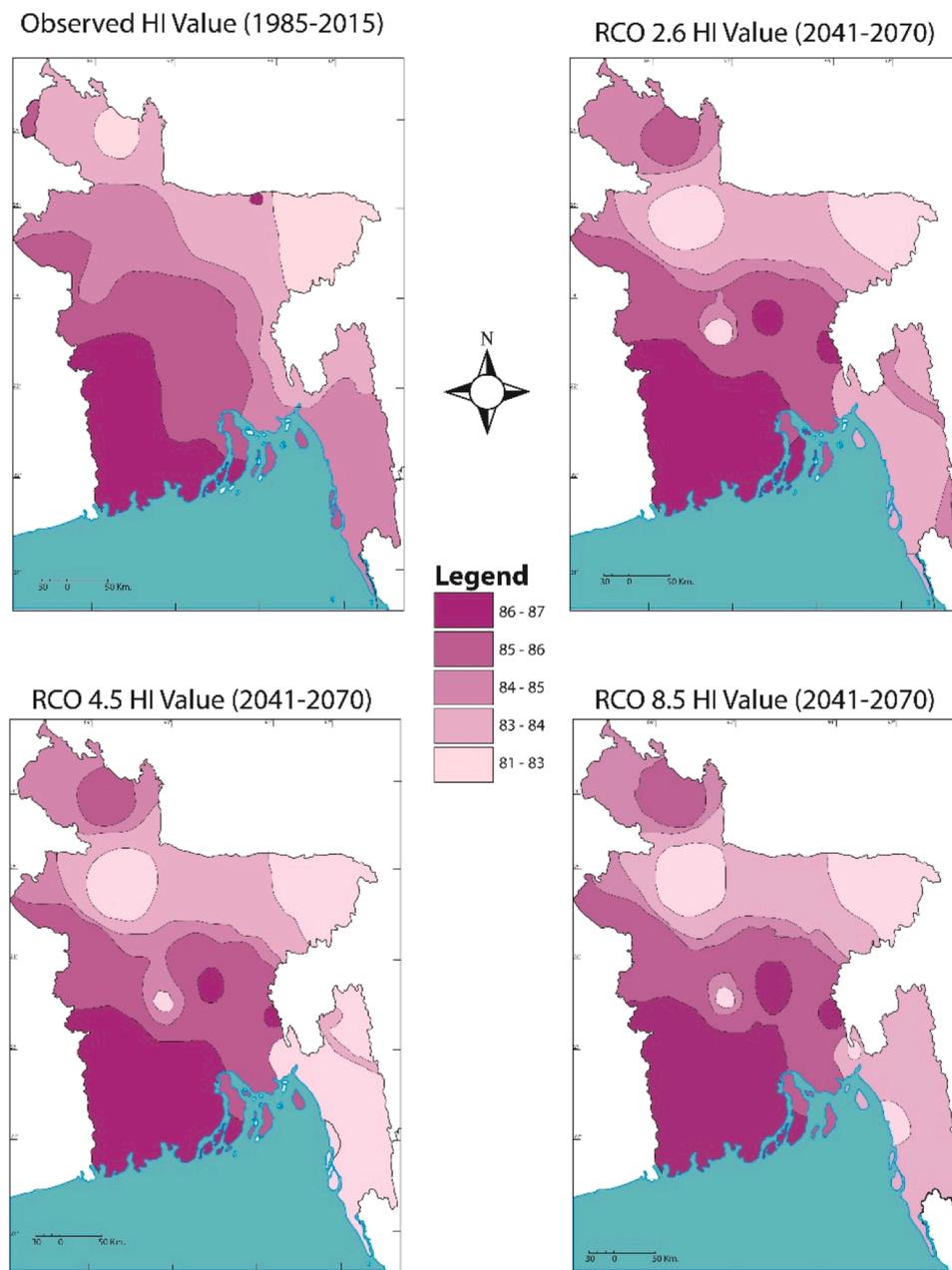


Fig. 6. Average heat index anomalies in different parts of Bangladesh during 1985–2015 and projected period (2041–2070) under three different Representative Concentration Pathway (RCP) scenarios. Adopted from [Rajib et al. \(2011\)](#) and [Rahman et al. \(2021\)](#).

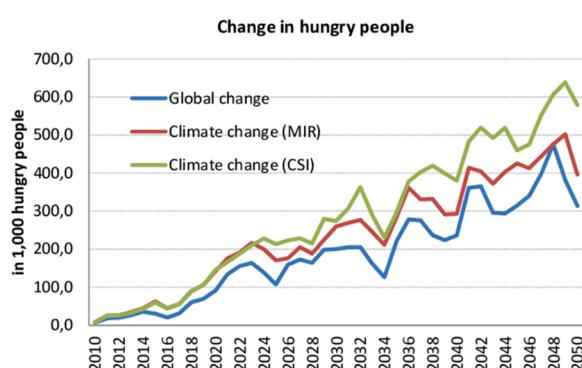


Fig. 7. Impact of climate change on food security adopted from [Breisinger et al. \(2011\)](#).

4.5. A framework for enhancing livelihood resilience

Heat is anticipated to happen more regularly in the near future. People's health is gravely jeopardized by them, particularly that of vulnerable populations such as children, the elderly, and those suffering from chronic illnesses ([Al-Maruf et al., 2023](#)). Bangladesh frequently experiences heat waves, particularly from March through June when highs of up to 40 °C are possible. Heat waves have a significant impact on human health and food security, especially in north-eastern part of Bangladesh. Thus, it is essential to develop a framework ([Haque et al., 2023](#)) that enables the country to enhance overall livelihood resilience by combining health and food security into a comprehensive plan that lessens the adverse effects of these occurrences.

The formulation and implementation of heat-health action plans at the national and regional levels can greatly reduce the negative health effects of heat waves. These plans should include actions for long-term

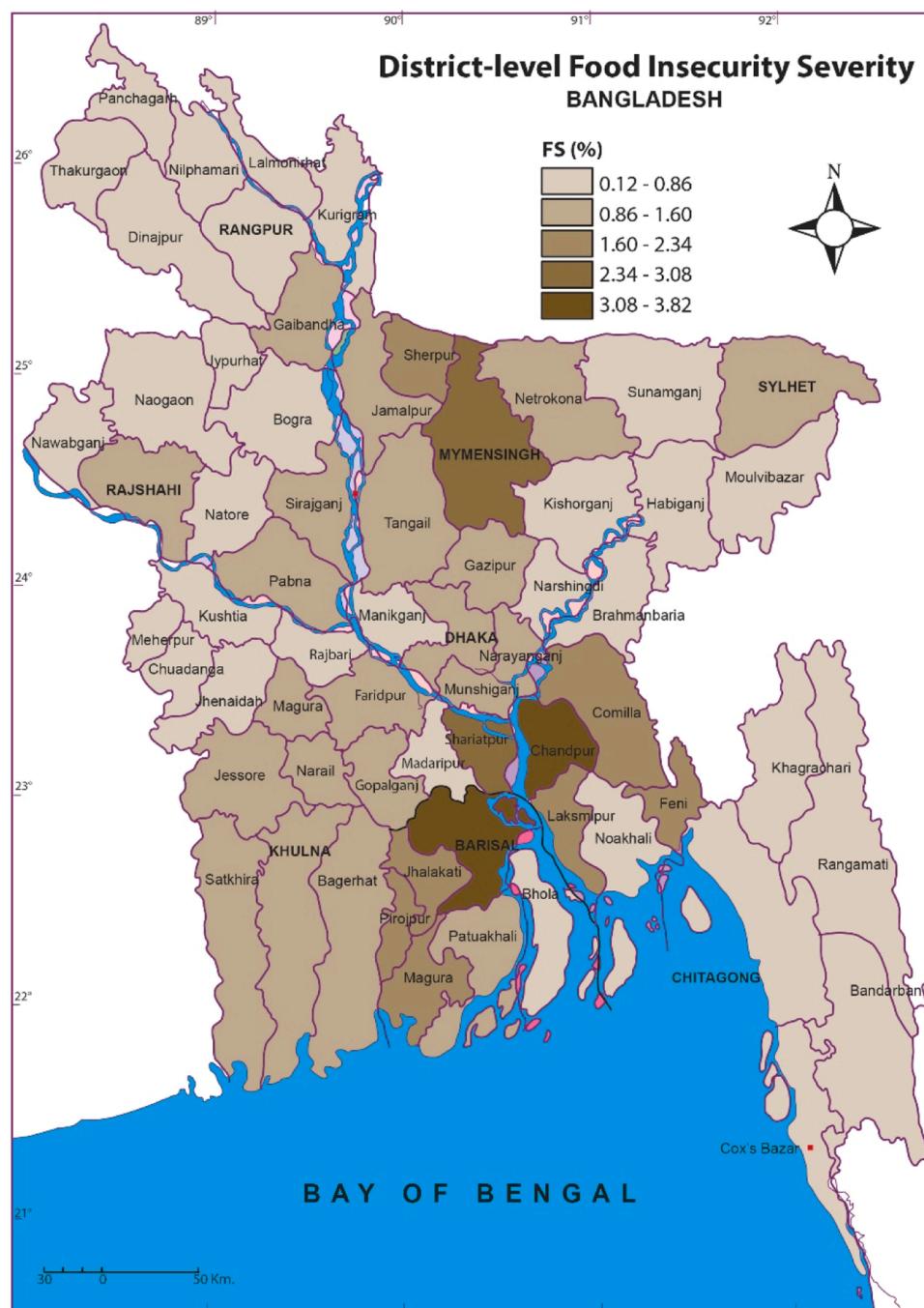


Fig. 8. Status of district level food insecurity in Bangladesh. Adopted from Hossain et al. (2020).

prevention, medium-term preparation, and short-term emergency measures. The objectives are to prevent, respond and contain health risks associated with heat (WHO; 2008a, 2008b). As South Asia is a heat wave-prone area in the global context, Bangladesh is one of the most vulnerable countries among those nations. Bangladesh is a developing country as well as a low-income country (Al-Maruf et al., 2022; Chowdhury et al., 2022). The health system, medical system, and planning for disaster management are not well structured, which could result in destructive effects on vulnerable populations. Being the most vulnerable country, it needs to construct a strong resilience framework for preventing heat wave effects by developing the health system and food supply and chain system by inventing heat-associated or heat-tolerance yields and climate-adaptive crops.

During heat waves, Bangladesh has a number of vulnerable

communities that need extra care. These comprise the elderly, small children, expectant mothers, and people suffering from long-term illnesses. These populations should be identified by the government, which should also make sure they have access to sufficient medical care, cooling centers, and clean drinking water. Encouragement of climate-smart agricultural methods Bangladesh is an agricultural nation, and the growth of the economy and social fabric of the nation are closely linked to the agricultural sector. Therefore, in order to lessen the negative effects of heat waves on food security, it is imperative to promote climate-adaptive agricultural practices. Crop diversity, drought-resistant crop introduction, and water resource conservation are a few examples of this. Bangladesh should give disaster risk reduction measures a priority since they can help prevent heat-related illnesses and injuries. This includes putting in place early warning systems, creating

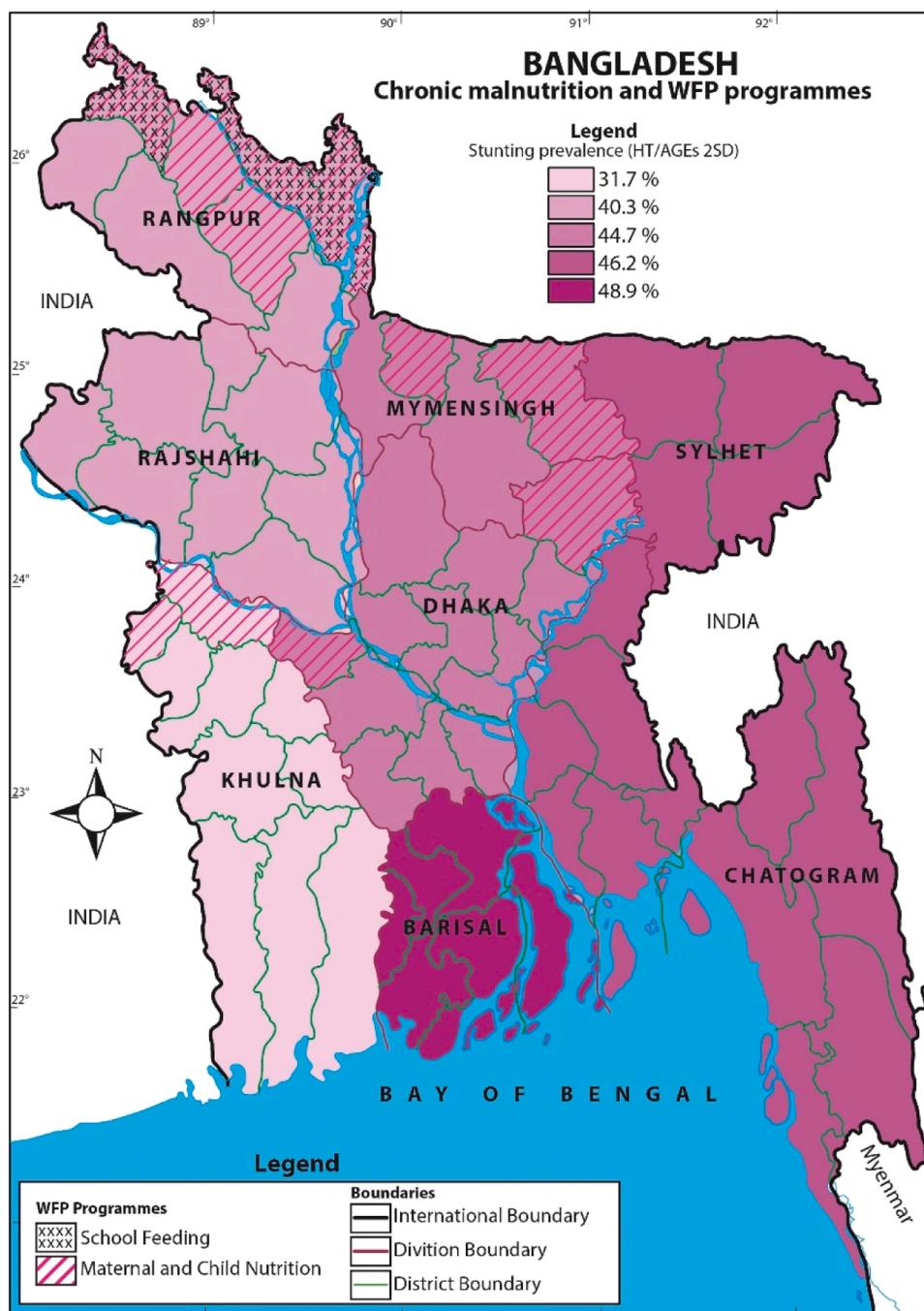


Fig. 9. Status of malnutrition in Bangladesh. Adopted from WFP (2006).

community-based emergency plans, and distributing health messaging tailored to particular heat waves.

Public health interventions to address the health effects of heat waves, the government should prioritize public health interventions. This includes the implementation of emergency protocols, the establishment of heat wave health warning systems, and increasing the capacity and access to healthcare services. Education and awareness-raising campaigns are essential to ensuring that communities are equipped with the knowledge and skills to cope with heat waves. This involves engaging communities in educational campaigns that promote heat wave preparedness, awareness of health risks, and climate-resilient practices (Al-Maruf et al., 2021). The preventions mentioned above are inter-related, and implementation of each component requires collaboration between different stakeholders, including farmers, health

workers, community leaders, and government agencies. The government of Bangladesh should establish policies and programs that integrate these components and involve communities in decision-making processes.

World relevance organizations and governments must take action to mitigate the effects of climate change, reduce greenhouse gas emissions, and invest in climate adaptation measures. Individuals can also take actions, such as conserving water, reducing food waste, and supporting local farmers. To address these issues and diminish their impact on vulnerable people, immediate action is required. We can lessen the harmful effects of heat waves and create a more sustainable and resilient future by working together.

Finally, building human health resilience during heatwaves in Bangladesh is a complex and multifaceted challenge. The framework

presented below (Fig. 8) is a starting point for policymakers, practitioners and researchers to design programs and initiatives that promote climate resilience and prevent the negative impacts of heatwaves on human health and food security. By implementing this framework, Bangladesh can strengthen its resilience to heatwaves by improving its ability to endure heatwaves, changing its agricultural practices and improving the well-being of citizens by putting this paradigm into practice (Fig. 10).

5. Conclusion

South Asian countries, particularly Bangladesh, have experienced more frequent heatwaves due to its geographical location in the world. Heat waves undoubtedly have a major influence on food security, which emphasizes the pressing need to address climate change and create plans to make agricultural systems more resilient to extreme weather events. To prevent future threats to the population, an adequate understanding of the impacts of heat waves on food security and human health is required. Bangladesh has limited adequate economic conditions to support sufficient food production, food supply and food access due to several issues such as price inflation, rain-fed system, climate-sensitive crops and yields and a seasonal agricultural structure. Further

heatwaves may lead to crop failures, reduced yields and damage to livestock, affecting the food supply chain and leading to food shortages and price increases. To address these challenges, our framework for improving health resilience in Bangladesh includes measures such as improving climate information systems for better preparedness, improving irrigation infrastructure, promoting crop diversification and the use of drought-tolerant seeds, and investing in renewable energy to reduce dependency of reducing fossil fuels. In addition, social safety nets such as food assistance programs can help mitigate the impact of food shortages on vulnerable groups, while strengthening local food systems and building the capacity of smallholder farmers can help promote food sovereignty and resilience. Overall, addressing the impacts of heat waves on food security in Bangladesh requires a comprehensive approach that includes both short-term and long-term strategies to build resilience and promote sustainable development. To overcome health challenges, our framework includes measures such as building more resilient infrastructure, including cooling centers in densely populated areas, a climate-resilient care system and improving access to quality healthcare. Additionally, community-based strategies such as public education campaigns on heat safety and the promotion of shade trees and green spaces can help reduce the impact of the heat wave on vulnerable populations. To address the interface between heatwaves and

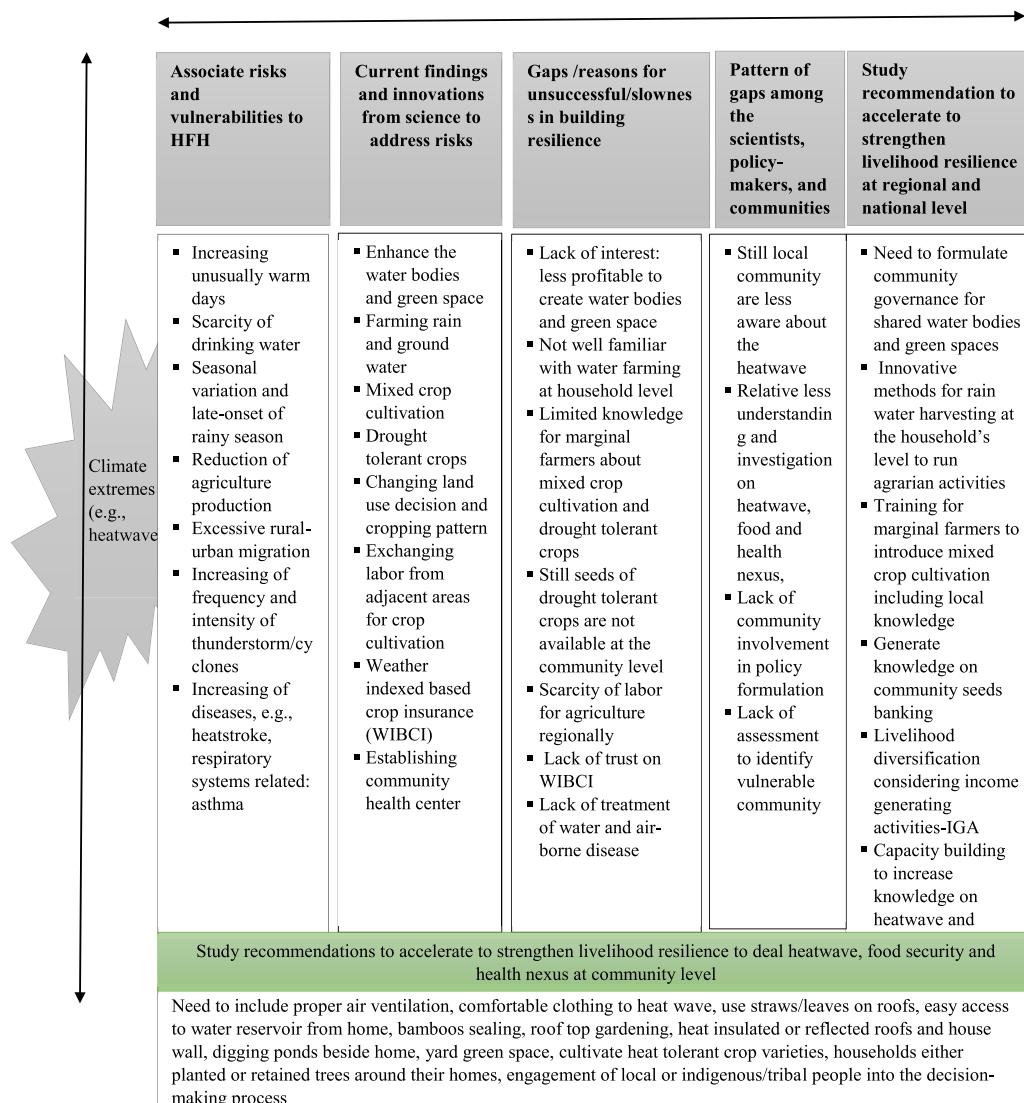


Fig. 10. A Framework for addressing heatwave, food security, and human health nexus. Based on Al-Maruf et al. (2021), Tawsif et al. (2022), Turek-Hankins et al. (2021), Rahman et al. (2021), and case study.

human health, it is critical to prioritize both short-term and long-term strategies to promote public health and environmental sustainability. This may include measures such as reducing greenhouse gas emissions, promoting energy efficiency and strengthening disaster preparedness and response capacity.

In order to address the nexus of heat waves, food security, and human health, a comprehensive approach that prioritizes sustainable agriculture and environmental sustainability is necessary (Figure). This framework demonstrates the complex relationship among heatwaves, food security, and human health. The heat wave, food security, and human health nexus requires more attention to be paid to building a resilience system through the collaboration of multi-disciplinary sectors like water, health, agriculture, the environment, urban planning, trade, social policy planning, and relevant stakeholders. All these sectors together can play a collaborative role in building a resilient food system and health system framework for the country.

Addressing the link between heatwaves, food security and human health requires a comprehensive approach that prioritizes sustainable agriculture and environmental sustainability (Figure). This framework illustrates the complex relationship between heatwaves, food security and human health. The connection between heatwave, food security and human health requires that more attention be paid to building a resilience system through the collaboration of multidisciplinary sectors such as water, health, agriculture, environment, urban planning, trade, social policy planning, etc. and relevant stakeholders. All these sectors together can play a collective role in building a resilient food and health systems framework for the country. Further research and data collection are needed to better understand the specific impacts of heatwaves, food insecurity and health challenges faced by Bangladesh. This framework can be a useful guiding tool for further research and lead future researchers to a deep understanding of the relationships between heat waves, food security and human health. Additionally, further research can be conducted on the barriers to awareness and how removing them would improve the country's knowledge and preparedness for extreme heat events. This data can serve as the basis for evidence-based policies, programs, and interventions that address their individual needs and vulnerabilities.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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