The Study of Heat Wave Condition in Bangladesh during 1990 to 2019

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ABSTRACT

When temperature exceed 36 degrees with a large area and linger for minimum three or more days can be considered as heat wave (HW). In the Pre-monsoon, the sun ray drops down vertically on the 'Thar' desert (India-Pakistan) and the foothill of the Himalayas, the area makes a hot-tempered zone. That is why, these regions produce a trough of low and there is a possibility to advect temperature towards Bangladesh. In the same time, from the Bay of Bengal, the south/south westerly wind carries a high amount of moisture over Bangladesh. The heat capacity of moist air is higher than that of dry air. Solar insolation, temperature advection and moisture incursion are three main phenomena that are responsible for extreme hot temperature condition. Veering is also responsible for especially severe and very severe HW condition. The present study is concerned on all categories of HW frequencies accompanying with all categories of HW days frequency for the Pre-monsoon (March to May) over most of the stations (34) of Bangladesh for the period 1990-2019.The highest numbers of HW days frequencies are found in Jashore (30.9 days) of all types of events whereas the highest frequencies of HW are found in Rajshahi (4.2333) during pre-monsoon season. The lowest numbers of frequency of HW days and HW, both are found at Chattogram. April is the highest warm month in Bangladesh. On the basis of frequency of HW days, the highest hot places are Jashore, Chuadanga, Rajshahi, Ishurdi and Satkhira. While in Kutubdia and Teknaf, no HW is found at all. Among 30 years, 2014 is found the highest hottest year (803days/100spells) and 2018 is the lowest hot day recorded year (7days/2spells). By Mann-Kendall test, the HW trend of M. court, Mongla, Patuakhali and Chandpur have indicated positive significant value, and Mymensing station has given only negative significant value. From spatial distribution, it shows the hottest areas which are south western and middle-western parts of Bangladesh.

Keywords: Extreme temperature, heat wave, Mann-Kendall test, pre-monsoon, severe conditions.

1. Introduction

Bangladesh is one of the top most vulnerable countries to climate change. The Intergovernmental Panel on Climate Change (IPCC) also recognizes Bangladesh as one of the most vulnerable countries in the world to the negative impacts of climate change. In Bangladesh, different climate changes like recurring floods, river bank erosion, drought in dry season, salinity increase as a result of back water effect, downing ground water level, have been contributing to augment the vulnerability of many regions (Nissan *et al*., 2017). Modeling studies indicated that the average increase in temperature would be 1.3^0 C and 2.6^0 C for the projected years of 2030 and 2075, respectively. Similar to IPCC projections, the rise in winter temperature in Bangladesh was predicted to be higher probably due to significant increase in monsoon precipitation (Basak *et al*., 2013). A lot has been discussed about climate change and how it affects Bangladesh. The country is expected to be among the worst affected climate change. Bangladesh is often exposed to severe natural disasters because of its very flat topography and low land above sea level. Therefore, almost every year, a huge portion of the population is displaced, both temporarily and permanently, due to these calamities. Approximately 500,000 people were displaced when the Bhola Island was permanently inundated by the floods of 2005. In addition, recent occurrences of major cyclones like Sidr, 2007, and Aila, 2009, may be an indication of more frequent and severe climatic catastrophes. But there is still a lack of awareness among the public about climate change (Akter, 2009).

A study has been carried out by Shahid *et al*. (2012) to analyze the spatial and seasonal patterns in the trends of daily temperature range (DTR) in Bangladesh. Daily temperature data from 18 stations for the time period of 1961–2008 has been used for the study. The result shows that both mean minimum and mean maximum temperatures of Bangladesh have increased significantly at a rate of 0.15°C/decade and 0.11°C/decade, respectively. Some studies also linked the heat waves to the re-curving tropical cyclones in the Bay of Bengal. The re-curving tropical cyclones before the onset of the heat waves could change the direction of the winds and cut-off moisture to the inland regions leading to heat waves. In spite of the large societal impact, there has been no systematic attempt to understand the principal mechanism of heat waves (Ratnam *et al*., 2016). Urbanization increases air temperature, dust particles, cloudiness and precipitation whereas it decreases relative humidity, radiation, albedo and wind speed. These in turn affect the water balance parameters like evapotranspiration, soil moisture storage, run off etc. Significant increase in the frequency, persistency and spatial coverage of heat waves/severe heat waves and cold waves/severe cold waves has been observed during the decade 1991-2000 in comparison to that during the earlier two decades. These changes might be the regional impact of the observed general increase in the global warming during the recent succession being 1998, 1999, 1997, 1995, 1990, 1996 and 1991 (WMO, 2001). Other possible reasons behind these increases of air temperature are the local factors such as deforestation, urbanization etc.

Extreme temperature events (mainly HW) caused significant adverse impact on mortality from plenty of diseases worldwide (Chen *et al*., 2020). The evidences of impacts of climate change across the world and also the geographical location of Bangladesh have experienced different types of adverse phenomena that there has been an increasing climate extremity such as heat wave, sudden moderate cold wave (Spinoni *et al*., 2015; Karmakar *et al*., 2019), etc. Global warming or the rise in mean surface air temperature over the last century is now an established fact. Particularly, in half of the twentieth century, the annual magnitudes of the lowest and highest daily minimum and maximum temperatures have raised throughout the world (Alexander *et al*., 2006). The genesis and spread of HW and extreme weather event are responsible to this upward shift in temperature (Rahmstorf & Coumou, 2011). In the fifth Assessment report of Intergovernmental Panel on Climate Change (IPCC), it has been showed that this state will deteriorate and there will be high probability of increase in frequency, duration and intensity of heat waves over land areas in near future (Stocker *et al*., 2014). The world's most temperate prone areas are found over the South Asia including Bangladesh (Saeed *et al*., 2021). South Asia belongs to one-fifth of the global population with poor infrastructure set up. The effect of extreme heat is associated with higher population density and is reported by the fifty US cities (Medina-Ramón & Schwartz, 2007). There is concrete evidence that the densely populated agricultural regions of the Ganges and Indus River basin will face serious vulnerability issue if proper steps for the mitigation of climate change are not taken (Im *et al*., 2017). Recently, UNIDSR reported that HW ranked as the fourth deadliest natural calamities in 2015 across the world, and third in the South Asia. HW has become the highest matter of concern in the context of Bangladesh climatology. High population density, less awareness, inadequate infrastructure and low adaptive capacity and mind setup have made the urban population of Bangladesh highly vulnerable to climate change (Shahid *et al*., 2016). Very few studies have been conducted on HW in terms of the patterns, frequency, annual and seasonal variability in Bangladesh. The climatological HW analysis during 1961-2010 has represented the combined effects of temperature and relative humidity and exposed significant scenario of both temperature and relative humidity in past 20 years. The South-West, central part and southwestern part of Bangladesh are considered as the most vulnerable zone. The mean heat index value ranges from 42-50^0 C are reported by Rajib *et al*. (2011) during the summer season in Bangladesh. In another study it is revealed that vertical shift in daily maximum and minimum temperature, and the discomfort level due to excessive heat in the monsoon and pre-monsoon season has also been confirmed over Bangladesh (Rakib, 2013). The similar pattern in monthly and seasonal (pre-monsoon) distribution of mean maximum temperatures is found in Karmakar & Das (2020) in Bangladesh. This rising trend of temperature is the highest in the urban areas due to the influences of rapid urban development processes and its impacts. From the analysis of the BMD's observed temperature trend during 1901-2015, Khatun *et al*. (2019) found that temperature is increasing day by day. The result also shows that the climate change and global warming is currently occurring in Bangladesh and the scenario of the country will be worse by 2050. A plethora of studies assessed that the influence of seasonal and climatic conditions on human mortality will increase the fatality rate during cold months (Basu, & Samet, 2002; Baccini *et al*., 2008; Basu, 2009, etc.). However, as seen from the heat waves analysis during summer of 2003 in Europe by Robine *et al*. (2008), extreme heat can cause significant rises in death rates. In fact, these recent instances involving high mortality tolls caused by heat waves have widened the research frontier. An increase of high heat related fatality during heat wave events with a probability 146% was found in research employing probabilistic method (Mazdiyasni *et al*., 2017). The study evidence suggests that hot weather causes a significant increase in death, with higher impacts in cities and among the children, elderly and men (Burkart & Endlicher, 2011). From all-cause mortality, mortality of cardiovascular disease and infectious illness mortality in general were reported by heat impacts. Further, heat-related mortality was detected in all age categories, with considerable effects observed in the elderly over the 65 years aged in Bangladesh, though effect on children and teenagers was delayed compared to other ages (Nissan *et al*., 2020). Due to the lacking of efficient adaptation strategies, heat related risk is magnifying. Focusing on the determination of heat stress on human body and the complete valuation of outdoor thermal conditions, it is needed the action plan for reducing heat wave impacts. For quantifying thermal stress and determining the upper limit of thermal exposure, the heat stress index is a tool. Outstandingly, the indices formulated using human heat balance equation provides better understanding of heat stress (Epstein & Moran, 2006).

Extreme events such as heat waves often involve significant damage and loss. For example, the 2003 heat wave and drought in Europe killed more than 30,000 people (at least 15,000 in France), destroyed large areas of forest by fire, and caused about US$14 billion in monetary damages through crop loss (Europe, 2003; GarcÃa-Herrera *et al*., 2003; Koppe *et al*., 2004; Nicholls & Alexander, 2007, etc.). Additionally, drought in Italy has increased air pollution in all major cities. Therefore, the prime objectives of this research are to-

- find out the climatology of Bangladesh for extreme temperature in Pre-monsoon,
- analyze the trend of hot days duration, and
- investigate the trend of heat wave frequency.

2. DATA COLLECTION AND METHODOLOGY

The 1990-2019's temperature data have been collected from the Climate Section of the Bangladesh Meteorological Department (BMD). Warm day data are found out from the daily maximum temperature. FORTRAN language has been used for calculating warm day frequencies. There are four types of heat waves counted by the BMD. Those are mild HW (36-37.9^{0}C), moderate HW (38-39.9^{0}C), severe HW (40-41.9^{0}C) and very severe HW (≥ 42^{0}C). One missing data is replaced by the average value of nearest data, but 2 or more missing values at a time are replaced by the surrounding station areas average value. Only 3 days or more swept HW are considered in this study. All of the data have been calculated using excel, Surfer and Arc GIS software. Mann-Kendall test also been used to draw the trend of HW frequency.

3. RESULT AND DISCUSSION

In this study, an attempt has been taken to draw the recent scenario and trend of extreme hot temperature in Bangladesh during the period of 1990 to 2019. It has been counted only three or more days continued HW according to the temperature and the area mentioned by Bangladesh Meteorological Department (BMD).

3.1 Monthly and Seasonal Analysis of Frequency of HW and HW Days (HWD)

The frequency (i.e. the 30 years average) of HW and HWD features of all stations in Bangladesh for the study period 1990-2019 are shown in Table 1. In this study, temperature data from 1st March to 31st May of each year are considered. It shows the highest and lowest frequencies of HWD are obtained at Jashore (30.9 days) and Chittagong (0.23 days) respectively. The next top 4 highest frequencies of HWD are obtained at Chuadanga (29.9 days), Rajshahi (29.53 days), Ishurdi (26.13 days) and Satkhira (21.13 days). No HW occurred at Teknaf and Kutubdia. It may be because of the coastal area. With respect to the frequency of HW, the highest and lowest numbers of HW is occurred in Rajshahi (4.23) and in Chittagong (0.07). After Rajshahi station, the next highest frequency of HW 4 stations is Jashore (4), Chuadanga (3.97), Ishurdi (3.63) and Satkhira (3.43). It is noted that the highest frequency of HWD (at Jashore) and the highest frequency of HW (at Rajshahi) do not occur in the same station (Table 1). From Table 1, it is observed that both of the frequency of HW and HWD mostly occurred in the month of April compared to the others at every station over Bangladesh in pre-monsoon.

Table 1: Monthly and seasonal frequency of HW and HWD

Station name	Monthly and seasonal frequency of HW and HWD							
	March		April		May		Pre-monsoon	
	HW	HWD	HW	HWD	HW	HWD	HW	HWD
Dhaka	0.20	1.07	0.90	4.90	0.50	2.53	1.60	8.50
Tangail	0.17	0.67	0.87	5	0.63	3.27	1.67	8.93
Mymensingh	0.03	0.10	0.17	0.70	0	0	0.20	0.80
Faridpur	0.30	1.50	1.23	7.40	0.77	4.10	2.30	13
Madaripur	0.13	0.60	0.77	3.97	0.87	4.33	1.77	8.90
Srimangal	0.17	0.77	0.33	2.03	0.03	0.10	0.53	2.90
Sylhet	0.13	0.47	0.07	0.43	0.03	0.10	0.23	1
Bogra	0	0	0.77	4.13	0.70	2.97	1.47	7.10
Dinajpur	0.03	0.17	0.83	3.97	0.50	2.13	1.37	6.27
Ishurdi	0.70	4.50	1.60	11.80	1.33	9.83	3.63	26.13
Rajshahi	0.73	4.73	1.70	13.50	1.80	11.3	4.23	29.53
Rangpur	0	0	0.13	0.60	0.13	0.50	0.27	1.10
Syedpur	0.03	0.13	0.50	2.33	0.30	1.23	0.83	3.70
Chuadanga	1.03	5.30	1.57	13.83	1.37	10.77	3.97	29.90
Jashore	0.67	3.90	1.70	14.43	1.63	12.57	4	30.90
Khulna	0.23	1	1.33	8.10	1.33	8.50	2.90	17.60
Mongla	0.33	1.43	1.20	7.03	1.37	7.23	2.90	15.70
Satkhira	0.30	1.27	1.37	7.97	1.77	11.9	3.43	21.13

Barisal	0.07	0.20	0.33	1.73	0.20	0.87	0.60	2.80
Bhola	0.07	0.20	0.17	0.63	0.03	0.10	0.27	0.93
Khepupara	0.10	0.33	0.17	0.77	0.13	0.43	0.40	1.53
Patuakhali	0.17	0.67	0.47	2.43	0.53	2.37	1.17	5.47
Chandpur	0.03	0.10	0.20	0.87	0.20	0.93	0.43	1.90
Chittagong	0	0	0.07	0.23	0	0	0.07	0.23
Comilla	0	0	0.10	0.47	0.10	0.43	0.20	0.90
Cox's Bazar	0.07	0.20	0.10	0.47	0.07	0.23	0.23	0.90
Feni	0.03	0.27	0.13	0.70	0.17	0.63	0.33	1.60
Hatiya	0	0	0.10	0.40	0	0	0.10	0.40
M.court	0	0	0.23	1.40	0.67	3.10	0.90	4.50
Rangamati	0.33	1.33	0.77	5.30	0.40	1.57	1.50	8.20
Sandwip	0	0	0.10	0.43	0.03	0.10	0.13	0.53
Sitakunda	0.07	0.37	0.27	1.03	0.20	0.83	0.53	2.23
Kutubdia	0	0	0	0	0	0	0	0
Teknaf	0	0	0	0	0	0	0	0

3.2 Yearly (Pre-monsoon) Analysis of the Numbers of Heat Wave Days (HWD) and Heat Waves (HW)

The numbers of HWD and HW features of all stations in Bangladesh for the study period 1990-2019 are shown in Table 2. In this study, the temperature data from 1st March to 31st May of each year are considered. It shows the highest and lowest numbers of HWD are obtained in 2014 (803 days) and 2018 (7 days) respectively. The next top 5 highest numbers of HWD recorded years are obtained in 1995 (585 days), 1992 (452 days), 2010 (436 days), 2012 (398 days) and 2016 (366). No HW occurred at Teknaf and Kutubdia. With respect to the numbers of HW, the highest and lowest numbers of HW is occurred in 2014 (100) and in 2018 (2). After 2014, the next 5 highest numbers of HW recorded years are 1995 (83), 2010 (71), 1996 (70), 1992 (66) and 1999 (65). It is noted that the highest numbers of HWD (803) and the highest numbers of HW (100) are occurred in the same year 2014. And also, the lowest numbers of HWD (7) and the lowest numbers of HW (2) are occurred in the same year 2018.

Table 2(a): Yearly Numbers of Heat Wave Days and Heat Waves during 1990-1999

	1990		1991		1992		1993		1994		1995		1996		1997		1998		1999	
St. Name	D	Sp	D	Sp	D	Sp	Da	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp
Dhaka	0	0	7	2	14	2	0	0	6	2	34	5	19	4	0	0	1	3	24	5
Tangail	0	0	10	2	24	3	3	1	10	2	16	2	9	2	0	0	6	2	12	3
Mymensi	0	0	6	2	7	1	0	0	3	1	0	0	4	1	0	0	0	0	0	0
Faridpur	0	0	4	1	39	5	6	1	9	1	33	7	12	3	0	0	7	2	19	4
Madaripu	0	0	8	2	22	5	3	1	12	4	27	4	13	2	0	0	0	0	0	0
Srimanga	0	0	0	0	7	1	0	0	0	0	11	3	0	0	0	0	0	0	19	3
Sylhet	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
Bogra	0	0	7	2	15	3	0	0	13	2	18	4	17	4	3	1	9	2	8	2
Dinajpur	0	0	6	2	11	2	3	1	17	3	27	6	17	3	12	3	4	1	0	0
Ishurdi	4	1	31	6	51	8	11	3	30	6	62	5	45	7	11	2	9	2	32	5
Rajshahi	15	2	30	5	57	5	23	6	37	8	48	5	44	6	18	4	21	5	33	6
Rangpur	0	0	0	0	6	1	0	0	3	1	3	1	0	0	0	0	3	1	0	0
Syedpur	0	0	3	1	7	1	0	0	4	1	18	3	9	3	0	0	4	1	0	0
Chuadanga	19	2	42	7	33	3	20	4	44	6	59	5	46	8	13	2	19	3	44	5
Jashore	0	0	25	5	57	6	11	3	38	5	57	6	34	7	15	3	16	3	39	6
Khulna	0	0	11	2	28	6	0	0	11	2	44	6	24	6	6	2	9	2	18	5
Mongla	0	0	6	2	18	4	0	0	11	3	35	5	13	3	6	1	3	1	16	4
Satkhira	0	0	15	2	46	8	9	3	31	5	44	6	31	6	9	3	18	3	30	4
Barisal	0	0	0	0	0	0	0	0	6	1	7	2	7	2	0	0	0	0	3	1
Bhola	0	0	3	1	0	0	0	0	3	1	3	1	0	0	0	0	0	0	0	0
Khepupar	0	0	3	1	0	0	0	0	3	1	0	0	3	1	0	0	0	0	0	0
Patuakhal	0	0	0	0	0	0	0	0	5	1	7	2	3	1	0	0	4	1	6	2
Chandpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chittagon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comilla	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
Cox'sBazar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	7	2

Feni	0	0	0	0	0	0	0	0	0	0	8	1	3	1	0	0	0	0	0	0
Hatiya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M.court	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2
Rangama	0	0	0	0	10	2	0	0	7	1	21	3	0	0	3	1	0	0	23	4
Sandwip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1
Sitakund	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	3	1
Kutubdia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teknaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	38	5	217	45	452	66	92	24	303	57	585	83	353	70	96	22	141	34	346	65

Table 2(b): Yearly Numbers of Heat Wave Days and Heat Waves during 2000-2009

	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009	
St. Name	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp
Dhaka	0	0	6	1	0	0	0	0	14	2	0	0	9	3	10	2	7	1	18	4
Tangail	3	1	4	1	0	0	3	1	19	3	8	2	9	3	12	2	7	1	9	2
Mymensi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Faridpur	4	1	11	2	0	0	16	3	17	2	17	3	7	2	11	3	13	3	19	3
Madaripu	4	1	4	1	0	0	7	1	15	1	14	3	10	3	9	2	11	2	11	2
Srimanga	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	6	1	0	0
Sylhet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	0	0	0	0
Bogra	0	0	3	1	0	0	0	0	14	3	5	1	6	2	17	3	5	1	8	2
Dinajpur	4	1	15	2	0	0	0	0	9	2	0	0	0	0	5	1	0	0	8	2
Ishurdi	9	2	17	3	3	1	22	3	32	3	45	4	22	5	32	4	25	4	27	4
Rajshahi	11	1	29	4	6	2	21	3	35	3	28	4	23	6	32	4	32	5	31	4
Rangpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0
Syedpur	3	1	6	1	0	0	0	0	8	2	0	0	0	0	5	1	0	0	6	2
Chuadan	9	2	30	5	7	2	31	4	39	4	46	5	28	6	31	4	25	5	28	3
Jashore	16	3	17	3	12	2	32	4	33	5	47	3	41	5	36	5	39	5	37	4
Khulna	10	2	16	3	4	1	13	2	13	1	15	4	22	2	13	2	25	5	29	4
Mongla	3	1	10	2	7	2	9	2	14	1	29	5	16	2	9	2	16	4	22	5
Satkhira	7	1	12	3	6	1	13	2	17	1	34	4	14	4	17	3	26	4	23	3
Barisal	0	0	6	1	0	0	0	0	0	0	0	0	0	0	3	1	5	1	4	1
Bhola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0
Khepupar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0
Patuakhali	3	1	9	2	0	0	0	0	7	1	0	0	3	1	6	2	13	3	7	2
Chandpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	6	2	4	1
Chittagong	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comilla	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	7	2
Cox'sBazar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feni	0	0	4	1	0	0	0	0	0	0	0	0	0	0	5	1	3	1	0	0
Hatiya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M.court	0	0	0	0	0	0	5	1	7	2	9	2	5	1	9	2	8	2	8	2
Rangamati	4	1	12	3	4	1	8	2	11	1	4	1	18	3	3	1	17	4	17	4
Sandwip	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0
Sitakunda	4	1	8	2	6	1	0	0	3	1	0	0	9	2	3	1	3	1	0	0
Kutubdia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teknaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	94	20	223	42	55	13	184	29	307	38	301	41	249	52	290	53	295	56	323	56

Table 2(c): Yearly Numbers of Heat Wave Days and Heat Waves during 2010-2019

	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019	
St. Name	D	Sp	D	Sp	D	Sp	Da	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp	D	Sp
Dhaka	11	2	0	0	7	2	3	1	34	4	0	0	15	2	7	1	0	0	7	2

Tangail	12	3	0	0	15	4	8	1	37	4	0	0	16	2	7	1	0	0	7	2
Mymensi	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0
Faridpur	25	4	0	0	18	5	12	2	43	5	0	0	22	3	15	2	0	0	11	2
Madaripu	12	3	0	0	6	1	0	0	37	5	6	2	11	3	7	1	0	0	18	4
Srimanga	11	2	0	0	7	1	8	1	11	2	0	0	0	0	0	0	0	0	3	1
Sylhet	5	1	0	0	0	0	0	0	10	1	3	1	0	0	0	0	0	0	3	1
Bogra	5	1	0	0	9	3	3	1	28	4	0	0	28	4	0	0	0	0	0	0
Dinajpur	9	3	0	0	10	3	0	0	18	4	0	0	13	2	0	0	0	0	0	0
Ishurdi	42	4	3	1	53	5	25	3	46	4	22	4	28	3	21	3	0	0	24	4
Rajshahi	50	5	12	3	54	3	28	3	52	5	37	7	27	3	27	5	0	0	25	5
Rangpur	0	0	0	0	0	0	0	0	11	2	0	0	3	1	0	0	0	0	0	0
Syedpur	7	2	0	0	0	0	0	0	18	3	0	0	13	3	0	0	0	0	0	0
Chuadanga	46	5	18	3	50	4	31	4	54	5	22	4	25	2	14	3	0	0	24	4
Jashore	49	5	27	5	48	5	31	4	53	5	25	2	31	2	28	4	3	1	30	4
Khulna	30	5	3	1	37	5	11	2	44	5	19	3	30	4	14	2	0	0	29	3
Mongla	32	7	4	1	22	3	22	4	51	6	12	3	35	5	18	3	4	1	28	5
Satkhira	32	7	16	3	36	6	11	3	42	5	25	2	32	4	16	3	0	0	22	2
Barisal	4	1	0	0	3	1	0	0	21	3	0	0	3	1	8	1	0	0	4	1
Bhola	0	0	0	0	0	0	0	0	10	2	0	0	0	0	3	1	0	0	3	1
Khepupar	4	1	0	0	7	2	0	0	16	3	0	0	3	1	0	0	0	0	4	1
Patuakhal	18	3	0	0	10	3	9	2	29	3	4	1	5	1	8	1	0	0	8	2
Chandpur	5	1	0	0	3	1	0	0	12	2	0	0	8	2	10	1	0	0	0	0
Chittagon	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0
Comilla	0	0	0	0	0	0	0	0	13	2	0	0	0	0	0	0	0	0	0	0
Cox'sBazar	6	2	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0	4	1
Feni	0	0	0	0	0	0	0	0	13	2	0	0	3	1	5	1	0	0	4	1
Hatiya	0	0	0	0	0	0	0	0	9	2	0	0	0	0	0	0	0	0	3	1
M.court	9	2	0	0	3	1	0	0	30	3	7	1	4	1	13	2	0	0	12	3
Rangamati	7	1	0	0	0	0	17	2	31	3	4	1	6	2	3	1	0	0	16	3
Sandwip	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0	3	1
Sitakunda	5	1	0	0	0	0	0	0	11	2	0	0	5	1	0	0	0	0	3	1
Kutubdia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teknaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	436	71	83	17	398	58	219	33	803	100	186	31	366	53	224	36	7	2	295	55

3.3 Trend of the Frequency of HW and HWD

The frequency (i.e. the 30 years average) of HW and HWD features of all stations in Bangladesh for the study period 1990-2019 and the calculated values of Sen's slope and Z score with its significance level using Mann-Kendall & Sen's slope estimator are tabulated in Table 3. It shows Jashore, the highest frequency of HWD station, is indicating insignificant positive tendency, Sen's slope value for the pre-monsoon season is 0.192 days/year. According to Z score (0.55) this trend is statistically insignificant. Chittagong, the lowest frequency of HWD, has not given any trend value using Mann-Kendall test because of maximum null (zero) data The next top 4 highest frequency of HWD are occurred at Chuadanga, Rajshahi, Ishurdi and Satkhira (Table 1). Among these stations, Chuadanga, Rajshahi and Ishurdi are indicating negative tendency and Sen's slope values at these stations for pre-monsoon season are -0.299, -0.097 and -0.087 days/year, respectively. According to Z values, the trend -0.86, -0.25 and -0.20 are statistically insignificant. Whereas Satkhira revealed positive tendency; value of Sen's slope at this station is 0.050 days/year with Z value is 0.57 that's insignificant. No HW occurred at Teknaf and Kutubdia (Table 3).

In summary, out of 34 stations, 2 stations do not have any data of HW. Rest of the 32 stations, 18 have a positive tendency, 9 have a negative tendency and 5 have not given any tendency because of maximum null data. Finally, it is clear that most of the stations show a positive (increasing) tendency.

With respect to the frequency of HW; Rajshahi, the highest numbers of HW, is indicating a negative tendency, Sen's slope value is -0.042 days/year and Z score (-0.99) is statistically insignificant. Whereas Chittagong, the lowest numbers of HW, is indicating without any trend value. After Rajshahi station, the next 4 highest frequency of HW stations are Jashore, Chuadanga, Ishurdi and Satkhira (Table 1). It indicates that in pre-monsoon season all stations experienced significant negative tendency. Sen's slope values are -0.025, -0.051, -0.058 and -0.011 spell/year. According to Z-scores (-0.99, -1.10, -1.02 and 0.00) these trends are statistically insignificant (Table 3).

In summary, out of 34 stations, 2 stations do not have any data of HW. Rest of the 32 stations, 16 have a positive tendency, 11 have a negative tendency and 5 have not given any tendency because of maximum null data. Finally, it is clear that most of the stations show a positive (increasing) tendency.

Table 3: Trend, Z-score and level of significance of HW and HWD

Station Name	HWD			HW		
	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	0.40	
Srimangal	0.027	0.86		0.004	0.80	
Sylhet	0.082	1.62		0.016	1.60	
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	-0.70		-0.003	-0.63	
Syedpur	-0.037	-0.84		-0.009	-0.79	
Chuadanga	-0.299	-0.86		-0.051	-1.10	
Jashore	0.192	0.55		-0.025	-0.99	
Khulna	0.369	1.90		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	2.70	**	0.039	2.45	*
Chittagong	-	-	-	-	-	-
Comilla	-	-	-	-	-	-
Cox's Bazar	-	-	-	-	-	-
Feni	0.083	1.40		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.

It is noted that the highest frequencies of HWD and the highest frequencies of HW do not occur in the same station (Table 1). Overall Rajshahi is the hottest place in the sense of frequency of HW and Jashore in the sense of HWD among all the places in Bangladesh during 1990-2019.

3.4 Level of Significance of Trend of the Frequency of HWD and HW

Having drawn the trend analysis of the frequency of HWD and HW in Bangladesh during the period 1990 to 2019 using Mann-Kendall test, the stations which are revealed the level of significance have been discussed in this para. It is remarkable that the data of 1990 at Mymensingh station is missing, so the data from 1991 to 2019 has been considered for this station (Table 3). The stations M. Court, Mongla, Patuakhali, Chandpur and Mymensingh have revealed the level of significance in both cases of the frequency of HWD and HW. The frequency of HWD and HW of these stations are 4.5, 15.7, 5.47, 1.9 and 0.8 days/year, and 0.9, 2.9, 1.17, 0.43 and 0.2 spell/year respectively. All of these stations indicated significant positive tendencies except Mymensingh from the analysis of the frequency of HWD and HW. The station Mymensingh indicated a significant negative tendency. Sen's slope values of these stations with respect to frequency of HWD and HW are 0.386, 0.607, 0.305, 0.197 and -0.103 days/year, and 0.066, 0.080, 0.047, 0.039 and -0.026 spell/year respectively.

Again, the Z values extend the critical values for all these stations but they vary for different level of significance. For the station M. Court, 99.9% and 99% significance are found for the frequency of HWD and for the frequency of HW respectively. And the trend of Mongla, Patuakhali and Chandpur is significant at level of 99% confidence interval for the frequency of HWD and 95% significant confidence level for the frequency of HW. Another station Mymensingh shows a negative tendency with a value of Z score -2.24 and -2.27 for the frequency of HWD and HW respectively which is statistically significant at the level of 95% confidence interval for both cases. Satkhira has not given any Z-score value in the sense of frequency of HW.

In summary, out of 34 stations, 2 stations do not have any data of HW. Rest of the 32 stations, 4 have a positive tendency with different levels of significance, 1 has a negative tendency with a 95% level of significance and 27 have given positive and negative tendencies but are not given any significance level of confidence.

3.5 Analysis of the spatial distribution of HW frequency

Figures 1 (a) – (b) show the spatial distribution of the frequency of HW and HW days. Figures shows the hottest area which are the southwestern and middle-western parts of Bangladesh in pre-monsoon in terms of HW and HW days (Table 1).

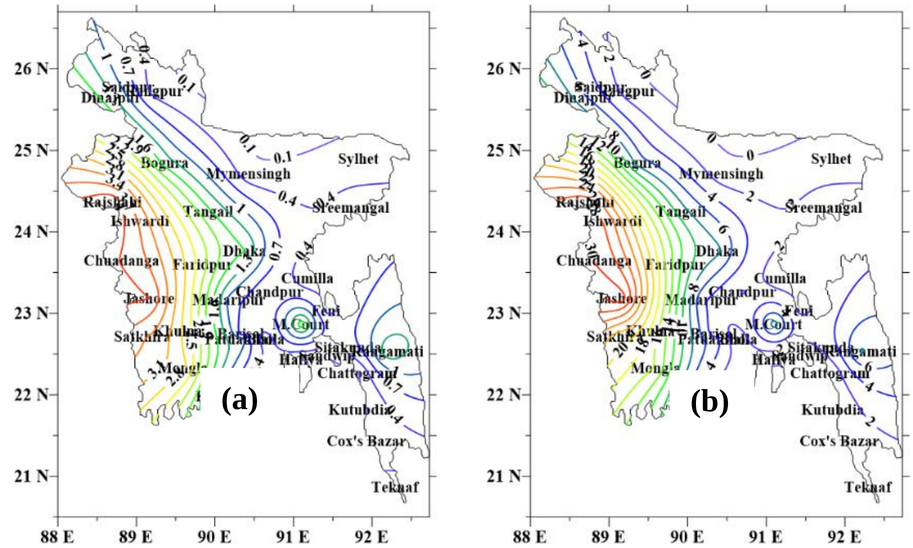

Figure 1: Spatial distribution of frequency of (a) HW and (b) HW days in Bangladesh.

4. Conclusions

The foot hill of Himalaya is warmer in pre-monsoon and its temperature is varies 40^0 – 48^0 C in the part of India. that means it is over heated region. In the foot hills of Himalaya, trough of heat low extends to Bangladesh. There is a possibility to advect temperature towards Bangladesh. Besides in the pre-monsoon, south/south westerly wind carries a high amount of moisture over Bangladesh. The heat capacity of moisture is higher than that of dry air. Solar insulation, temperature advection and moisture incursion, these three phenomena are responsible for extreme temperature conditions. Another thing is Veering. Due to the geographical location, Bangladesh experiences HW in pre-monsoon. So, it is very important to predict these Extreme hot temperature condition time and location specific to minimize casualties. In the present study, the category of the frequency of HW days and frequency of HW have been studied for Pre-monsoon (March to May) over most of the stations (34) of Bangladesh for the period 1990-2019. It shows the highest and lowest frequency of HW days are obtained at Jashore (30.9 days) and Chittagong (0.23 days) respectively. The next top 4 highest frequency of HW days are obtained at Chuadanga (29.9 days), Rajshahi (29.53 days), Ishurdi (26.13 days) and Satkhira (21.13 days). No HW occurred at Teknaf and Kutubdia. It may be because of the coastal area. With respect to the frequency of HW, the highest and lowest numbers of HW is occurred in Rajshahi (4.23) and in Chittagong (0.07). After Rajshahi station, the next highest frequency of HW 4 stations is Jashore (4), Chuadanga (3.97), Ishurdi (3.63) and Satkhira (3.43). It is noted from Table 1 that, the highest numbers of HW days and the highest number of HW do not occur at the same station. The highest numbers HW days are found in Jashore (30.9 days) of all types of events and frequency is found in Rajshahi (4.23) for HW during Pre-monsoon season respectively. April is the warmest month in Bangladesh. The warmest places are Jashore, Chuadanga, Rajshahi, Ishurdi and Satkhira and the lowest numbers HW days show at Chittagong (0.23 days) and the lowest is in the Chittagong (0.06) on the basis of frequency of HW. It is also observed from Table 1 that, the highest numbers of frequency of HW days and the highest number of frequencies of HW do not occur at the same station. 2014 is the warmest year and 2018 is the lowest warm recorded year. By Mann-Kendall test, according to the Z score the stations M. court, Mongla, Patuakhali, Chandpur and Mymensingh have obtained the level of significance in both cases of the frequency of HW days and the frequency of HW. For the frequency of HW days, out of 5 stations M. court has a 99.9 % significance confidence level with positive tendency; Mongla, Chandpur and Patuakhali have obtained 99% significance confidence level with positive tendency and Mymensingh has given negative tendency with 95% significance confidence level. For the frequency of HW, out of 5 stations M. court has a 99% significance confidence level with positive tendency. Rest of the stations have obtained 95% significance confidence level with positive tendency except Mymensingh; Mymensingh has given negative tendency. Satkhira has not given any Z-score value in the sense of frequency of HW. Finally, it is clear that most of the stations show a positive (increasing) tendency significance confidence level. From spatial distribution, it shows that south western and middle-western parts of Bangladesh are the hottest area.

Acknowledgements

The authors are grateful to the Bangladesh Meteorological Department (BMD) for approving and supporting the present study and providing relevant meteorological data associated with the research.

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