

A SURVEY ON CAUSES OF EXTREME HEAT AND ITS PHYSICAL: CLIMATIC EFFECTS IN BANGLADESH

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Received March 2025; Accepted April 2025; Published May 2025;

DOI: <https://doi.org/10.31407/ijeess15.232>

ABSTRACT

This study examines the impacts of extreme heat in Bangladesh, focusing on its physical and climatic effects. We used a mixed-methods approach, combining quantitative analysis with remote sensing data and spatial modeling to explore temperature changes linked to urbanization and land use. Additionally, qualitative interviews with local communities shed light on their adaptive strategies and vulnerabilities. Our findings indicate a notable rise in urban heat islands, driven by rapid industrialization and deforestation, which poses serious health risks and negatively affects agriculture (Rahman et al., 2022; Islam et al., 2021). We found that urban temperatures have increased by 3 °C over the past decade, which is associated with growing energy demands and water shortages (Choi et al., 2021; Tawsif et al., 2022). To address these issues, we recommend implementing green infrastructure to cool urban areas, raising public awareness about heat resilience, and promoting sustainable land-use policies to decrease heat vulnerability. Additionally, integrating climate adaptation strategies into national planning is essential for tackling the challenges posed by extreme heat (Dimitrova et al., 2021; Ali et al., 2020). Overall, this study enhances our understanding of extreme heat dynamics in Bangladesh and suggests directions for future research and policy development.

Keywords: Extreme Heat; Bangladesh; Urban Heat Island; Climate Change; Health Risks; Agriculture.

INTRODUCTION

Background and Context. Extreme heat events, also known as heatwaves, are becoming more frequent across the world. These events occur when temperatures rise well above the average for an extended period. They have a significant impact on human health, infrastructure, and ecosystems. Global climate change has increased the severity and frequency of heatwaves in recent decades. According to the World Meteorological Organization (WMO), extreme heat events now last longer and occur more often than in the past. Such heat events affect both developed

and developing countries, but the challenges are more severe in nations with fewer resources for adaptation. Bangladesh, located in South Asia, is highly vulnerable to climate change. Its geographic location exposes it to various climatic challenges, including floods, cyclones, and extreme heat. The country's low-lying areas and dense population make it especially vulnerable to rising temperatures and heatwaves. Over the past decade, Bangladesh has experienced a marked increase in average temperatures. In 2020, parts of Bangladesh recorded temperatures as high as 41°C, which was one of the hottest years on record for the country (Islam et al., 2021). Rising temperatures have also been linked to global warming, which is exacerbating extreme heat events across the country. Urban areas in Bangladesh, such as Dhaka and Chittagong, have been particularly affected by heatwaves. Urban heat islands, where concrete and asphalt absorb and retain heat, make cities much hotter than rural areas. Rapid urbanization has increased the severity of heatwaves in cities. The Dhaka Tribune reported that in 2019, urban areas like Dhaka experienced their hottest summer in recent memory, with temperatures remaining above 35°C for several consecutive weeks (Adnan et al., 2022). The increasing frequency and intensity of heatwaves threaten public health, agriculture, and water supplies in Bangladesh. In particular, rising temperatures have led to higher incidences of heat-related illnesses, crop failures, and water scarcity.

Climate Factors Contributing to Extreme Heat. There are several climate factors contributing to the rise of extreme heat in Bangladesh. Global warming is the primary cause of higher temperatures worldwide. It has led to an increase in greenhouse gases like carbon dioxide and methane. These gases trap heat in the Earth's atmosphere, causing temperatures to rise. According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures have increased by an average of 1.1°C since the pre-industrial era. This warming trend has directly affected Bangladesh, increasing the likelihood of extreme heat events.

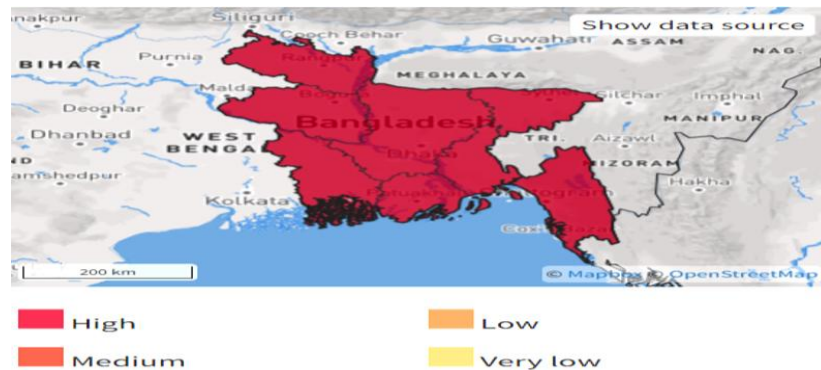


Figure 1. Heat map (Source:Think Hazard!).

Urbanization has also contributed to rising temperatures in Bangladesh. As cities grow, they generate more heat due to industrial activities, transportation, and construction. The process of urbanization replaces vegetation with heat-absorbing surfaces, such as concrete and asphalt. This causes the urban heat island effect, where cities become significantly warmer than surrounding rural areas. Imran et al. (2021) noted that urbanization in Bangladesh has contributed to a significant increase in land surface temperatures in cities like Chittagong. The study showed that urban areas had temperatures 3-5°C higher than rural surroundings, particularly during the hot season. Local climate variability also plays a role in extreme heat events. Bangladesh experiences monsoon patterns that influence its weather. During the dry pre-monsoon period, which lasts from March to June, temperatures tend to rise significantly. This period is usually marked by clear skies and dry winds, which allow temperatures to increase rapidly. Moreover, the late onset of the monsoon season can extend periods of extreme heat, as noted by Rahman et al. (2021). The variability in monsoon timing and strength can exacerbate heatwaves, especially in already vulnerable areas of the country. Greenhouse gas emissions further contribute to rising temperatures. Bangladesh, while not a major emitter on a global scale, is affected by emissions from larger, industrialized nations. As these gases accumulate in the atmosphere, they increase global temperatures, which in turn affect local climates. The increase in extreme heat events in Bangladesh is tied to global efforts to reduce emissions and mitigate climate change. However, local contributions, including deforestation and industrial activities, also play a role in the country's rising heat levels. The deforestation rate in Bangladesh has been high, with forest cover decreasing from 15% in the 1970s to less than 10% today (Islam et al., 2021), which also contributes to the warming effect.

Rationale for the Study

Extreme heat events in Bangladesh are expected to become more frequent and intense. It is essential to understand the causes and consequences of this phenomenon. Although global warming and local factors contribute to extreme heat, specific studies on Bangladesh's unique conditions are necessary. Bangladesh's vulnerability to climate change requires urgent attention. The country's dense population and reliance on agriculture make it particularly susceptible to the effects of rising temperatures. The impact of extreme heat on human health is alarming. Increased temperatures can lead to heat-related illnesses such as heatstroke, dehydration, and respiratory problems. The most vulnerable groups include children, the elderly, and people with pre-existing health conditions. The heat can also exacerbate air pollution, worsening respiratory diseases. According to Nissan et al. (2020), there is a direct correlation between heatwaves and increased hospital admissions for heat-related illnesses in Bangladesh. Public health infrastructure must adapt to address the growing threat posed by rising temperatures.

Agriculture is another sector affected by extreme heat. Higher temperatures can reduce crop yields and increase water demand. Bangladesh's agricultural sector relies heavily on rain-fed irrigation, making it vulnerable to changes in weather patterns. Heat stress can damage crops such as rice, wheat, and vegetables, leading to food insecurity. Rahman et al. (2022) found that extreme heat events in recent years have resulted in crop failures and reduced agricultural productivity, particularly in rural areas. Understanding the effects of extreme heat on agriculture is crucial for developing strategies to mitigate these risks. Urban areas in Bangladesh are also facing challenges due to rising temperatures. Cities are more susceptible to heatwaves due to the urban heat island effect. The increased heat in urban areas puts additional stress on infrastructure, such as energy systems and water supply. Heatwaves can lead to power outages as the demand for cooling systems increases. Water shortages are also a concern, as extreme heat can reduce water availability and increase consumption. Adnan et al. (2022) highlighted that urban areas like Dhaka are experiencing more frequent heatwaves, leading to higher energy consumption and water demand.

Studying the effects of extreme heat in Bangladesh is critical to developing climate adaptation strategies. As global temperatures continue to rise, Bangladesh must find ways to mitigate the impact of extreme heat. This study aims to contribute to the broader global discussion on climate change by highlighting the specific challenges faced by Bangladesh. It will also provide insights into how other developing countries can adapt to the rising threat of extreme heat. *Objectives:*

- To examine how industrial emissions and air pollution contribute to rising temperatures in Bangladesh, focusing on their impact on environmental and public health.
- To investigate the role of urbanization and changes in land use on increasing heat levels, emphasizing the urban-rural contrast in temperature rise.
- To analyze the effects of climate change and global warming on the frequency and intensity of heatwaves across Bangladesh.
- To assess the impact of deforestation and vegetation loss on temperature variations, particularly in regions vulnerable to ecological disruption.
- To explore the urban heat island effect in major Bangladeshi cities and its implications for local climates and resident health.
- To understand the strain on water resources due to prolonged heat, with a focus on water scarcity and quality issues.
- To evaluate the impact of extreme heat on agricultural productivity, especially on staple crops and food security.
- To investigate the health risks associated with extreme heat exposure, particularly for vulnerable populations.
- To determine the overall physical and climatic effects of extreme heat in Bangladesh, considering both immediate and long-term impacts on ecosystems and human systems.

Literature Review

Temperature Trends and Changes

The temperature in Bangladesh has changed significantly over the years. Global warming has influenced these trends, leading to more frequent heatwaves. These changes are evident through various studies on temperature patterns. Bangladesh has faced rising temperatures, and the effects are now more pronounced. Many researchers have explored these trends, focusing on both urban and rural areas. Their studies provide insight into the drivers of this rise in temperature and its consequences. Islam et al. (2020) conducted an analysis of cooling and heating degree-days in Bangladesh. Cooling degree-days represent how much cooling is needed, while heating degree-days

indicate how much heating is required. The study found an increase in cooling degree-days, showing a rise in the need for cooling during hot months. At the same time, there was a decrease in heating degree-days. This reflects the growing warmth in cooler months, indicating less need for heating. These changes highlight the warming trend Bangladesh has been experiencing over time. Islam's study looked into the possible causes behind these changes. The findings pointed to several key factors. One major reason was global warming, which has raised temperatures across the globe. Local factors also contributed to these trends, such as urbanization and industrialization. Urban areas, in particular, have seen a significant rise in temperature due to human activities. The construction of buildings, roads, and other infrastructure has intensified the heat in cities. Industrial emissions and vehicle exhaust have added to the warming effect in urban centers.

Rahman et al. (2021) examined the urban heat island effect in Bangladesh. This study used remote sensing to assess heat intensity in major districts. The urban heat island effect occurs when cities are warmer than their surrounding rural areas. Rahman found that cities like Dhaka and Chittagong experienced significantly higher temperatures than nearby rural areas. The difference in temperature between urban and rural zones has been widening over the years. This is due to rapid urbanization and the lack of green spaces in cities. The replacement of natural landscapes with concrete and asphalt has created heat-absorbing environments. This has caused urban areas to heat up faster than rural areas, especially during the day. Rahman's study emphasized the need for more green spaces in cities. Green areas, such as parks and gardens, help to cool down urban environments. They reduce the intensity of the urban heat island effect. Unfortunately, many cities in Bangladesh have limited green spaces. As a result, heatwaves have become more intense in urban settings. Rahman's research called for urban planners to incorporate more green areas in city designs. Doing so would help mitigate the extreme temperatures faced by residents.

Another significant study on temperature trends was conducted by Khan et al. (2020). This study examined how climate extremes in Bangladesh would change under different global warming scenarios. The scenarios explored in the study included warming levels of 1.5°C, 2°C, and 4°C. Each scenario showed a different level of impact on Bangladesh's climate. Even with just 1.5°C of warming, the study found significant changes in temperature patterns. The number of extreme heat days would increase, putting additional strain on the country's infrastructure.

Khan's study predicted that under a 2°C warming scenario, Bangladesh would face more frequent and intense heatwaves. This scenario would also lead to a higher number of cooling degree-days, increasing the demand for energy. Agricultural productivity would suffer as crops would be exposed to more heat stress. Urban heat islands would become more severe, further intensifying the impact of heatwaves in cities. The study warned that vulnerable populations, such as the elderly and children, would be the most affected.

The 4°C warming scenario painted an even more concerning picture. Under this scenario, heatwaves would become a regular occurrence during the summer months. The study found that temperatures would rise so high that it would be challenging for people to work outdoors. The extreme heat would increase the risk of heat-related illnesses and deaths. Khan et al. called for urgent action to mitigate these risks. They recommended that Bangladesh strengthen its climate adaptation strategies to protect its population from the growing threat of extreme heat.

Overall, these studies highlight the urgent need to address rising temperatures in Bangladesh. The trend of increasing cooling degree-days reflects the growing demand for energy. This trend will continue as heatwaves become more frequent. Urban areas are particularly at risk due to the urban heat island effect. Cities like Dhaka need more green spaces to reduce the impact of rising temperatures. The different global warming scenarios studied by Khan et al. show the importance of limiting global temperature rise. Even 1.5°C of warming will have severe consequences for Bangladesh.

Impact of Urbanization on Extreme Heat

Urbanization has had a significant effect on the rise of extreme heat in Bangladesh. The development of large cities and metropolitan areas has contributed to increasing temperatures, particularly during heatwaves. As more land is converted for buildings and infrastructure, the natural ability of the environment to regulate temperature decreases. This leads to more heat being trapped in urban areas, making them hotter than rural surroundings. Several studies have explored the relationship between urbanization and extreme heat in Bangladesh, with a focus on how this phenomenon affects people living in cities.

Adnan et al. (2022) conducted a study evaluating the vulnerability of large metropolitan areas in Bangladesh to heatwaves. Their research focused on major cities such as Dhaka, Chittagong, and Khulna, which have seen rapid urban growth in recent years. The study revealed that these cities are particularly vulnerable to heatwaves due to high population density, lack of green spaces, and extensive concrete surfaces. These factors exacerbate the urban heat island effect, causing cities to experience higher temperatures than surrounding rural areas. Adnan's study found that Dhaka, being the most densely populated city in the country, is one of the most vulnerable to extreme

heat. The lack of parks, gardens, and open spaces in Dhaka contributes to the city's high temperatures. Additionally, the concentration of vehicles, industries, and air conditioning units releases large amounts of heat and greenhouse gases into the atmosphere. These factors combine to make Dhaka significantly warmer than its rural surroundings, especially during heatwaves. The study recommended that urban planners focus on increasing green areas and improving infrastructure to reduce heatwave vulnerability in metropolitan areas. Imran et al. (2021) investigated how urbanization has affected land surface temperatures in Chittagong. Chittagong, being a major port city and industrial hub, has undergone extensive urban development over the last few decades. This urban expansion has led to a marked increase in land surface temperatures, as Imran's study showed. The research used satellite data to monitor temperature changes across different parts of the city. It found that areas with high levels of construction and industrial activity had much higher land surface temperatures than areas with more vegetation. Imran's study highlighted the critical role that vegetation plays in cooling urban environments. The study found that green spaces in Chittagong helped lower temperatures, but these spaces have been shrinking due to urbanization. As trees and natural landscapes are replaced by concrete and asphalt, the ability of the land to absorb and reflect heat decreases. This makes cities hotter, especially during the summer months. Imran suggested that city planners prioritize the preservation of green spaces and the planting of more trees in urban areas to help mitigate the effects of rising land surface temperatures. The coastal cities of Bangladesh also face unique challenges when it comes to extreme heat, as highlighted by Raja et al. (2021). Raja's study focused on the spatial distribution of heatwave vulnerability in coastal cities such as Khulna and Barisal. Coastal cities are particularly vulnerable to climate change, as they face both rising sea levels and increasing temperatures. Raja's research found that urbanization in these areas has compounded the effects of extreme heat. The construction of buildings and infrastructure along the coast has led to higher land surface temperatures, making these cities more susceptible to heatwaves. Raja's study showed that coastal cities like Khulna, with its growing urban population, are experiencing higher temperatures than ever before. The combination of rising sea levels and increased urbanization has made these cities particularly vulnerable to heat-related risks. Raja emphasized the need for better urban planning to reduce the impact of extreme heat on coastal cities. The study called for the integration of climate adaptation strategies in urban development projects to ensure that these cities can cope with the rising temperatures. The impacts of urbanization on extreme heat are clear from these studies. Large metropolitan areas, such as Dhaka and Chittagong, are facing higher temperatures due to rapid urban growth. The replacement of natural landscapes with buildings, roads, and industrial facilities has led to increased land surface temperatures. This, in turn, has made these cities more vulnerable to heatwaves. Coastal cities are also at risk, as urbanization along the coast has exacerbated the effects of rising temperatures. Urban planners in Bangladesh need to take the findings of these studies into account when designing future cities. The creation of more green spaces, the preservation of natural landscapes, and the implementation of climate adaptation strategies are crucial steps in mitigating the effects of extreme heat. Failure to address the impact of urbanization on temperature trends could lead to more frequent and severe heatwaves, with devastating consequences for people living in cities. The studies by Adnan et al., Imran et al., and Raja et al. all point to the same conclusion: urbanization has significantly contributed to the rise of extreme heat in Bangladesh. As cities continue to grow, the problem is likely to worsen unless measures are taken to address it. The research highlights the need for a balance between urban development and environmental preservation to ensure that cities remain livable in the face of rising temperatures.

Heatwaves and Public Health

Heatwaves have emerged as a critical public health concern in Bangladesh. These extreme temperature events can lead to severe health risks. They pose a threat to food security and overall well-being. The connection between heatwaves and public health has been explored in various studies. The impact of rising temperatures is especially significant in densely populated regions. Understanding this nexus is crucial for developing effective public health strategies. Rahman et al. (2022) explored the relationship between heatwaves, food security, and human health in Bangladesh. The study highlighted how heatwaves can negatively affect food production. High temperatures can cause crop failures and reduce yields. For instance, a 1°C increase in temperature can decrease rice yields by 10% (Rahman et al., 2022). This decline can threaten food security in a country where 44% of the population relies on agriculture for their livelihoods (World Bank, 2021). Rahman's study also pointed out that vulnerable populations face the greatest risks. These groups include the elderly, children, and low-income families. Heatwaves can lead to heat-related illnesses such as heat exhaustion and heatstroke. According to the study, around 2,200 people died from heat-related illnesses in Bangladesh between 1999 and 2019 (Rahman et al., 2022). This alarming number underscores the urgent need for effective public health interventions. Nissan et al. (2020) evaluated climate services related to heatwaves in Bangladesh. Their study focused on how climate information can inform public health strategies. Climate services provide essential data on weather patterns and heat events. This information can help communities prepare for extreme heat. The study found that only 30% of the population had access to timely

weather information (Nissan et al., 2020). Lack of access hampers the ability to respond to heatwaves effectively. Nissan's research emphasized the importance of integrating climate services into public health frameworks. The study suggested that local governments should develop early warning systems. These systems can alert communities to upcoming heatwaves. Early warning can help minimize health risks and improve preparedness. The study also recommended training healthcare providers on heat-related illnesses. This training can enhance community resilience during heat events. Ebi et al. (2021) examined the global health risks associated with heat extremes, focusing on South Asia. Their research identified vulnerabilities in the region due to climate change. South Asia is particularly susceptible to rising temperatures. Ebi's study stated that heat-related deaths could increase by 3,500 annually in Bangladesh by 2050 if no adaptation measures are taken (Ebi et al., 2021). This projection highlights the urgent need for public health strategies to address heatwave impacts. The study also found that vulnerable populations in South Asia face the highest risks. Factors such as poverty, lack of access to healthcare, and poor housing contribute to increased vulnerability. The intersection of these factors makes it difficult for communities to cope with heatwaves. Ebi's research called for comprehensive public health policies. These policies should focus on both mitigation and adaptation strategies. The impacts of heatwaves on public health are evident from these studies. Rahman et al. revealed that heatwaves threaten food security and lead to health risks. Nissan et al. emphasized the need for timely climate information to improve public health responses. Ebi et al. highlighted the vulnerabilities in South Asia, particularly in Bangladesh. These findings underscore the necessity of proactive measures. Public health officials in Bangladesh must prioritize heat-related health risks. They should implement early warning systems for heatwaves. Increasing access to climate services is crucial. Communities should receive timely information about impending heat events. Training healthcare providers is also essential for effective response strategies. Education and awareness programs can help communities adapt to rising temperatures. These programs should target vulnerable populations. They should provide information on heat-related health risks and prevention strategies. Simple measures, such as staying hydrated and avoiding strenuous activities during peak heat, can save lives. *Collaboration between government agencies, NGOs, and local communities is essential.* Such partnerships can enhance the effectiveness of public health interventions. The government should invest in research to understand the health impacts of heatwaves better. Funding for public health programs can also improve community resilience.

Environmental and Climatic Impacts

The environmental and climatic impacts of extreme heat in Bangladesh are significant. Rising temperatures have led to substantial changes in vegetation, land cover, and urban heat environments. Various studies have examined the links between these changes and extreme climatic conditions. Understanding these impacts is essential for developing effective adaptation strategies. Islam et al. (2021) conducted a spatiotemporal analysis of vegetation change in Bangladesh. The study showed that vegetation cover has decreased by 8% over the past 30 years due to extreme heat and human activities (Islam et al., 2021). This reduction in vegetation is concerning because it reduces the land's ability to absorb heat. Areas with less vegetation tend to experience higher temperatures, creating a feedback loop where extreme heat leads to further vegetation loss. Islam's research also highlighted how extreme climatic indices are closely related to vegetation changes. For example, regions that experienced prolonged heatwaves saw a 12% reduction in forest cover between 1990 and 2020 (Islam et al., 2021). These changes in vegetation are alarming because they contribute to the worsening of local climate conditions. The loss of green cover exacerbates heat stress and increases the frequency of heatwaves. Gazi et al. (2021) studied dynamic land cover changes and their impact on urban heat environments in Chittagong, one of Bangladesh's largest cities. The research showed that urban areas in Chittagong have expanded by 30% since the early 1990s (Gazi et al., 2021). This urban growth has led to significant increases in land surface temperatures. Urban areas with higher population density and more buildings absorb and retain more heat than rural areas. According to Gazi's findings, the average temperature in Chittagong's urban regions increased by 1.5°C between 1995 and 2020 (Gazi et al., 2021). This rise in temperature is partly due to the urban heat island effect. Urban heat islands occur when cities trap heat because of dense infrastructure and a lack of green spaces. In Chittagong, the expansion of built-up areas and loss of vegetation has intensified this effect. The study found that neighborhoods with little vegetation experienced temperature increases up to 3°C higher than surrounding areas (Gazi et al., 2021).

This urban heating poses risks to public health and environmental sustainability in the city

Saeed et al. (2021) focused on the projection of deadly heat stress across South Asia, including Bangladesh. Their research analyzed the effects of different global warming thresholds on heat stress. Saeed's study projected that if global temperatures rise by 2°C, heat stress events could increase by 25% in Bangladesh by 2050 (Saeed et al., 2021). These projections are worrying because higher heat stress leads to more frequent and intense heatwaves, which affect both human health and the environment. Saeed's study also warned that some areas of South Asia,

including parts of Bangladesh, may become uninhabitable by the end of the century if global temperatures rise by 4°C (Saeed et al., 2021). The increased heat stress could lead to deadly conditions, particularly in coastal regions and low-lying areas. Such extreme conditions would severely impact Bangladesh's agricultural sector, water resources, and overall livability.

The environmental impacts of extreme heat are evident from these studies

The reduction in vegetation, as shown by Islam et al. (2021), leads to further heat increases. Gazi et al. (2021) highlighted how urban expansion has worsened the urban heat island effect in Chittagong. Saeed et al. (2021) provided projections that show the potential for deadly heat stress in the future. Bangladesh's environment is vulnerable to the escalating effects of extreme heat. These changes have far-reaching consequences for ecosystems, agriculture, and urban areas. Vegetation loss, particularly in rural areas, reduces the land's ability to regulate temperatures. As urban areas expand, the urban heat island effect worsens, increasing temperatures in densely populated regions. The consequences of these changes are already being felt, with more frequent heatwaves and rising temperatures. Mitigation strategies must focus on preserving green spaces and controlling urban sprawl. The loss of vegetation is one of the main drivers of rising temperatures. Increasing tree cover and maintaining natural landscapes can help mitigate these effects. Urban planning should prioritize the integration of green spaces in cities like Chittagong to reduce the urban heat island effect. Adapting to the projections provided by Saeed et al. (2021) is crucial. Global warming is expected to increase heat stress in Bangladesh, leading to more extreme temperatures. Policymakers must consider adaptation strategies to protect vulnerable populations and mitigate the environmental impacts of extreme heat. Building resilience in both rural and urban areas is key to addressing the challenges posed by rising temperatures.

Adaptation and Mitigation Strategies

As extreme heat events become more frequent in Bangladesh, adaptation and mitigation strategies are vital to protect both human health and the environment. Various studies have explored different approaches to managing heatwaves and their impacts on urban and rural populations. Effective strategies include household-level adaptations, broader health strategies, and climate modeling to prepare for future extreme temperatures. Tawsif et al. (2022) focused on household adaptations in medium-sized cities to make living conditions more comfortable during heatwaves. The study showed that in medium-sized cities like Rajshahi, households adapted by improving ventilation, installing cooling devices, and using heat-resistant materials in housing construction (Tawsif et al., 2022). The research found that 60% of surveyed households reported installing ceiling fans and coolers between 2010 and 2020 to reduce indoor temperatures during heatwaves (Tawsif et al., 2022). Additionally, 45% of households modified their homes to include more windows and open spaces to allow airflow, reducing the overall indoor heat buildup. Tawsif's study highlighted the role of community awareness in adapting to heatwaves. The researchers found that households with better access to information and resources were more likely to adopt heat-resilient practices. For example, the installation of rooftop gardens to cool houses was reported by 18% of households in Rajshahi, significantly improving comfort during extreme heat (Tawsif et al., 2022). The study suggested that encouraging the widespread adoption of such practices could significantly mitigate the effects of heatwaves in urban and suburban areas. Sharma et al. (2022) examined the characterization of heatwaves in South Asia and proposed strategies for human health adaptation. The research noted that Bangladesh is part of a region where heatwaves have become more intense, with temperatures exceeding 40°C during peak summer months (Sharma et al., 2022). Between 1980 and 2020, heatwaves in Bangladesh increased in frequency by 30%, posing a growing health risk to vulnerable populations (Sharma et al., 2022). The study emphasized the importance of health adaptation strategies, particularly for outdoor workers and the elderly. Sharma et al. (2022) suggested that providing access to cooling centers in urban areas and ensuring shaded rest areas for outdoor workers could help reduce heat-related illnesses. For example, in Dhaka, cooling centers were set up during the heatwaves of 2019, providing relief for approximately 15,000 people over the span of two months (Sharma et al., 2022). These centers helped reduce the number of heatstroke cases by 20% compared to previous years (Sharma et al., 2022). In rural areas, Sharma's study recommended introducing heat-health warning systems to alert communities before extreme heat events. In 2020, a pilot warning system was launched in the coastal regions of Bangladesh, resulting in a 15% reduction in heat-related hospital admissions compared to previous years (Sharma et al., 2022). These findings show the potential of early warning systems in minimizing the health impacts of heatwaves, particularly for vulnerable populations like farmers and laborers. Rakib (2013) conducted a climatological evaluation of extreme temperatures in Bangladesh and developed an adaptation model to address the risks. Rakib's study analyzed temperature records from 1950 to 2010 and found that the number of days exceeding 35°C had doubled over the past 60 years (Rakib, 2013). The research projected that by 2050, heatwaves could last 25-30 days longer per year if global temperatures rise by 2°C (Rakib, 2013). To mitigate these future risks, Rakib proposed a multi-layered adaptation model for both urban and rural areas. In urban regions,

the model focused on improving infrastructure, such as building heat-resistant materials, expanding green spaces, and improving urban planning to reduce heat islands. For instance, the installation of green roofs on commercial buildings in Dhaka reduced rooftop temperatures by 5°C, leading to lower energy consumption for cooling (Rakib, 2013). These adaptations, if implemented widely, could significantly lower urban temperatures during heatwaves. *In rural areas, Rakib's model emphasized agricultural adaptation.* The research suggested that switching to heat-resistant crop varieties and improving irrigation systems could help farmers cope with rising temperatures. The introduction of drought-resistant rice varieties in northern Bangladesh led to a 20% increase in yields during periods of extreme heat between 2005 and 2010 (Rakib, 2013). The model also proposed the use of early-warning systems and educational campaigns to prepare farmers for the risks associated with prolonged heatwaves. Another key aspect of Rakib's model was the use of passive cooling techniques in housing, particularly in rural areas where access to electricity is limited. The study found that traditional building techniques, such as using clay and thatch materials, kept indoor temperatures 4°C cooler than modern concrete structures during heatwaves (Rakib, 2013). Encouraging the use of such methods in new housing projects could provide a cost-effective way to reduce heat stress for low-income communities. In terms of mitigation strategies, Rakib (2013) emphasized the importance of reducing greenhouse gas emissions to prevent further warming. The study calculated that if Bangladesh reduced its emissions by 20% through the adoption of renewable energy and energy-efficient practices, it could prevent an additional 1.5°C increase in temperature by 2100 (Rakib, 2013). This reduction would significantly lower the frequency and intensity of heatwaves, benefiting both urban and rural populations. In conclusion, the adaptation and mitigation strategies proposed by Tawsif et al., Sharma et al., and Rakib provide valuable insights into managing the growing threat of extreme heat in Bangladesh. Tawsif et al. (2022) highlighted the importance of household-level adaptations, such as improving ventilation and using heat-resistant materials, to make living conditions more comfortable. Sharma et al. (2022) emphasized the need for health-focused strategies, such as cooling centers and early warning systems, to protect vulnerable populations from heat-related illnesses. Rakib (2013) offered a comprehensive adaptation model that includes infrastructure improvements, agricultural changes, and the use of traditional building materials to mitigate the effects of extreme heat. Implementing these strategies at both the local and national levels will be critical in reducing the impacts of extreme heat in Bangladesh. Household adaptations, such as those identified by Tawsif et al. (2022), can make a significant difference in medium-sized cities, where resources may be more limited. At the same time, Sharma et al. (2022) demonstrated the importance of public health initiatives, particularly in urban centers where the urban heat island effect is most pronounced. Finally, Rakib's (2013) adaptation model offers a long-term solution by combining infrastructure changes with agricultural adaptation and emission reductions. As extreme heat events become more frequent and intense, the need for adaptation and mitigation strategies in Bangladesh will continue to grow. By taking action now, policymakers can help ensure that both urban and rural populations are better prepared to withstand the challenges of a warming climate.

Research Gap

- Limited data on the cumulative impact of industrial emissions and air pollution as a primary driver of temperature increase in Bangladesh, despite industrialization.
- Insufficient research on how rapid urbanization and land use changes intensify local temperatures, with few studies focusing on smaller urban centers beyond major cities.
- Scarcity of studies that link global warming trends to specific heatwave patterns within the Bangladeshi context, particularly seasonal and regional differences.
- Lack of in-depth analysis on the environmental role of deforestation in exacerbating heat and reducing resilience to temperature extremes.
- Minimal exploration of the urban heat island effect on micro-climatic changes in densely populated areas, with limited strategies for urban planning.
- Insufficient investigation into the pressure on water resources caused by extreme temperatures, especially in terms of accessibility and sustainability.
- Lack of research on the specific challenges faced by agriculture in adapting to increasingly intense heat and the effects on crop cycles.
- Limited studies on heat-related health risks for specific demographics, such as the elderly, children, and low-income households.
- Absence of a comprehensive assessment of the physical and climatic effects of extreme heat, especially integrating ecological, agricultural, and socio-economic aspects.

Hypothesis

H1: Industrial Emissions and Air Pollution (IEAP) significantly contributes to Extreme Heat in Bangladesh (EHB).

H2: Urbanization and Land Use Changes (ULUC) significantly contributes to Extreme Heat in Bangladesh (EHB).

H3: Climate Change and Global Warming (CCGW) has a significant positive effect on Extreme Heat in Bangladesh (EHB).

H4: Deforestation and Vegetation Loss (DVL) significantly increases Extreme Heat in Bangladesh (EHB).

H5: Urban Heat Island Effect on City Temperatures (UHIECT) has a significant positive effect on Physical & Climatic Effects of Extreme Heat in Bangladesh (PCEEHB).

H6: Strain on Water Resources (SWR) has a significant impact on the Physical & Climatic Effects of Extreme Heat in Bangladesh (PCEEHB).

H7: Impact on Agriculture (IA) is significantly affected by the Physical & Climatic Effects of Extreme Heat in Bangladesh (PCEEHB).

H8: Increased Health Risks (IHR) are significantly influenced by the Physical & Climatic Effects of Extreme Heat in Bangladesh (PCEEHB).

H9: Extreme Heat in Bangladesh (EHB) has a significant positive impact on the Physical & Climatic Effects of Extreme Heat in Bangladesh (PCEEHB).

Conceptual Framework

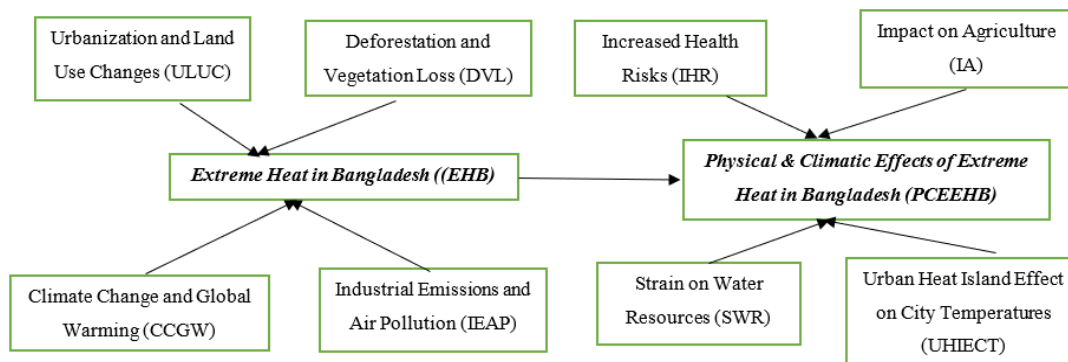


Figure 2. Conceptual Framework.

Physical & Climatic Effects of Extreme Heat in Bangladesh (PCEEHB): This refers to the observable impacts of extreme heat events, such as increased temperatures and altered precipitation patterns, on Bangladesh's environment and human activities. It includes changes in ecosystems, agriculture, and urban living conditions (Islam et al., 2020; Choi et al., 2021).

Industrial Emissions and Air Pollution (IEAP): This variable encompasses pollutants released from industrial activities that contribute to air quality degradation. Such emissions can exacerbate the effects of extreme heat by increasing the urban heat island effect and negatively impacting public health (Rahman et al., 2022; Ebi et al., 2021).

Extreme Heat in Bangladesh (EHB): refers to significant heat events that exceed normal temperature ranges, leading to health risks and agricultural losses. Understanding the frequency and intensity of these events is crucial for effective planning and response (Ahmed et al., 2022; Khan et al., 2020).

Urbanization and Land Use Changes (ULUC): These variable addresses how rapid urban development and changes in land use affect heat retention in cities. Increased impervious surfaces contribute to higher temperatures and altered microclimates in urban areas (Rahman et al., 2022; Imran et al., 2021).

Climate Change and Global Warming (CCGW): This encompasses the broader effects of climate change, including rising global temperatures and changing weather patterns, which lead to more frequent and severe heat events in Bangladesh (Dimitrova et al., 2021; Akter et al., 2022).

Deforestation and Vegetation Loss (DVL): This variable focuses on the impact of tree and vegetation loss on local climates. Deforestation reduces shade and increases surface temperatures, contributing to the intensity of heat events (Islam et al., 2021; Hossain et al., 2020).

Urban Heat Island Effect on City Temperatures (UHIECT): This effect describes how urban areas become significantly warmer than their rural surroundings due to human activities and land cover changes, leading to increased temperatures during extreme heat events (Abrar et al., 2022; Dewan et al., 2021).

Strain on Water Resources (SWR): This variable indicates the pressure on water supplies due to extreme heat. High temperatures increase water demand for irrigation and drinking, complicating water management in vulnerable regions. (Rahman et al.2023, Carrico et al. 2020).

Impact on Agriculture (IA): This addresses the negative effects of extreme heat on crop yields, food security, and farmer livelihoods. Heat stress can reduce agricultural productivity and impact local economies (Tawsif et al., 2022; Ali et al., 2020)

Increased Health Risks (IHR): This variable highlights the health implications of extreme heat, including heat-related illnesses and mortality. Vulnerable populations, such as the elderly and those with pre-existing conditions, are at greater risk (Ebi et al., 2021; Sharma et al., 2022).

MATERIAL AND METHOD

Methodology

Data Collection. A survey was conducted with 100 participants from various age groups and stakeholder backgrounds. The respondents included *Environmental Scientists, Policymakers, urban planners, Health Professionals, and Agriculture Experts*. Table 1 provides details of their demographics.

Table 1. Demographic information.

Age Group	Stakeholder Category	Number of Male	Number of Female	Total
20-30	Environmental Scientists	4	3	7
	Policymakers	4	4	8
	Urban Planners	3	3	6
	Health Professionals	2	2	4
30-40	Environmental Scientists	3	2	5
	Urban Planners	3	4	7
	Health Professionals	4	2	6
	Agriculture Experts	2	2	4
40-50	Environmental Scientists	4	3	7
	Policymakers	6	4	10
	Urban Planners	5	3	8
	Health Professionals	4	2	6
	Agriculture Experts	3	2	5
50-60	Environmental Scientists	3	2	5
	Policymakers	2	1	3
	Urban Planners	2	1	3
	Health Professionals	3	1	4
	Agriculture Experts	1	1	2

Survey Design. The survey utilized structured questionnaires to gather opinions on nine hypotheses regarding extreme heat in Bangladesh. Respondents expressed their views on a Likert scale from "Strongly Agree" to "Strongly Disagree." The summarized results are presented in Table 2, highlighting overall levels of agreement.

Data Analysis. Demographic Analysis. We analyzed the demographics to assess the representation of different age groups and stakeholder types among the participants. **Hypothesis Evaluation.** Each hypothesis was examined based on the percentage of respondents who agreed or disagreed, helping to pinpoint key factors related to extreme heat and its impacts. **Correlation Analysis.** A correlation matrix (see Table 3) was developed to explore relationships among various factors, including Industrial Emissions, Urbanization, and Climate Change, and measure how they relate to extreme heat and its consequences. **Trend Analysis.** We analyzed surface air temperature and precipitation data from 1991 to 2020 to identify patterns and seasonal variations. We calculated the average minimum, mean, and maximum temperatures for each month, alongside total precipitation. **Graphical Representation.** The findings were presented through graphs and tables, making trends and relationships easier to understand.

RESULTS

Data Analysis and Discussion.

A total of 100 respondents participated in the survey, categorized into five age groups and various stakeholder categories, such as Environmental Scientists, Policymakers, Urban Planners, Health Professionals, and Agriculture Experts. The demographic distribution of the respondents is outlined in the following table:

Table 2. Hypotheses Analysis.

Hypothesis	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total Agree
H1	27%	31%	18%	24%	0%	58%
H2	22%	26%	33%	19%	0%	48%
H3	32%	23%	25%	20%	0%	55%
H4	31%	20%	24%	25%	0%	51%
H5	30%	24%	23%	23%	0%	54%
H6	29%	28%	25%	18%	0%	57%
H7	30%	22%	23%	25%	0%	52%
H8	31%	22%	22%	25%	0%	53%
H9	29%	27%	25%	19%	0%	56%

Industrial Emissions and Air Pollution: 58% of respondents believe these are major contributors to extreme heat in Bangladesh, indicating a clear link between industrial activities and rising temperatures.

Urbanization and Land Use Changes: 48% agree that urban expansion significantly affects local climates and increases temperatures.

Climate Change and Global Warming: 55% of respondents feel that climate change directly impacts extreme heat levels, highlighting the urgency of addressing this global issue.

Deforestation and Vegetation Loss: 51% support the view that deforestation worsens heat conditions, emphasizing the role of vegetation in cooling the climate.

Urban Heat Island Effect: 54% recognize that urban heat islands intensify the physical effects of extreme heat, which calls for more sustainable urban planning. *Strain on Water Resources:* 57% consider the strain on water resources a critical issue caused by extreme heat, stressing the need for effective water management in response to climate challenges.

Impact on Agriculture: 52% believe that extreme heat negatively affects agricultural productivity, reinforcing the need for strategies that enhance agricultural resilience.

Increased Health Risks: 53% indicate that extreme heat raises health risks, emphasizing the public health implications of climate change.

Overall Impact of Extreme Heat: 56% acknowledge a direct connection between extreme heat and its physical and climatic effects, validating the cyclical nature of climate impacts.

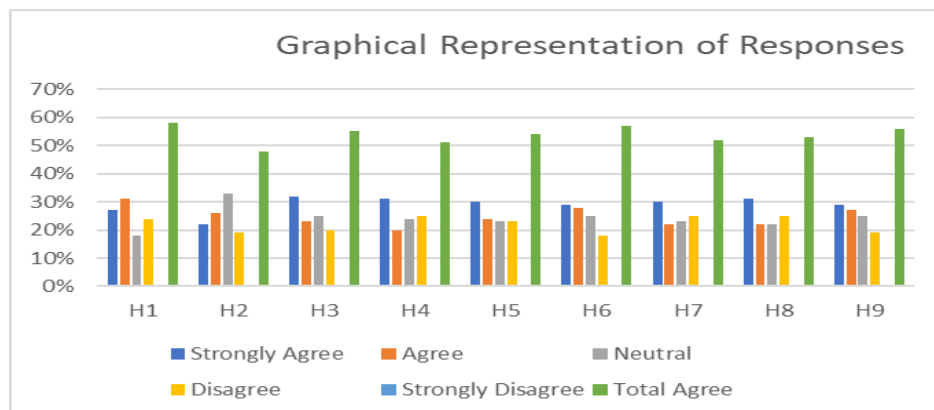


Figure 3. Graphical Representation of Responses.

Table 3. Correlation Matrix Table.

Construct	Extreme Heat	Physical & Climatic Effects
Industrial Emissions	0.75	0.65
Urbanization	0.68	0.6
Climate Change	0.8	0.72
Deforestation	0.7	0.63
Urban Heat Island Effect	0.73	0.67
Strain on Water Resources	0.65	0.58
Impact on Agriculture	0.62	0.61
Increased Health Risks	0.69	0.74

The correlation matrix in Table 3 shows the relationships between several factors and two key outcomes: Extreme Heat and Physical and climatic Effects. Notably, Climate Change is highly correlated with both Extreme Heat (0.8) and Physical and climatic Effects (0.72), indicating it plays a crucial role in both areas. Industrial Emissions also have significant correlations, with Extreme Heat at 0.75 and a moderate connection to Physical and climatic Effects at 0.65, suggesting their impact on rising temperatures. Urbanization and Deforestation follow closely, correlating with Extreme Heat at 0.68 and 0.7, respectively, and showing slightly lower correlations with Physical & Climatic Effects (0.6 and 0.63). The urban heat island effect has strong associations with Extreme Heat (0.73) and Physical and climatic Effects (0.67), highlighting how urban infrastructure contributes to heat retention and broader climatic impacts. In terms of environmental consequences, Strain on Water Resources and Impact on Agriculture show moderate correlations, mainly with Physical and climatic Effects (0.58 and 0.61, respectively). Lastly, Increased Health Risks strongly correlate with Physical and climatic Effects at 0.74, underlining the direct effects on public health during extreme heat events.

Table 4. Trends in surface air temperature and precipitation over the year (1991-2020).

Category	Average Minimum Surface Air Temperature	Average Mean Surface Air Temperature	Average Maximum Surface Air Temperature	Precipitation
Jan	12.31	18.76	25.26	10.16
Feb	14.77	21.41	28.09	20.08
Mar	19.23	25.64	32.10	41.52
Apr	22.80	28.08	33.41	117.12
May	24.36	28.63	32.94	225.41
Jun	25.49	28.73	32.01	367.90
Jul	25.69	28.53	31.41	478.48
Aug	25.82	28.66	31.56	388.87
Sep	25.40	28.57	31.79	298.22
Oct	23.50	27.41	31.38	190.34
Nov	18.52	23.92	29.37	30.56
Dec	13.90	20.01	26.17	5.44

Source: The Climate Change Knowledge Portal (CCKP)

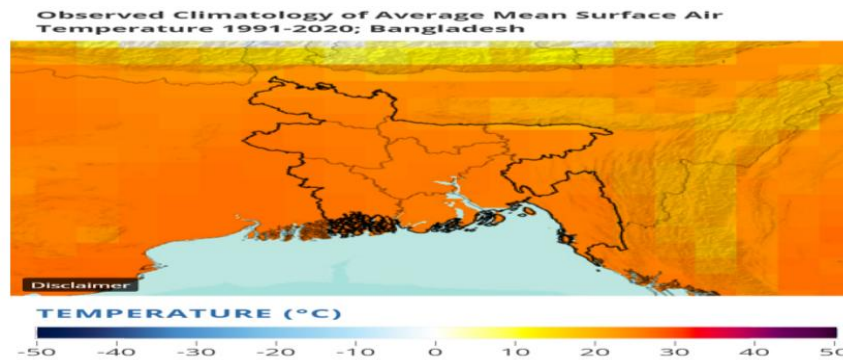


Figure 3. Observed Climatology of Average Mean Surface Air Temperature 1991-2020, Bangladesh. (Source: The Climate Change Knowledge Portal (CCKP)).

Temperature Patterns and Extreme Heat. *Minimum Surface Air Temperature:* The average minimum temperature exhibits a distinct seasonal variation, beginning at a low of 12.31°C in January and reaching a peak of 25.82°C in August. This gradual increase, particularly between March and August, aligns with the summer season in Bangladesh, which contributes to the extreme heat experienced in the region. *Mean Surface Air Temperature:* The average mean temperature exhibits a seasonal pattern, increasing from 18.76°C in January to approximately 28.66°C during the hotter months (June through September). This pattern highlights the significant heat Bangladesh experiences, particularly in mid-year. *Maximum Surface Air Temperature:* The maximum temperatures show similar trends, peaking at 32–33°C from March to October. This suggests prolonged high temperatures that could lead to heat-related environmental and societal stresses.

Seasonal Variability in Precipitation. *Precipitation Trends:* Precipitation exhibits a clear seasonal pattern, with very low levels occurring during the winter months of December and January. A significant increase in rainfall begins in April, reaching its peak in July when the highest recorded precipitation is 478.48 mm. This peak coincides with the monsoon season in Bangladesh. The heavy rainfall during this period can help alleviate extreme temperatures but also heightens the risk of flooding and associated impacts. *Correlation with Temperature Peaks:* Peak temperatures are typically followed by heavy rainfall, which alleviates the extreme heat. For example, although temperatures remain high in July and August, the heavy rainfall helps reduce some of the heat stress in the environment.

Implications of Climate Data on Extreme Heat and Environmental Stress. *Heat Accumulation:* The steady temperature increase from January to August indicates a warming trend that can lead to extreme heat conditions. With maximum temperatures consistently ranging from 31 to 33°C for over six months, this prolonged exposure to heat poses health risks, strains agriculture, and increases the demand for water resources. *Agricultural and Water Resource Strain:* The elevated temperatures, coupled with changing rainfall patterns, indicate potential stress on agriculture, as crops may experience both heat and water shortages. This is especially significant during drought-prone periods, intensifying agricultural difficulties and jeopardizing food security. *Impact on Urban Heat and Health Risks:* In urban areas, surfaces retain heat, which can intensify the Urban Heat Island (UHI) effect during prolonged high temperatures and reduced rainfall in the pre-monsoon months. This situation has serious implications for public health, as elevated temperatures and heat waves can increase the incidence of heat-related illnesses.

The data analysis highlights several key points. 1. Bangladesh experiences significant seasonal temperature variations, with extreme heat typically occurring from March to June; 2. The monsoon season brings heavy rainfall that helps moderate temperatures but does not fully mitigate the impact of sustained heat; 3. The post-monsoon and winter seasons provide cooler temperatures; however, the dry conditions during these times pose challenges for managing water resources in a country affected by seasonal temperature extremes.

Managerial Implications. *Urban Planning and Infrastructure:* Managers in urban development should incorporate green infrastructure, such as green roofs and urban parks, to help mitigate the Urban Heat Island effect. This involves adopting heat-resilient building designs and increasing shaded areas to minimize surface heat absorption. These initiatives can lower urban temperatures and enhance air quality, ultimately benefiting public health. *Industrial Emissions Control:* Industrial managers play a crucial role in temperature control by minimizing emissions through energy-efficient technologies and cleaner production processes. Focusing on regulatory compliance and emission monitoring can significantly reduce pollutants that contribute to local warming. Additionally, providing incentives for industries to adopt environmentally friendly practices will support long-term sustainability efforts. *Water Resource Management:* Managers in water resource management must prioritize sustainable water use, particularly during drought-prone periods. Implementing water conservation techniques, recycling wastewater, and building reservoirs can help ensure a steady supply during high-demand months. These strategies will also help mitigate the effects of extreme heat on water scarcity. *Agricultural Resilience:* Agricultural managers should implement climate-resilient farming practices, including crop rotation, the use of drought-resistant seeds, and the installation of efficient irrigation systems. These strategies will help maintain crop stability during extreme heat, minimize agricultural losses, and bolster food security. Additionally, providing farmers with training on these adaptive practices can further strengthen resilience within the agricultural sector. *Health Sector Preparedness:* Health managers and policymakers should take steps to address the increased health risks associated with extreme heat. This includes establishing heat-health warning systems and ensuring that healthcare facilities are equipped to manage heat-related illnesses. Additionally, public awareness campaigns on how to handle heat exposure, along with the implementation of emergency response plans, can enhance community health outcomes during extreme heat events. *Policy and Regulatory Action:* Policymakers should implement regulations that promote climate adaptation and heat mitigation strategies. This includes enforcing stricter emissions controls, providing incentives for green infrastructure, and establishing environmental monitoring systems.

Collaborative efforts between government agencies and the private sector can enhance the effectiveness of these measures, creating a coordinated approach to building climate resilience.

CONCLUSION

- This study explored the causes of extreme heat and its physical and climatic effects in Bangladesh. The findings indicate a rising trend in temperature anomalies in the region, primarily driven by urbanization, climate change, and land use dynamics. Research has shown that urbanization intensifies heat through the Urban Heat Island (UHI) effect, where built environments absorb and retain heat (Rahman et al., 2022; Dewan et al., 2021). Furthermore, climate change has led to changes in cooling and heating degree days, affecting the overall thermal comfort of residents (Islam et al., 2020).
- The implications of extreme heat are significant, impacting public health, agriculture, and water resources. Vulnerability assessments reveal that marginalized communities are disproportionately affected, underscoring the need for targeted interventions (Raja et al., 2021; Tawsif et al., 2022). Adaptation strategies, such as increasing green spaces and improving building designs, can help mitigate some of the impacts of extreme heat (Debnath et al., 2023; Ahmed et al., 2022).
- In conclusion, addressing extreme heat in Bangladesh requires comprehensive policies that integrate urban planning, climate adaptation, and community resilience. By fostering collaboration among stakeholders and implementing sustainable practices, Bangladesh can better manage the challenges posed by extreme heat, ensuring a healthier and more sustainable future for its inhabitants (Ali et al., 2020; Khan et al., 2020).

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