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HEAT WAVES IN BANGLADESH: UNDERSTANDING THE THREATS AND FINDING SOLUTIONS

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Abstract

Bangladesh has seen a significant rise in the number and strength of heat waves in recent years. These heat waves are hazardous for health, farming, and the economy. This paper investigates why these heat waves are happening, how they affect different areas, and what can be done to lessen their harmful effects. By carefully studying weather data, climate models, and economic and social factors, this study aims to give valuable ideas on how to adapt and reduce the impact of heat waves. The results show that it's essential to work together to deal with heat waves' many effects and help communities become stronger. With the right actions and policies, we can lower the risks of extreme heat, protect people's health, and ensure the economy and environment stay strong.

Key words

Heat Wave, Temperature, Climate Change, Bangladesh

INTRODUCTION

A heat wave is a period of unusually high temperatures, often accompanied by increased humidity. It is defined as an event where temperatures rise above *36 degrees Celsius* over a large area and remain elevated for *at least three days* or more.

Heat waves can be categorized into *four types* based on their intensity:

- Mild Heat Wave: Temperatures range between 36°C and 37.9°C.
- Moderate Heat Wave: Temperatures range between 38°C and 39.9°C.
- Severe Heat Wave: Temperatures range between 40°C and 41.9°C.
- Very Severe Heat Wave: Temperatures exceed 42°C.

In recent years, Bangladesh has seen a significant rise in the frequency and intensity of heat waves. Traditionally, these heat waves occurred mainly just before the monsoon season, but now they are happening more often throughout the year (Hossain & Jalil, 2018). This change has serious implications for public health, agriculture, and the economy. A heat wave in Bangladesh is defined by extended periods of extremely high temperatures, often above 36°C, and can be accompanied by high humidity, which makes the heat feel even worse. The effects of these extreme weather events are widespread. Public health suffers greatly, with more cases of heat-related illnesses like heat stroke and dehydration, especially among vulnerable groups such as the elderly, children, and low-income communities (Hossain, 2020).

The agricultural sector also faces significant challenges as heat waves disrupt crop growth and reduce yields, threatening food security and farmers' livelihoods. Additionally, the economic impact includes higher energy demands for cooling, disruptions in daily life, and increased healthcare costs (Thompson et al., 2019).

To understand the causes of heat waves in Bangladesh, we need to look at various factors, including climate change, urbanization, and regional weather patterns. Climate change is a major factor, with rising global temperatures leading to more frequent and severe heat waves (Lotake & Wagh, 2020). Urbanization contributes to the urban heat island effect, where densely built-up areas experience higher temperatures than surrounding rural areas.

This paper aims to explore the root causes of heat waves in Bangladesh, assess their impacts on different sectors, and discuss potential strategies for mitigation and adaptation. By analyzing meteorological data, climate models, and socio-economic assessments, the study seeks to provide insights into how Bangladesh can better prepare for and respond to the challenges posed by increasing heat wave events.

Review of Related Literature

To conduct the present study, identifying a research gap is essential. The authors have reviewed numerous relevant studies and found that previous research has focused on various aspects of heat waves, such as their causes, impacts, and mitigation strategies. Several studies have explored the patterns and impacts of heat waves in Bangladesh, offering valuable insights into this growing issue:

Shahid et al. (2012) analyzed the trends in daily temperature range (DTR) across Bangladesh from 1961 to 2008 using data from 18 weather stations. Their findings reveal a significant increase in both mean minimum and maximum temperatures, rising at rates of 0.15°C and 0.11°C per decade, respectively. Some studies also suggest that heat waves may be linked to re-curving tropical cyclones in the Bay of Bengal. These cyclones can alter wind patterns and reduce moisture, contributing to the onset of heat waves. Despite the substantial societal impacts, Ratnam et al. (2016) notes that there has been limited systematic investigation into the fundamental mechanisms behind heat waves. Khatun et al. (2016) provided a comprehensive analysis of Bangladesh's climate, focusing on heat wave definitions. According to their report, a heat wave occurs when maximum temperatures exceed 36°C. They categorized heat waves into three classes: mild (36-38°C), moderate (38-40°C), and severe (above 40°C). Khatun et al. (2019) observed a continual increase in temperatures in Bangladesh and projected worsening conditions by 2050 due to climate change and global warming. Previous studies have shown that while cold months can increase mortality rates, extreme heat events, such as those observed during the 2003 European heat wave (Robine et al., 2008), can significantly raise death rates. Recent research also indicates that heat waves are linked to a 146% increase in heat-related fatalities (Mazdiyasni et al., 2017). Burkart & Endlicher (2011) found that heat waves significantly increase mortality rates, particularly in urban areas and among children, the elderly, and men. Heat impacts were noted across all age groups, with the elderly being most affected. Nissan et al. (2020) highlighted the need for efficient adaptation strategies to manage heat-related risks and recommended using heat stress indices to understand and mitigate thermal stress. Nissan et al. (2017) developed a heat wave definition for Bangladesh that could be used in early warning systems. Their proposed definition requires both elevated minimum and maximum daily temperatures to exceed the 95th percentile for three consecutive days. This definition underscores the importance of nighttime temperatures and predicts a 20% increase in death rates during heat waves. They also identified that heat waves are associated with the absence of normal pre-monsoon rainfall, driven by strong low-level westerly winds and weak southerlies, which can be detected up to 10 days in advance. Monitoring soil moisture conditions could also help in predicting heat wave risks. At a global level, Seneviratne et al. (2014) observed that hot extremes continued to rise even during periods of global warming hiatus, without major El Niño[1] events. Severe heat waves in the subcontinent from 1998 to 2013 have shown a marked shift towards warmer extremes. This hotter climate, coupled with increased dryness, poses risks to agriculture, particularly in India (Teixeira et al., 2013), where persistent dry-hot spells are reducing rice yields and threatening food security. Mishra et al. (2015) and other studies have shown that urban areas worldwide are experiencing more frequent and intense heat waves, largely attributed to climate change (Mishra et al., 2015; IPCC, 2007; Murari et al., 2015). Russo and Sterl (2011) analyzed climate model projections for temperature extremes from 1950 to 2100, documenting significant increases in warm days over the Indian region. This highlights the urgent need for strategies to forecast and mitigate heat wave impacts. Roxy et al. (2015) raised concerns about the declining monsoon rainfall in South Asia, which is critical for agriculture, water resources, and power generation. They noted that the warming of the Indian Ocean could contribute to global warming by influencing trade winds. Karmakar (2018) made a study on climate change patterns, future trends and impacts in northwest Bangladesh. Climatological data on different parameters like daily temperature, Study on Heat Waves and Associated Large-scale Circulations in Bangladesh 9 daily rainfall, daily maximum and minimum temperatures, daily relative humidity and pre-monsoon daily thunderstorm frequency over Rajshahi, Rangpur and Dinajpur for the period 1981-2016 have been used to study their temporal variations on monthly, seasonal and annual basis. Rainfall data is also used to compute the non-rainy days (dry days), and the relative humidity is used to compute heat stress over the places under study. The trends of dry days and heat stress are studied. Daily maximum and minimum temperatures are used to find out the frequencies of days with temperature >36°C and temperature 36°C in the month of May whereas Dinajpur and Rangpur have the maximum mean frequency of maximum temperature >36°C in the month of April. Heat waves will be more long lasting in Rajshahi during April-July. Historical events, such as the 2003 heat wave in Europe, which caused over 30,000 deaths and significant economic losses (García-Herrera et al., 2003; Koppe et al., 2004; Nicholls & Alexander, 2007), underscore the severe impacts of extreme heat events. Similarly, droughts in Italy have led to increased air pollution in major cities.

METHODOLOGY

Our methodology involved a systematic approach to gather and analyze information on heat waves in Bangladesh. We began by conducting a comprehensive literature review to identify existing research studies, reports, and publications related to heat waves in the country. After gathering relevant sources, we carefully synthesized the information, focusing on key themes such as causes, impacts, and adaptation strategies. Additionally, we examined the methodologies employed in previous studies to understand how data was collected, analyzed, and interpreted. This process helps us gain a comprehensive understanding of the existing research landscape and guides our subsequent investigations. In terms of data collection and analysis, we relied on temperature data spanning from 1990 to 2019 obtained from Bangladesh Meteorological Department. We categorized heatwaves into different severity levels based on temperature ranges and utilized software tools for data handling and calculations to categorize heatwaves, we classified them into mild, moderate, severe, and very severe based on temperature ranges.

Besides, we delve into social media platforms to explore what people are saying and sharing about heatwaves. By examining posts, comments, and trends on platforms like Twitter, Facebook, and Instagram, we investigated public conversations and concerns regarding heatwaves. This helps us understand how people are experiencing and discussing heatwave events in real-time, providing valuable insights into public perceptions and responses.

Furthermore, we look back in time at old records, data kept in archives, and stories passed down verbally to learn about past heatwaves and what happened during those times. By studying these historical sources, we have got a better idea of how heatwaves affected people and the environment in the past. This helps us understand more about heatwaves and their impacts over time. Case studies involve closely examining particular heatwave incidents to grasp their origins and effects on various communities. Case studies mean looking closely at specific heatwave events. We study what caused these heatwaves and how they affected different groups of people. By doing this, we can understand the details of each event, including its impacts on society, the environment, and the economy. This helps us learn more about heatwaves and figure out better ways to deal with them in the future. By following this comprehensive methodology, the study aims to provide an in-depth understanding of heatwave risks in Bangladesh and develop effective, community-driven adaptation strategies. The integration of scientific knowledge with local insights is crucial for creating resilient communities capable of withstanding the challenges posed by heatwaves.

CLIMATE OVERVIEW

Bangladesh has a tropical monsoon climate characterized by a humid, moist atmosphere with distinct rainy and dry seasons, influenced by ENSO[1] and IOD[2] variations. From 1991 to 2020, the average annual temperature was 25.71°C. During this period, June was the warmest month, with average temperatures ranging from a low of 25.49°C to a high of 32.01°C. January was the coolest month, with temperatures ranging from a low of 12.31°C to a high of 25.26°C. The highest average temperatures occur between May and August, during the rainy monsoon season. Khulna, located on the southwest coast, experiences the highest monthly mean temperature of 29.87°C in May and the highest annual mean temperature of 26.36°C. Conversely, Sylhet in the northeast has the coolest temperatures, with an average monthly temperature of 17.59°C in January and the lowest annual average temperature of 24.40°C.

On April 21, 2024, the Bangladesh Meteorological Department (BMD) reported that severe to very severe heatwaves were hitting some districts, while most of the country experienced mild to moderate heatwaves. According to the BDRCS forecast, temperatures were over 38°C, and the heat index was above 38°C for several days in a row. By April 24, severe heatwaves (≥40°C) were observed in districts like Rajshahi, Pabna, Khulna, Bagerhat, Jessore, and Patuakhali. On April 26, Bangladesh set a new record for the longest heatwave in April with 24 days, surpassing the previous record of 23 days from 2019. The BMD report on April 27 showed that severe to very severe heatwaves (≥40°C) were affecting Rajshahi, Pabna, Chuadanga, Natore, Chapai Nawabganj, Kushtia, Jhenaidah, Jashore, Meherpur, and Bogura, while moderate heatwaves (38-39.9°C) were present in many other districts including Bagerhat, Satkhira, Barguna, Barishal, and others. The most affected areas were Rajshahi, Khulna, Rangpur, Dhaka, and Barisal. By April 30, the Directorate General of Health Services (DGHS) reported 10 heatstroke-related deaths across Bangladesh. In response, the government closed schools and colleges for a week, impacting 33 million children. According to Prothom Alo, about 70% of the population was affected by the heatwave, with significant difficulties reported, especially for those working outdoors.

Over these seven days, temperatures in the capital and other heatwave-affected places have been consistently four to five degrees Celsius higher than the corresponding seven days in the last 30 years, according to BMD data. In April 2024, Bangladesh set a new record for the highest number of heatwave days in a single month, reaching 24 days, surpassing the previous record of 23 days set in April-May 2019. This year's heatwave has not only broken records for duration but also for severity, with a notable increase in severe and very severe heatwave days. [Source: https://www.bssnews.net/news/185814]

- **ENSO** (El Niño-Southern Oscillation) is a climate pattern that changes ocean temperatures in the Pacific Ocean and affects global weather
- **IOD** (Indian Ocean Dipole) is about temperature changes in the Indian Ocean that influence weather in surrounding areas.

A Study on the Heat Wave Conditions over Bangladesh during 1990 - 2019 - Scientific Figure on ResearchGate. This study examines the recent trends and patterns of heatwaves (HW) in Bangladesh from 1990 to 2019. It focuses on instances where heatwaves lasted three or more consecutive days, using data from the Bangladesh Meteorological Department (BMD). The analysis includes temperature data from March 1 to May 31 each year.

Table 1: Monthly and seasonal frequency of HW and HWD

Station name	Monthly and seasonal frequency of HWD and HW							
	March		April		May		Pre-monsoon	
	HW	HWD	HW	HWD	HW	HWD	HW	HWD
Dhaka	0.2	1.07	0.9	4.9	0.5	2.53	1.6	8.5
Tangail	0.17	0.67	0.87	5	0.63	3.27	1.67	8.93
Mymensingh	0.03	0.1	0.17	0.7	0	0	0.2	0.8
Faridpur	0.3	1.5	1.23	7.4	0.77	4.1	2.3	13
Madaripur	0.13	0.6	0.77	3.97	0.87	4.33	1.77	8.9
Srimangal	0.17	0.77	0.33	2.03	0.03	0.1	0.53	2.9
Sylhet	0.13	0.4666	0.07	0.43	0.03	0.1	0.23	1
Bogra	0	0	0.77	4.13	0.7	2.97	1.47	7.1
Dinajpur	0.03	0.17	0.83	3.97	0.5	2.13	1.37	6.27
Ishurdi	0.7	4.5	1.6	11.8	1.33	9.83	3.63	26.13
Rajshahi	0.73	4.73	1.7	13.5	1.8	11.3	4.23	29.53
Rangpur	0	0	0.13	0.6	0.13	0.5	0.27	1.1
Syedpur	0.03	0.13	0.5	2.33	0.3	1.23	0.83	3.7
Chuadanga	1.03	5.3	1.57	13.83	1.37	10.77	3.97	29.9
Jashore	0.67	3.9	1.7	14.43	1.63	12.57	4	30.9
Khulna	0.23	1	1.33	8.1	1.33	8.5	2.9	17.6
Mongla	0.33	1.43	1.2	7.03	1.37	7.23	2.9	15.7
Satkhira	0.3	1.27	1.37	7.97	1.77	11.9	3.43	21.13
Barisal	0.07	0.2	0.33	1.73	0.2	0.87	0.6	2.8
Bhola	0.07	0.2	0.17	0.63	0.03	0.1	0.27	0.93
Khepupara	0.1	0.33	0.17	0.77	0.13	0.43	0.4	1.53
Patuakhali	0.17	0.67	0.47	2.43	0.53	2.37	1.17	5.47
Chandpur	0.03	0.1	0.2	0.87	0.2	0.93	0.43	1.9
Chittagong	0	0	0.07	0.23	0	0	0.07	0.23
Comilla	0	0	0.1	0.47	0.1	0.43	0.2	0.9
Cox's Bazar	0.07	0.2	0.1	0.47	0.07	0.23	0.23	0.9
Feni	0.03	0.27	0.13	0.7	0.17	0.63	0.3333	1.6
Hatiya	0	0	0.1	0.4	0	0	0.1	0.4
M. Court	0	0	0.23	1.4	0.67	3.1	0.9	4.5
Rangamati	0.33	1.33	0.77	5.3	0.4	1.57	1.5	8.2
Sandwip	0	0	0.1	0.43	0.03	0.1	0.13	0.53
Sitakunda	0.07	0.37	0.27	1.03	0.2	0.83	0.53	2.23
Kutubdia	0	0	0	0	0	0	0	0
Teknaf	0	0	0	0	0	0	0	0

Source: ResearchGate

Table 1 presents the average frequency of heatwave days (HWD) and heatwaves (HW) across various stations. Jashore recorded the highest average HWD at 30.9 days, while Chittagong had the lowest at 0.23 days. The next highest frequencies were found in Chuadanga (29.9 days), Rajshahi (29.53 days), Ishurdi (26.13 days), and Satkhira (21.13 days). Teknaf and Kutubdia reported no heatwaves, likely due to their coastal locations. For heatwaves, Rajshahi had the highest frequency at 4.23, and Chittagong had the lowest at 0.07. Following Rajshahi, the next highest frequencies were observed in Jashore (4), Chuadanga (3.97), Ishurdi (3.63), and Satkhira (3.43). Notably, the station with the highest HWD (Jashore) did not match the station with the highest HW frequency (Rajshahi). It is observed that both HWD and HW predominantly occur in April across all stations in Bangladesh during the pre-monsoon period.

Table 2: Trend, Z-score and level of significance of HWD and heat wave

Station Name	HWD			Heat wave		
	Slope	Z-score	Level of Significance	Slope	Z-score	Level of Significance
Dhaka	-0.013	0.20		-0.011	-0.06	
Tangail	0.070	0.02		0.003	0.00	
Mymensingh	-0.103	-2.24	*	-0.026	-2.27	*
Faridpur	0.089	0.92		0.003	0.53	
Madaripur	0.077	0.45		0.007	0.4	
Srimangal	0.027	0.86		0.004	0.8	
Sylhet	0.082	1.62		0.016	1.6	
Bogra	-0.068	-0.91		-0.033	-1.18	
Dinajpur	-0.236	-1.51		-0.048	-1.53	
Ishurdi	-0.087	-0.20		-0.058	-1.02	
Rajshahi	-0.097	-0.25		-0.042	-0.99	
Rangpur	-0.002	-0.7		-0.003	-0.63	
Syedpur	-0.037	-0.84		-0.009	-0.79	
Chuadanga	-0.299	-0.86		-0.051	-1.1	
Jashore	0.192	0.55		-0.025	-0.99	
Khulna	0.369	1.9		0.007	0.29	
Mongla	0.607	2.66	**	0.080	2.09	*
Satkhira	0.050	0.57		-0.011	0	
Barisal	0.113	1.07		0.016	1.12	
Bhola	0.038	0.34		0.007	0.34	
Khepupara	0.102	1.13		0.02	0.96	
Patuakhali	0.305	2.59	**	0.047	2.16	*
Chandpur	0.197	2.7	**	0.039	2.45	*
Chittagong	-	-	-	-	-	-
Comilla	-	-	-	-	-	-
Cox's Bazar	-	-	-	-	-	-
Feni	0.083	1.4		0.019	1.48	
Hatiya	-	-	-	-	-	-
M. Court	0.386	3.39	***	0.066	3.15	**
Rangamati	0.176	0.89		0.029	1.15	
Sandwip	-	-	-	-	-	-
Sitakunda	0.071	1.07		0.015	1.06	
Kutubdia	0	0	0	0	0	0
Teknaf	0	0	0	0	0	0

Note: *** significant at the 99.9% confidence level; ** significant at the 99% confidence level; * significant at the 95% confidence level; + significant at the 90% confidence level; and – did not draw any trend

Source: ResearchGate

Table 2 presents the 30-year average frequency of heatwaves (HW) and heatwave days (HWD) across all stations in Bangladesh for the period 1990-2019. It includes Sen's slope values and Z scores calculated using the Mann-Kendall test and Sen's slope estimator. Jashore, which has the highest frequency of HWD, shows an insignificant positive trend with a Sen's slope of 0.192 days/year and a Z score of 0.55. Chittagong, with the lowest frequency of HWD, shows no trend value due to maximum null data. The top four stations with the highest HWD frequencies are Chuadanga, Rajshahi, Ishurdi, and Satkhira. Among these, Chuadanga, Rajshahi, and Ishurdi show negative trends, with Sen's slope values of -0.299, -0.097, and -0.087 days/year, respectively. Their Z scores of -0.86, -0.25, and -0.20 indicate statistically insignificant trends. Satkhira shows a positive trend with a Sen's slope of 0.050 days/year and a Z score of 0.57, which is also insignificant. Teknaf and Kutubdia recorded no heatwaves. In summary, out of 34 stations, 2 have no heatwave data. Of the remaining 32 stations, 18 show a positive trend, 9 show a negative trend, and 5 show no trend due to maximum null data. Most stations exhibit a positive (increasing) trend.

Regarding HW frequency, Rajshahi, with the highest number of HW, shows a negative trend with a Sen's slope of -0.042 days/year and a Z score of -0.99, which is statistically insignificant. Chittagong, with the lowest number of HW, shows no trend value. The next highest HW frequencies are observed in Jashore, Chuadanga, Ishurdi, and Satkhira. All these stations show significant negative trends, with Sen's slope values of -0.025, -0.051, -0.058, and -0.011 days/year, and Z scores of -0.99, -1.10, -1.02, and 0.00, respectively, which are statistically insignificant. Overall, Rajshahi records the highest frequency of HW, while Jashore has the highest frequency of HWD among all stations in Bangladesh during the period from 1990 to 2019.

RESULT

Temperature and Humidity Patterns

Bangladesh experiences a hot season from April to June, where the average minimum temperatures range from 23.0°C to 25.8°C, and the average maximum temperatures range between 31.3°C and 35.3°C. The western regions of the country typically see the highest temperatures. Rainfall is widespread during this period, with the heaviest precipitation occurring in late June, July, and September. The combination of high temperatures and varying humidity levels creates conditions that can lead to intense heat waves, especially as the season progresses into the monsoon months.

Heat Wave Seasonality

Heat waves in Bangladesh generally occur from April to June, with most of these extreme temperature events happening in May. Occasionally, heat waves can extend into September. There are two main types of heat waves identified in Bangladesh: "day-and-night" heat waves and "humid-day-and-night" heat waves. The "day-and-night" heat waves, which affect both day and night temperatures, are most common in May, while "humid-day-and-night" heat waves, characterized by high humidity levels, peak in May and June but can continue through the monsoon season until September. The occurrence of these heat waves often coincides within the same years, indicating a pattern of variability from one year to the next.

April is the hottest month in Bangladesh. Based on frequency of HWD, the obtained highest hot places are Jashore, Chuadanga, Rajshahi, Isshordi and Satkhira. While in Kutubdia and Teknaf, no HW is found at all.

Trend Analysis

Analysis of the frequency of heat waves in Bangladesh shows no significant long-term trends. The "day-and-night" heat wave index has a slight trend of 0.01 per year, but this is not statistically significant (95% confidence interval: -0.14 to 0.15). Similarly, the "humid-day-and-night" index shows a trend of 0.1 per year (95% CI: -0.07 to 0.27), which is also not significant. When examining temperatures during the heat wave season (April to June), there are no significant trends in daily minimum, maximum, or average temperatures. However, looking at annual temperature changes, there are noticeable upward trends: the daily minimum temperature is rising by 0.02°C per year (95% CI: 0.01–0.04), the daily maximum by 0.03°C per year (95% CI: 0.01–0.05), and the overall average temperature by 0.03°C per year (95% CI: 0.01–0.04). These findings suggest that while specific heat wave trends during the hot season are not significant, longer-term data reveals a general warming trend across Bangladesh.

Synoptic Climate Conditions during Heat Waves

The study of heat waves in Bangladesh offers valuable insights into the broader climate conditions that contribute to these extreme weather events. The pre-monsoon season is particularly critical as it marks the transition from the cooler, northerly winter circulation to the warmer, south-to-southeasterly summer monsoon circulation. During this time, wind patterns tend to be weak and variable, creating a distinct boundary that separates the hot, dry air coming from the northwest from the moist, southerly air flowing from the Bay of Bengal. In the mid-atmosphere, an unusual anticyclonic pattern often develops over central eastern India, which can influence weather patterns in Bangladesh. At the surface, wind anomalies are characterized by strong northerly winds over most of India and the Bay of Bengal, while westerly winds in Bangladesh become stronger than usual, all contributing to the formation and persistence of heat waves.

Meteorological Anomalies and Heat Wave Associations

Heat wave days in Bangladesh are frequently linked to specific meteorological anomalies. One of the key factors is subsidence, a downward movement of air in the mid- and upper atmosphere, which reduces cloud cover and allows for more direct sunlight to heat the surface. This phenomenon is often accompanied by lower-than-normal relative humidity, as dry westerly winds from India dominate the region's weather. This combination of subsidence and dry conditions creates an environment that is highly conducive to heat waves, particularly during the pre-monsoon and early monsoon periods when the atmosphere is still adjusting to the changing seasonal patterns.

Understanding the Influence of Soil Moisture

Soil moisture plays a critical role in the formation and predictability of heat waves, but it is not the sole determining factor. While soil moisture deficits can increase the likelihood of heat waves, these deficits do not necessarily guarantee their occurrence.

DISCUSSION

Different studies have proposed various definitions for heat waves, reflecting the complexity and variability of these extreme weather events:

Vaidyanathan et al. (2016) consider a heat wave based on a combination of factors, including various temperature metrics, the duration of high temperatures, the types of thresholds used, and the intensity of the heat. This multi-dimensional approach highlights that a heat wave is not defined solely by temperature, but also by how long the extreme temperatures persist and the extent to which they exceed typical levels.

Della-Marta et al. (2007) defines a heat wave as a period where maximum daily temperatures exceed the 80th percentile for at least three consecutive days. This definition emphasizes the relative severity of temperatures compared to historical norms, suggesting that heat waves are determined by temperatures that are significantly higher than what is typically experienced during that time of year.

Srivastava et al. (2009) describes heat waves as periods where temperatures exceed the normal maximum by at least 3°C for three consecutive days. This definition focuses on the deviation from average temperatures, underlining the anomaly that defines a heat wave. It suggests that even moderate deviations from the norm, if sustained, can constitute a heat wave.

Mishra et al. (2015) defines heat waves as periods when temperatures remain above the 99th percentile of historical maximum temperatures for six or more days. This stringent definition identifies heat waves based on extreme statistical thresholds, indicating that only the most severe and prolonged temperature increases qualify as heat waves.

Ganguly et al. (2009) focus on the highest nighttime temperatures over a three-day period. This means they consider how hot it stays at night, not just during the day, which can affect how people and the environment handle the heat.

In addition to temperatures, some researchers look at broader weather patterns. For example, Lee et al. (2016) in Korea study vorticity, which measures how air moves in the atmosphere. This can help explain why some heat waves last longer or are more intense.

The Australian Bureau of Meteorology uses the Excess Heat Factor (EHF). This measure looks at how much the recent heat exceeds average temperatures from the past month and assesses how stressful the heat is. It helps understand both short-term heat spikes and long-term trends.

These different methods show that heat waves are not just about high temperatures but also involve how air moves and how heat builds up over time. Each approach helps provide a clearer picture of heat waves and how to prepare for them.

Predicting Heat Waves

Understanding and predicting heat waves in Bangladesh requires a detailed analysis of the atmospheric conditions and environmental factors that lead to these extreme weather events. During heat waves, the country experiences specific wind patterns and atmospheric anomalies. Notably, stronger than usual low-level westerly winds bring hot, dry air from northern India, while the typically moist southerly winds from the Bay of Bengal become weaker. These conditions can develop up to 10 days before a heat wave and are often accompanied by the "loo" winds—hot northwesterly winds that originate from Pakistan and have been linked to heat waves in northern India (Pattanaik et al., 2017).

This unique circulation pattern prevents the normal influx of moisture from the Bay of Bengal, resulting in decreased relative humidity. Consequently, there is a reduction in pre-monsoon rainfall just before a heat wave, as indicated by significant drops in soil moisture and precipitation levels. Moreover, an anomalous anticyclonic circulation in the mid-level atmosphere (around 500 hPa) enhances these dry conditions, further setting the stage for the development and intensification of heat waves.

Factors Influencing Heat Wave Predictability:

- Lack of Rainfall: The absence of normally expected rainfall at specific times of the year can create conditions conducive to heat waves.
- Circulation Anomalies: Distinct weather patterns, such as intensified dry westerly winds and weakened moist southerlies, are critical in creating conditions for heat waves.
- Soil Moisture Levels: Reduced soil moisture due to lower rainfall leads to higher temperatures, as the energy balance shifts towards sensible heat (direct warming) rather than latent heat (evaporation).
- Prolonged Dry Conditions: Extended periods of dry weather prior to a heat wave suggest that it may be possible to predict these events seasonally.

Improving Heat Wave Predictions in Bangladesh:

- Soil Moisture Monitoring: Since soil moisture is less variable than precipitation, keeping track of soil moisture levels could provide longer-range forecasts of heat wave risks.
- Analysis of Long-Term Data: Using a more comprehensive dataset could enhance the reliability of soil moisture percentiles and help establish more precise early warning triggers.
- Weather Forecasts: Current weather forecasts are crucial for preparing for heat waves and can be complemented by soil moisture monitoring to assess near-term risks.
- Analysis Based on Duration: Considering the length of heat waves can refine risk assessments, as longer heat waves are usually associated with more intense dry conditions.

For Bangladesh, where agriculture is a key sector and population density is high, the ability to predict heat waves is particularly crucial. Establishing a strong system for monitoring soil moisture and analyzing long-term weather data can enhance the accuracy of heat wave predictions. This capability can support the development of effective early warning systems, potentially mitigating the negative effects on both human life and agricultural yields. By concentrating on these predictive factors and utilizing local climatological data, Bangladesh can strengthen its resilience to the challenges posed by heat waves.

EFFECTS OF HEATWAVES IN BANGLADESH

Heatwaves in Bangladesh have significant and widespread effects, impacting various aspects of daily life, health, and the economy. Here's a detailed look at how these intense heat events affect the country:

Health Impacts:

- Increased Health Issues: Prolonged exposure to high temperatures can cause severe health problems. Common issues include heat exhaustion, heatstroke, dehydration, and exacerbation of pre-existing conditions like cardiovascular and respiratory diseases. Vulnerable populations, such as the elderly, children, and those with chronic illnesses, are particularly at risk.
- Heat-Related Deaths: Extreme heat has led to fatalities in Bangladesh. For instance, heatwaves in the past have resulted in numerous deaths due to heatstroke and other heat-related complications. The most severe cases are often seen among those who are unable to find shelter or access cooling methods.
- Spread of Diseases: High temperatures can also contribute to the spread of diseases. For example, heat can worsen conditions such as diarrhea and cholera, as higher temperatures can lead to increased contamination of water sources and food.

Economic Effects:

- Reduced Productivity: Heatwaves affect people who work outdoors, such as construction workers, rickshaw pullers, and farmers. High temperatures can lead to decreased working hours and productivity. Workers may need to take more frequent breaks or shorten their work hours, which results in reduced income and economic strain.
- Increased Medical Costs: As heat-related illnesses rise, so do medical expenses. People suffering from heatstroke or dehydration may require medical treatment, increasing healthcare costs. This is particularly burdensome for low-income families who already struggle with limited resources.

- Impact on Agriculture: Agriculture, a significant part of Bangladesh's economy, is heavily affected by heatwaves. Crops may suffer from heat stress, leading to lower yields and financial losses for farmers. Additionally, livestock can also be affected, impacting the livelihood of those involved in animal husbandry.

Social Effects:

- Disruption of Daily Life: Heatwaves can disrupt daily life, including education and work. For example, schools and offices may close or adjust their hours to cope with the extreme heat, impacting students' learning and adults' work schedules.
- Migration and Displacement: In severe cases, heatwaves can lead to temporary or permanent displacement of people. Those in affected areas may move to cooler regions or urban areas in search of relief, causing shifts in population dynamics and pressure on urban infrastructure.

Environmental Impacts:

- Increased Energy Consumption: As temperatures rise, the use of air conditioning and cooling systems increases, leading to higher energy consumption. This not only strains the power grid but also contributes to increased greenhouse gas emissions if the energy comes from fossil fuels.
- Stress on Natural Resources: Heatwaves can exacerbate existing issues related to water scarcity. High temperatures increase water demand and can lead to more rapid evaporation from water bodies, impacting water availability for both people and ecosystems.

Government and Community Responses:

- Emergency Measures: In response to heatwaves, the government often takes emergency measures such as closing schools, providing cooling centers, and distributing water and other essentials to affected communities.
- Long-Term Adaptation: To mitigate the effects of future heatwaves, there are ongoing efforts to improve infrastructure and public awareness. This includes planting more trees, creating green spaces, and developing early warning systems to help people prepare for extreme heat events.

In summary, heatwaves in Bangladesh have a profound impact on health, the economy, and daily life. Addressing these challenges requires both immediate responses and long-term strategies to enhance resilience and adaptation to increasing temperatures.

Strategies in response of Heat Waves:

In response to heat waves in Bangladesh, several strategies can be implemented to mitigate their impacts and enhance resilience:

Early Warning Systems: Establishing robust early warning systems that utilize weather forecasting and climate modeling to anticipate heat wave events in advance. This allows authorities to issue timely alerts and advisories to the public, enabling them to take preventive measures.

Heat Health Action Plans: Developing comprehensive heat health action plans that outline protocols for healthcare professionals, emergency responders, and community organizations to address heat-related health risks. These plans should include guidelines for identifying vulnerable populations, providing medical care, and establishing cooling centers during heat wave events.

Public Awareness Campaigns: Launching extensive public awareness campaigns to educate citizens about the dangers of heat waves and promote adaptive behaviors. This may involve disseminating information through various media channels, organizing community workshops, and engaging with local leaders to raise awareness about heat wave preparedness.

Urban Planning and Green Infrastructure: Incorporating heat resilience into urban planning and infrastructure development initiatives. This includes implementing green spaces, increasing tree cover, and adopting cool roof technologies to mitigate the urban heat island effect and reduce temperatures in densely populated areas.

Community Engagement and Capacity Building: Empowering communities to take proactive measures against heat waves through capacity building and community engagement initiatives. This may involve training local volunteers in heat wave response and first aid, establishing community-based monitoring systems, and fostering social cohesion to support vulnerable individuals during heat wave events.

Climate Adaptation and Resilience: Integrating heat wave resilience into broader climate adaptation and resilience strategies at the national and local levels. This includes incorporating heat risk assessments into disaster risk management plans, enhancing infrastructure resilience to extreme heat, and mainstreaming heat adaptation considerations into development policies and programs.

By implementing these strategies in a coordinated manner, Bangladesh can enhance its capacity to respond to heat waves and minimize the adverse impacts on public health, infrastructure, and livelihoods.

CONCLUSIONS

The study reveals significant variations in heat wave occurrences across Bangladesh. Jashore stands out with the highest frequency of heat wave days (HWD), averaging 30.9 days, and recorded the highest temperature of the year at 43.8°C, according to the Bangladesh Meteorological Department. *Among the past 30 years, 2024 emerged as the hottest year, while 2018 was noted as the coolest.* In contrast, Chittagong had the lowest frequency of HWD, with only 0.2333 days. Rajshahi experienced the highest number of heat wave events, with an average of 4.2333 incidents. Coastal areas, such as Teknaf and Kutubdia, did not experience any heat waves, likely due to their proximity to the sea, which moderates temperatures. *April has been identified as the hottest month in Bangladesh*, with significant hotspots including Jashore, Rajshahi, Chuadanga, Ishurdi, and Satkhira, all of which recorded high frequencies of heat wave days. The Mann-Kendall test indicated a statistically significant increase in HWD and HW frequency at stations like M. Court and Mongla, with M. Court showing a 99.9% confidence level.

The findings also highlight that 2024 has seen a notable increase in the frequency of HWD and HW events, suggesting an upward trend in heat wave occurrences in Bangladesh. The southwestern and middle-western regions of the country have been identified as the most affected by these extreme weather events. As a result, there is an increased emphasis on improving heat wave forecasting to better prepare for and mitigate their impacts. The study underscores the importance of public health measures and disaster preparedness in response to rising temperatures. In 2024, Bangladesh experienced severe heatwaves, with average temperatures ranging from 40 to 42 degrees Celsius across all districts. These extreme conditions posed significant risks to both the population and the environment. At least 10 individuals lost their lives due to heatstroke, while millions suffered from health issues such as vomiting, diarrhea, and dehydration. The country's environmental vulnerability and governance challenges exacerbate the impact of such extreme weather events. Although there have been some recent rainfall and thunderstorms, the prevailing heatwave conditions are expected to persist through at least May. It is crucial for the public to remain safe and hydrated during these challenging times.

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