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The study of extreme temperature conditions in Bangladesh during 1990 to 2019

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Abstract
An extreme temperature is a weather phenomenon that is distinguished by marked cooling or heating of the air, or with the invasion of very cold or hot air, over a large area within a certain period. When temperature plunges 10°C or less and continue for three or more days considered as cold wave (CW). In winter season, the sun shifted southwards and Indian sub-continent get incline solar insolation. Wind enters into the country through the Himalayan foot hills and drops the day-night temperature and makes the cold feelings. On the other hand, when temperature exceed 36 degrees Celsius and last for minimum three or more days can be considered as heat wave (HW). 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 insolation, temperature advection and moisture incursion these three phenomena are responsible for extreme temperature (HW) conditions. Backing and Veering is also responsible for especially severe and very severe CW and HW conditions. In the present study, all categories of cold wave and heat wave days (Duration) and frequencies (spell) have been studied for the winter (December to February) and Pre-monsoon (March to May) over most of the stations (34) of Bangladesh for the period 1990-2019. The highest numbers of cold wave and heat wave days are found in Srimangal (803 nights) and Jashore (927 days) of all types of events and frequencies are found Srimangal (114) for CW and Rajshahi (127) for HW during winter and pre-monsoon season respectively. January is the highest cold month and April is the highest warm month in Bangladesh. Cold nights in Bangladesh are decreased of all divisions except Barisal. The highest 5 coldest places are Srimangal, Ishurdi, Rajshahi, Chuadanga and Dinajpur and the highest hottest places are Jashore, Chuadanga, Rajshahi, Ishurdi and Satkhira on the basis of duration. Kutubdia and Teknaf had no CW or HW; Cox's Bazrar had no CW at all. Among 30 years, 1995 is the highest coldest year and 2009 is the lowest cold day recorded year and 2014 is the highest hottest year and 2018 is the lowest hot day recorded year. By Mann-Kendall test, the HW trend of Mymensingh station has given only significant and decreasing value. From spatial distribution, it shows coldest areas which are Srimangal and northwestern parts of Bangladesh and hottest area which are western and middle-western parts of Bangladesh.

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1. Introduction

Bangladesh is one of the tops most nations vulnerable to 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 [1]. Modeling studies by Haque et al 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 [2].

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 20051. 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 [3].

A study has been carried out to analyze the spatial and seasonal patterns in the trends of Daily temperature data (DTR) in Bangladesh. DTD from 18 stations for the time period 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 [4]. 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 [5]. 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 recent 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. Other possible reasons behind these changes are local factors such as deforestation, urbanization etc [6].

Bangladesh is a tropical country, this region normally temperatures fall about 10 degrees Celsius (°C) during January. The cold wave is defined in the occurrence of extremely low temperature of a large area and a number of cold days in succession association with the incursion of dry, cold winds from the north into the sub-continent. The northern parts hilly region of India and adjoining plains area, are influenced by transient disturbances in the mid-latitude westerly's which often have weak frontal characteristics. These are known as western disturbances [7, 8]. A cold surge, alternatively called a cold wave or northern winter monsoon surge, is a primary subsystem of the East Asian winter monsoon [9, 10]. All the cold events resulted in a huge amount of damage and great economic loss [11]. Crop yields in the cold wave year were lower of different percentage [11]. Extreme temperature events (mainly heat and cold waves) caused significant adverse impact on mortality from plenty of diseases worldwide [12]. In this century, extremes cold are observed at mid-latitudes [10]. Basically, the northwestern part of Bangladesh is getting so much of cold wave rather than southeast part. Rangpur, Dinajpur, Rajshahi, Thakurgaon, Nilphamari, Kurigram, Lalmonirhat, Gaibandha areas are the coldest part in winter season in Bangladesh. North and southwest parts of the Bangladesh experienced a few cold waves [13]. Some studies have suggested that Arctic warming, along with decreased sea ice, has resulted in a wavier jet stream and slower Rossby waves because of a reduced meridional gradient of the air temperature. This favor blocking over higher latitudes, which leads to more frequent and intense cold spells in the multitudes over the Northern Hemisphere [14]. 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 increase in climate extremity such as heat wave, sudden moderate cold wave [15, 16, 17]. So, now according to the experts' opinion of Bangladesh Meteorological Department (BMD), it can easily be stated that, Bangladesh is currently experiencing a severe cold wave. Northern and southwest parts of the country experienced a rapid fall in temperature on 1 January, 2010. Temperatures have remained low since, with cold winds and serve fog. Poor people in the northern region of the country are the worst affected. The impact of the cold wave has resulted in a significant rise in respiratory illnesses, and in some cases death. BMD has predicted that a further one or two severe cold waves (04°C - 06°C) is likely to sweep across the northern and central parts of the country during the remainder of January (UNDP Bangladesh, 2010) [13].

The objectives of this research are to

1. Find out the climatology of Bangladesh for extreme temperature in winter and Pre-monsoon,
2. Trend analysis of cold days and heat days conditions and
3. Trend analysis of cold wave and heat wave frequency.

2. Data and Methodology

The 1990-2019's cold and warm day data have been taken from the Climate Section of the Bangladesh Meteorological Department (BMD). Cold and Warm day data are found out from the daily minimum and maximum temperature. There are four types of cold and heat waves counted by the BMD. Those are mild CW (8.1-10°C), moderate CW (6.1-8°C), severe CW (4.1-6°C) and very severe CW (>=4°C) and mild HW (36-38°C), moderate HW (38.1-40°C), severe HW (40.1-42°C) and very severe HW (< 42°C). One missing data are replaced by the average value of nearest data, but 2 or more missing value at a time are replaced by the surrounding station areas average value. Only 3 days or more swiped CW or HW are considering in this study. All of the data have been calculated using excel, Surfer and Arc GIS software. Mann-Kendall test also have been used to draw the trend of CW and HW frequency. FORTRAN language has been used for the calculating cold and hot day duration.

3. Result and Discussion

Recent scenario and trend of extreme temperature in Bangladesh

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

hot days or cold nights means the number of hot days or cold nights counting on the spell, and frequency of HW or CW means how many spells occurred during the specific period.

3.1 Analysis of the frequency of heat waves and duration of hot days

The frequency of HW and duration of hot day features of all stations in Bangladesh are shown in Table 1. It shows the highest duration of hot days at Jashore (927 days). The next top 4 highest duration of hot day's shows at Chuadanga (900 days), Rajshahi (886 days), Ishurdi (780 days) and Satkhira (626 days); the lowest numbers duration of hot days shows at Chittagong (7 days). No HW occurred at Teknaf and Kutubdia. In respect of the frequency of HW, in Rajshahi (127) the highest numbers of HW occurred and lowest in the Chittagong (2). After Rajshahi stations, the next highest frequency's HW 4 stations are Chuadanga and Jashore (120 jointly), Ishurdi (110) and Satkhira (103). It is noted that the highest numbers of total days and the highest number of frequencies do not occur in the same station (Table 1). Overall Rajshahi is the hottest place among all the places in Bangladesh during 1990-2019 in the sense of frequency and Jashore in the sense of duration.

Table 1: Monthly and seasonal frequency of heat waves and duration of hot days

Station Name	March		April		May		Pre-Monsoon	
	Frequency	Duration	Frequency	Duration	Frequency	Duration	Frequency	Duration
Dhaka	6	32	27	147	15	76	48	255
Tangail	5	20	26	150	19	98	50	268
Mymensinghh	1	3	5	21	0	0	6	24
Faridpur	9	45	37	222	24	123	70	390
Madaripur	4	18	23	119	26	130	53	267
Srimangal	5	23	10	61	1	3	16	87
Sylhet	4	14	2	13	1	3	7	30
Bogra	0	0	23	124	21	89	44	213
Dinajpur	1	5	25	119	15	64	41	188
Ishurdi	21	137	49	354	40	295	110	780
Rajshahi	22	142	51	405	54	339	127	886
Rangpur	0	0	4	18	4	15	8	33
Sayedpur	1	4	15	70	9	37	25	111
Chuadanga	31	159	47	415	42	326	120	900
Jessore	20	117	51	433	49	377	120	927
Khulna	7	30	40	243	40	255	87	528
Mongla	10	43	36	211	41	217	87	471
Shatkhira	9	38	41	231	53	357	103	626
Barisal	2	6	10	52	6	26	18	84
Bhola	2	6	5	19	1	3	8	28
Khepupara	3	10	5	23	4	13	12	46
Patuakhali	5	20	14	73	16	71	35	164
Chandpur	1	3	6	26	6	23	13	52
Chittagong	0	0	2	7	0	0	2	7
Comilla	0	0	3	14	3	13	6	27
Cox'sBazar	2	6	3	14	2	7	7	27
Feni	1	8	4	21	5	19	10	48
Hatiya	0	0	3	12	0	0	3	12
Kutubdia	0	0	0	0	0	0	0	0
M.Court	0	0	7	42	20	93	27	135
Rangamati	10	40	23	159	12	47	45	246
Sandwip	0	0	3	13	1	3	4	16
Sitakunda	2	11	8	31	6	25	16	67
Teknaf	0	0	0	0	0	0	0	0

3.2 Analysis of the frequency of the cold wave and duration of cold nights

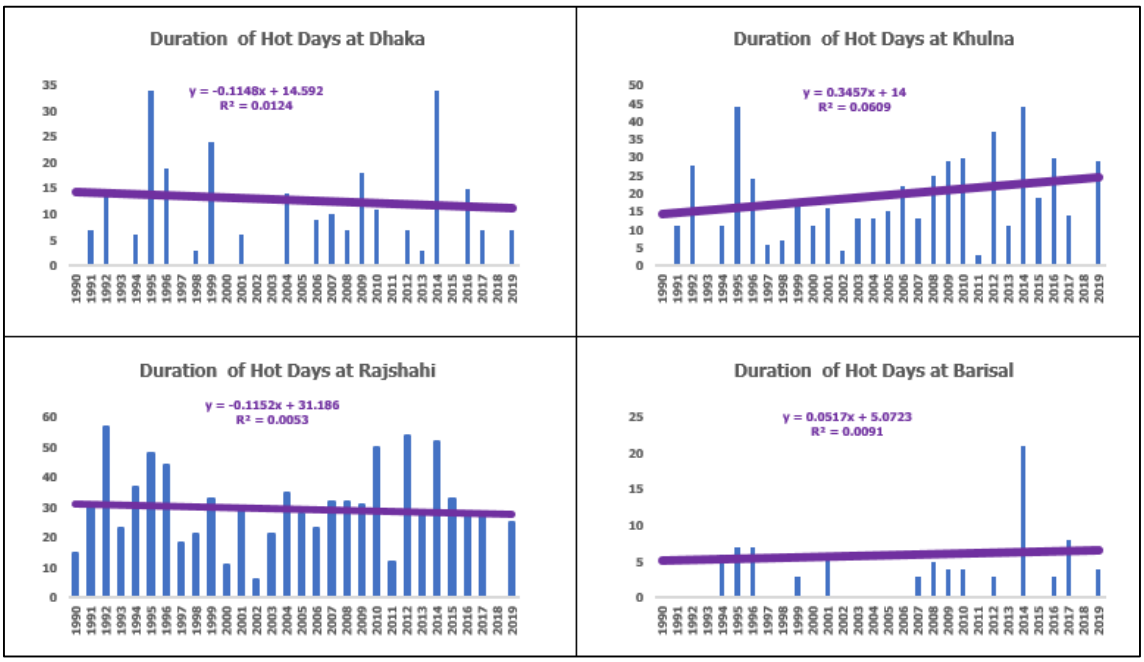
The frequency of CW and duration of cold night features of all stations of Bangladesh is shown in Table 2. It shows the highest duration of cold nights and frequency of CW at Srimangal (803 nights and 114). The next top 4 highest duration of cold nights show at Ishurdi (541 nights), Rajshahi (536 nights), Chuadanga and Dinajpur (533 nights jointly); the lowest numbers duration of cold nights shows at Chittagong (4 nights). No CW occurred at Cox's Bazar, Teknaf and Kutubdia. In the respect of the frequency of CW, in Rajshahi (90) is the 2nd highest number of CW occurred and the lowest is Chittagong (1). The next highest frequencies of CW 4 stations are Ishurdi (87), Jashore (85), Chuadanga (83) and Dinajpur (80). The Table 2 also shows that, highest numbers of total nights are all-time highest number of frequencies. Overall Srimangal is the coldest place among all the places in Bangladesh during 1990-2019.

Table 2: Monthly and seasonal frequency and duration of cold nights

Station Name	January		February		December		Winter	
	Frequency	Duration	Frequency	Duration	Frequency	Duration	Frequency	Duration
Dhaka	9	41	0	0	0	0	9	41
Tangail	40	201	5	18	8	32	53	251
Mymensinghh	26	140	1	3	5	18	32	161
Faridpur	30	122	1	3	4	15	35	140
Madaripur	27	121	0	0	5	18	32	139
Srimangal	59	442	23	103	32	258	114	803
Sylhet	6	24	0	0	1	6	7	30
Bogra	32	185	1	4	5	21	38	210
Dinajpur	47	357	12	46	21	130	80	533
Ishurdi	53	354	8	35	26	152	87	541
Rajshahi	54	357	10	41	26	138	90	536
Rangpur	40	250	6	23	9	51	55	324
Sayedpur	43	297	7	25	14	88	64	410
Chuadanga	53	344	9	27	21	162	83	533
Jessore	55	328	8	28	22	132	85	488
Khulna	24	120	0	0	1	3	25	123
Mongla	2	7	0	0	0	0	2	7
Shatkhira	31	175	0	0	11	44	42	219
Barisal	36	165	2	6	6	28	44	199
Bhola	18	86	0	0	3	9	21	95
Khepupara	7	28	0	0	0	0	7	28
Patuakhali	8	31	0	0	0	0	8	31
Chandpur	5	16	0	0	0	0	5	16
Chittagong	1	4	0	0	0	0	1	4
Comilla	24	106	2	6	8	43	34	155
Cox'sBazar	0	0	0	0	0	0	0	0
Feni	14	66	0	0	1	4	15	70
Hatiya	2	8	0	0	1	3	3	11
Kutubdia	0	0	0	0	0	0	0	0
M.Court	2	10	0	0	0	0	2	10
Rangamati	16	74	2	6	1	3	19	83
Sandwip	2	9	0	0	0	0	2	9
Sitakunda	31	152	3	14	6	28	40	194
Teknaf	0	0	0	0	0	0	0	0

3.3 Trend analysis of duration of hot days for divisional stations

3 days or more continuation hot days duration of divisional stations have been shown in Figure 1. Here it shows that the trend of the duration of hot days is increasing clearly at the stations Khulna, Sylhet, Rangpur, and Barisal a little bit; others are decreasing.



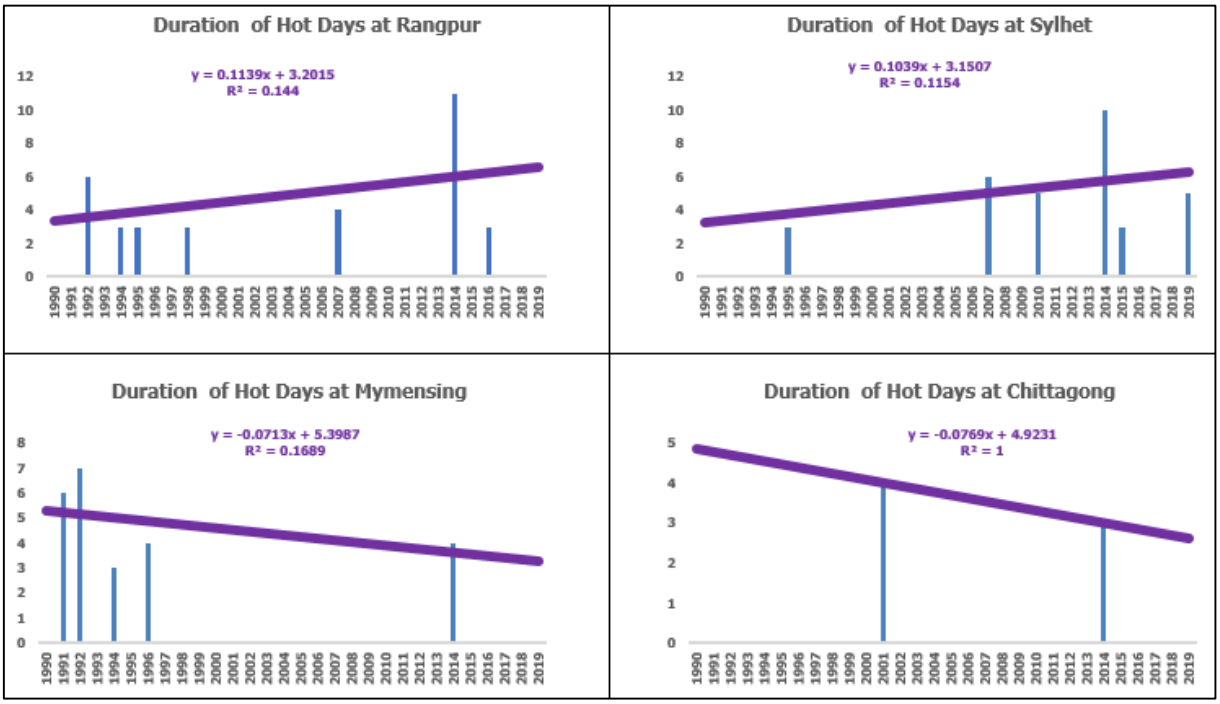
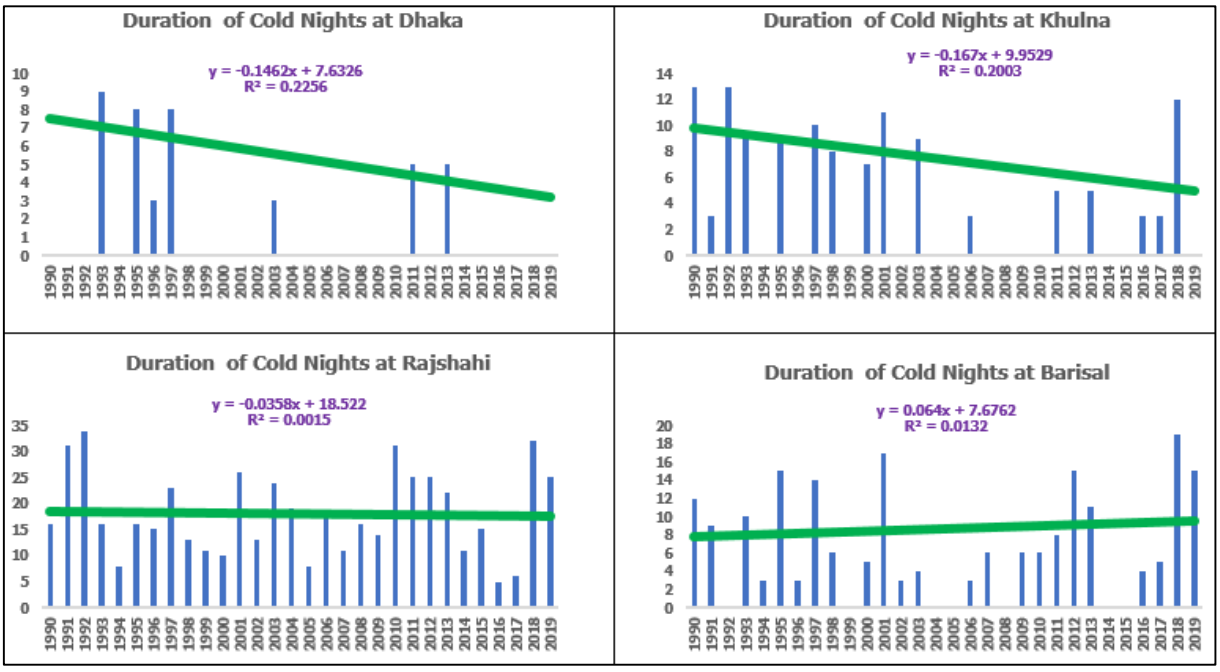


Fig 1: Duration of hot days at divisional stations in Bangladesh.

3.4 Trend analysis of duration of cold nights for divisional stations

3 nights or more continuation cold night's duration of divisional stations have been shown in Figure 2. Here it shows that the trend of the duration of cold nights is decreasing at every station except Barisal; the trend of duration of cold nights at Barisal is increasing. At Chattogram, there is a CW swiped over in the year 2013 among the 30 years. So, it is not possible to draw any trend value for Chattogram station.



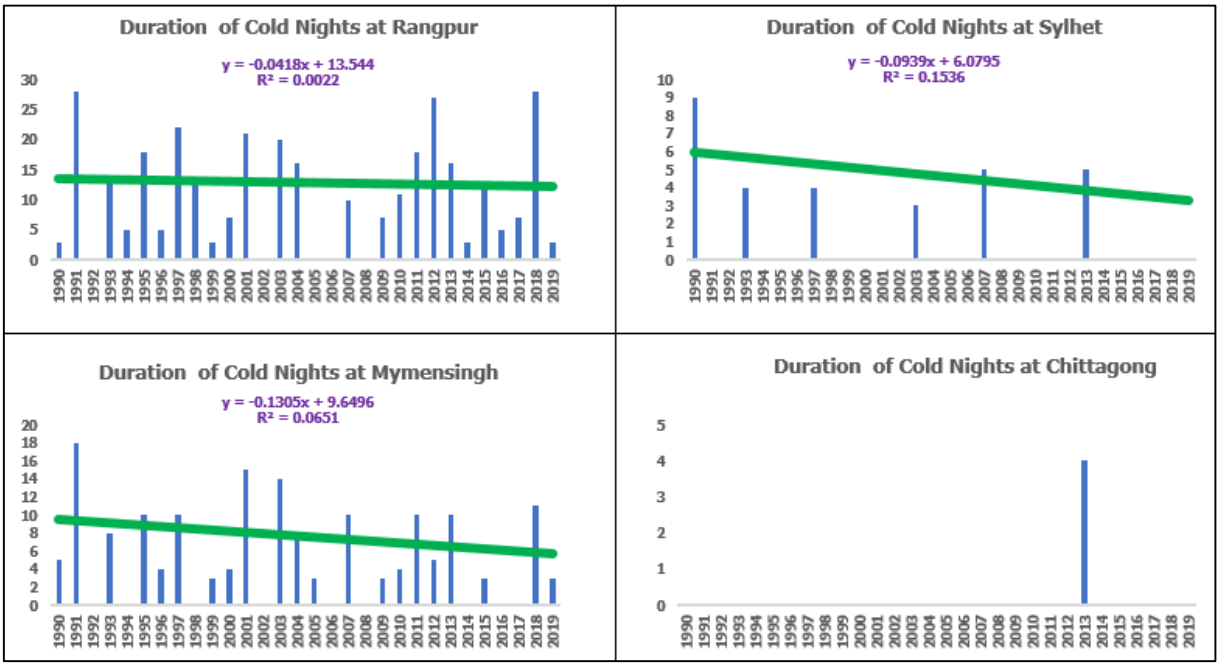


Figure 2 Duration of cold nights at divisional stations in Bangladesh

3.5 The trend analysis of the duration of the top 4 stations except for the hottest one

The trend analysis of the duration of the top 4 stations except the hottest one (Jashore station) in Bangladesh from 1990 to 2019 is shown in Figure 3 and Jashore station which is the highest among all is shown in Figure 5. It is shown that the trend of hot days duration at Chuadanga, Ishurdi and Rajshahi (Figure 1) is decreasing and Satkhira is increasing.

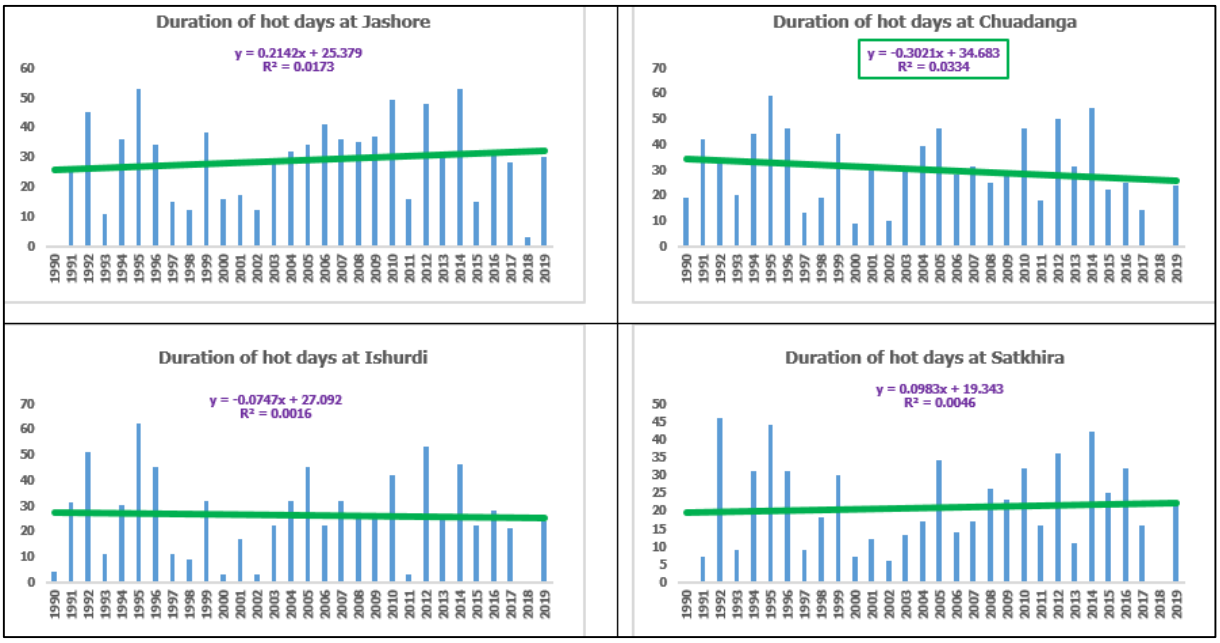


Fig 3: The trend analysis of the duration of the top 4 stations except the hottest one

3.6 The trend analysis of the duration of top 4 stations except for the coldest one

The trend analysis of the duration of top 4 stations except the coldest one (srimangal station) in Bangladesh from 1990 to 2019 is shown in Figure 4. srimongal station which is the highest among all is shown in Figure 6. It is shown that the trend of the duration of cold nights at every station is increasing. The cold nights duration at Chuadanga is increasing rapidly and others are a little bit.

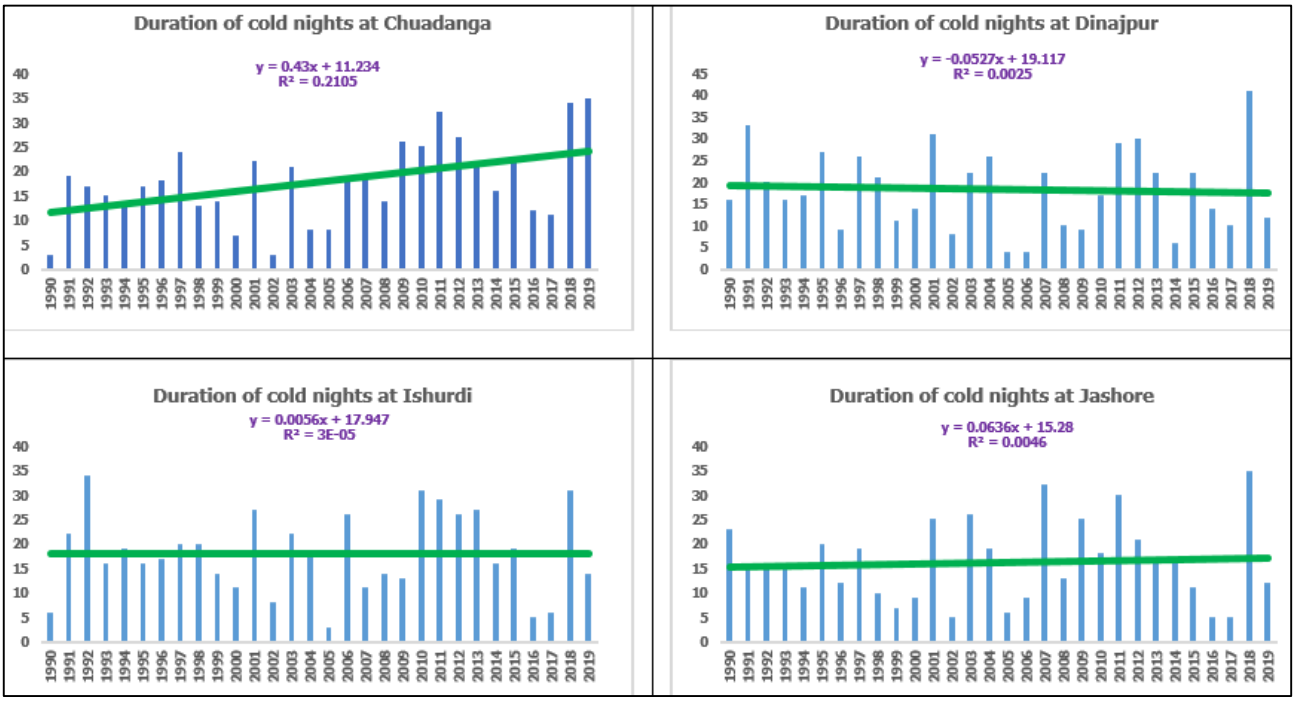


Fig 4: The trend analysis of the duration of the top 4 stations except the coldest one

3.7 Trend analysis of the duration of the hottest station

The trend analysis of the duration of hot days and cold nights at Jashore from 1990 to 2019 is shown in Figure 5. It is shown that Jashore is the hottest place in Bangladesh for the last three decades in the sense of the duration of hot days and the trend of hot days at this station is increasing. In winter, the trend of cold nights is also increasing.

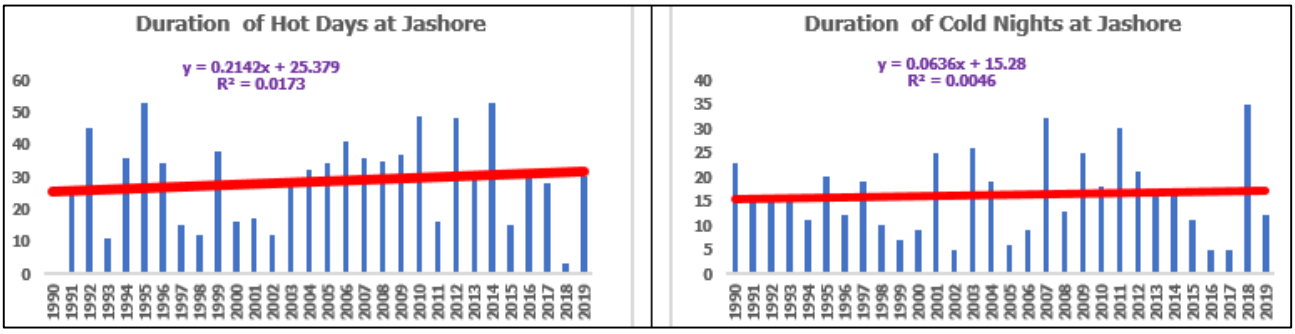


Fig 5: Analysis of the duration of hot days and cold nights at Jashore

3.8 Trend analysis of the duration of the coldest station:

The trend analysis of the duration of cold nights and hot days at Srimangal from 1990 to 2019 is shown in Figure 6. It is shown that Srimangal is the coldest place in Bangladesh for the last three decades in the sense of the duration of cold nights, and the trend of cold nights duration at this station is decreasing. In pre-monsoon, the trend of hot days duration is also decreasing.

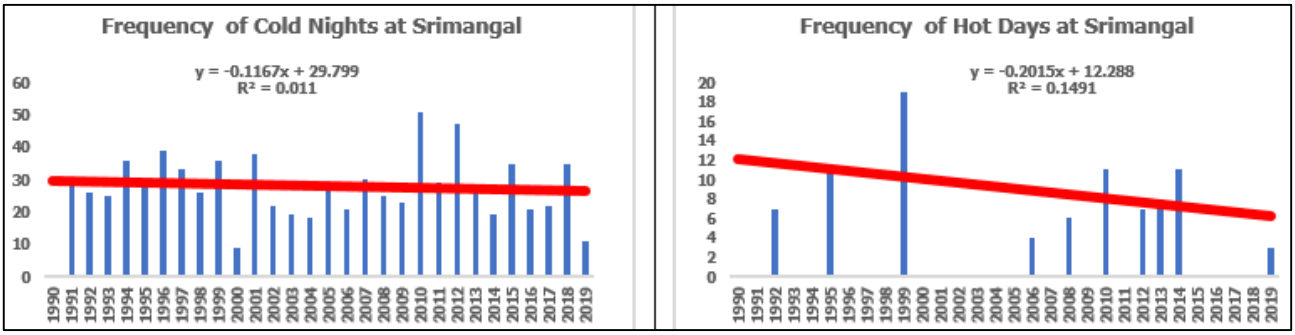


Fig 6: Analysis of the duration of cold nights and hot days at Srimangal.

3.9 Trend analysis of the frequency of HW in divisional stations using Mann-Kendall Test

Trend analysis of HW frequency in divisional stations is shown in Figure 7(a-h) by using Mann-Kendall test. It is shown that the trend of Khulna and Mymensingh stations has decreased; the Rangpur and Dhaka stations also decreased a little bit. Among these, only Mymensingh station has given significant values, for the rest of the stations (Rajshahi, Barisal, Sylhet), the trend is increasing but not found any significant values. Chattogram station has only two heat wave frequencies, so it is not possible to draw any trend from this station by Mann-Kendall test.

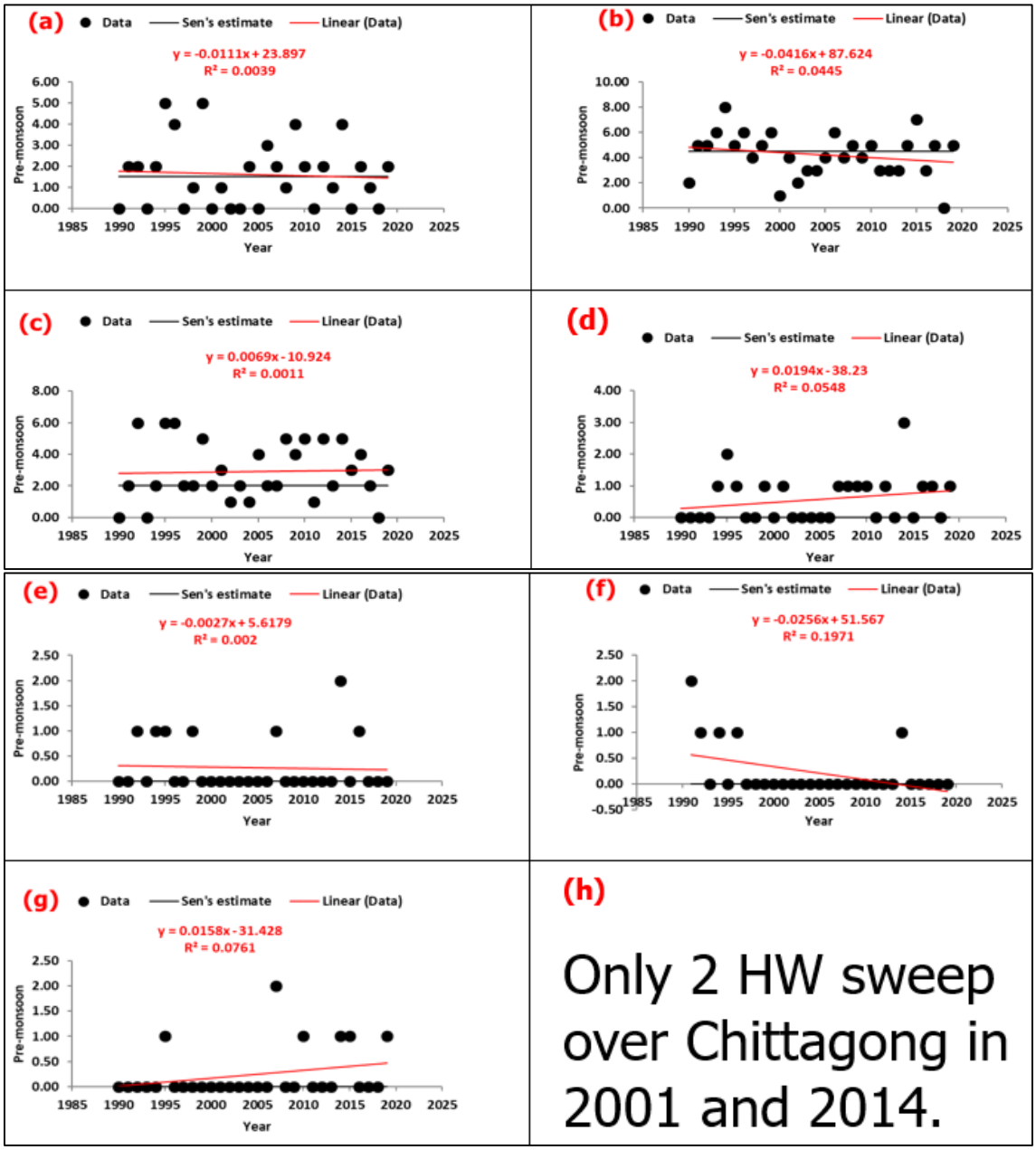


Fig 7(a-h): Trend analysis of heat wave frequency in divisional stations (a) Dhaka, (b) Khulna, (c) Rajshahi, (d) Barisal, (e) Rangpur, (f) Mymensingh (g) Sylhet, and (h) Chittagong

3.10 Trend analysis of the frequency of CW in divisional stations using Mann-Kendall test

Trend analysis of CW frequency in divisional stations is shown in Figure 8(a-h) by using Mann-Kendall test. It has shown that the trend of Dhaka, Rajshahi and Mymensingh stations has been decreasing; the station Sylhet is also decreasing a little bit. All the above stations have given no significant values. The trend of frequency of CW at Barisal station is increasing and the trend of CW at Khulna and Rangpur stations is increasing a little bit but have not found significant values. Chattogram has only one cold wave frequency, so it is not possible to draw any trend of this station by Mann-Kendall test.

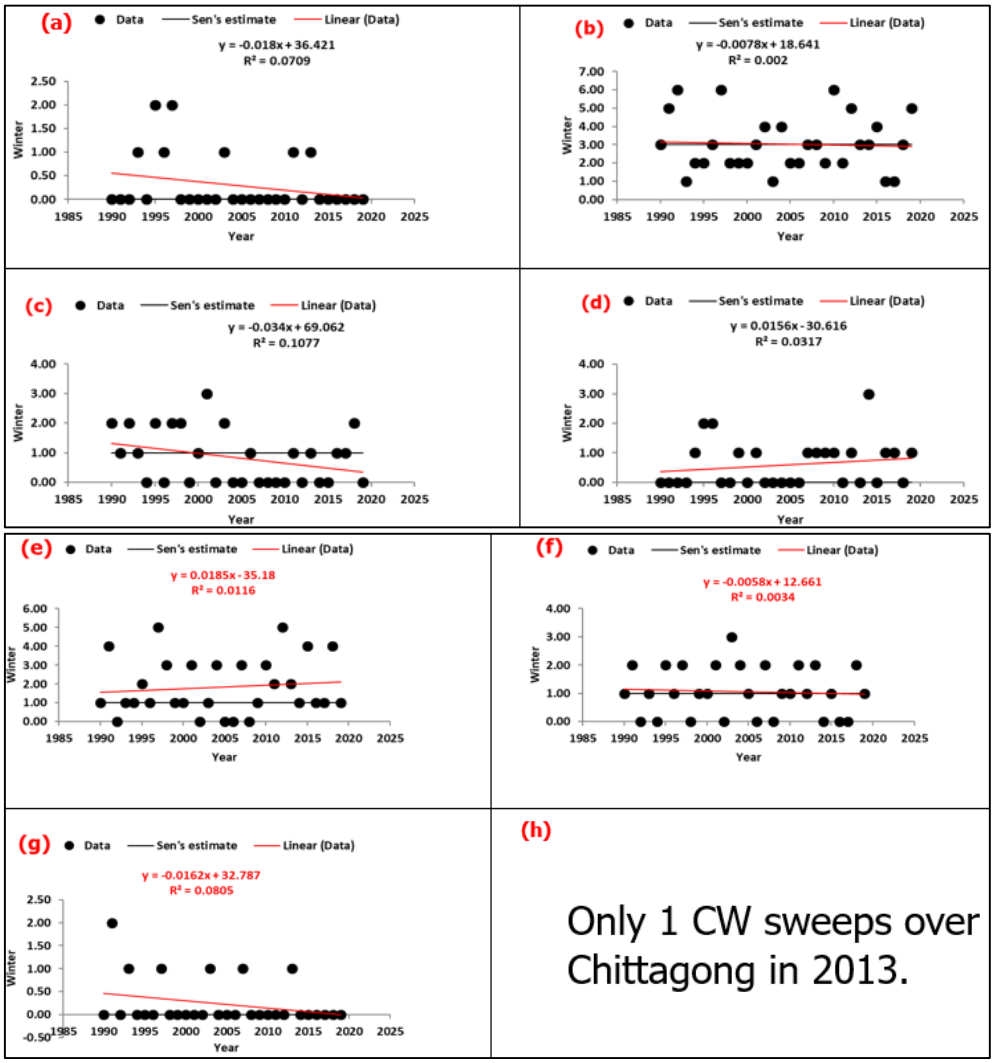


Fig 8(a-h): Trend analysis of cold wave frequency in divisional stations (a) Dhaka, (b) Khulna, (c) Rajshahi, (d) Barisal, (e) Rangpur, (f) Sylhet, (g) Mymensingh and (h) Chittagong.

3.11 The trend analysis of the frequency of HW of top 4 stations except the hottest one using Mann-Kendall test

The trend analysis of the duration of the top 4 stations except the hottest one using the Mann-Kendall test is shown in Figure 9(a-d). In the entire station, HW trend is decreasing, and it has no significant values.

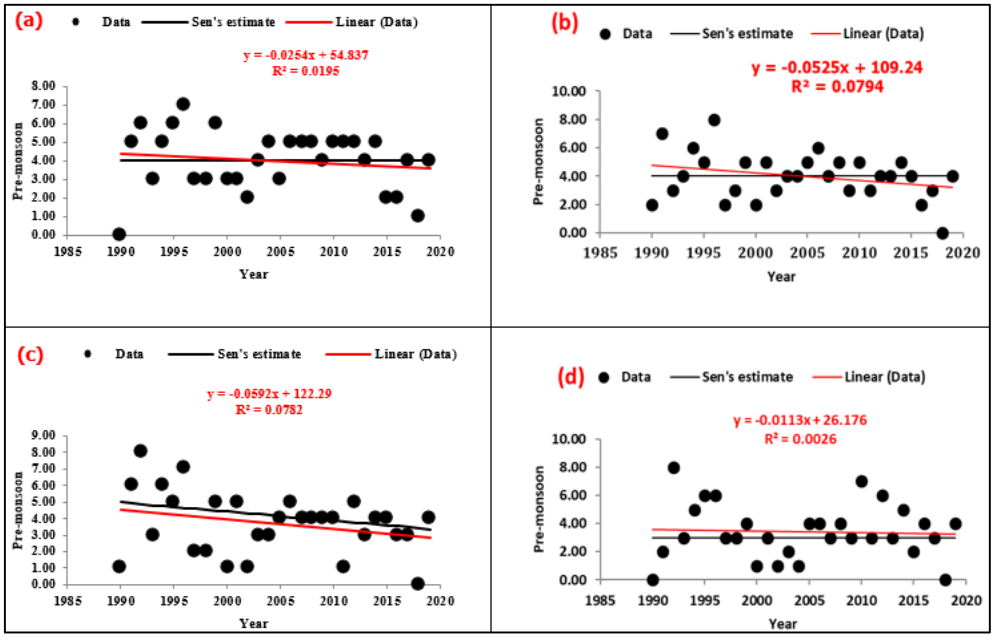


Fig 9(a-d): Trend analysis of HW frequency at (a) Jashore, (b) Chuadanga, (c) Ishurdi and (d) Satkhira.

3.12 The trend analysis of the frequency of CW of top 4 stations except coldest one using Mann-Kendall test

The trend analysis of the frequency of CW of top 4 stations except the coldest one using Mann-Kendall test are shown in figure 10(a-d). The entire stations CW trend is increasing a tiny number except Dinajpur; Dinajpur is decreasing a little bit and no significant values for the all stations.

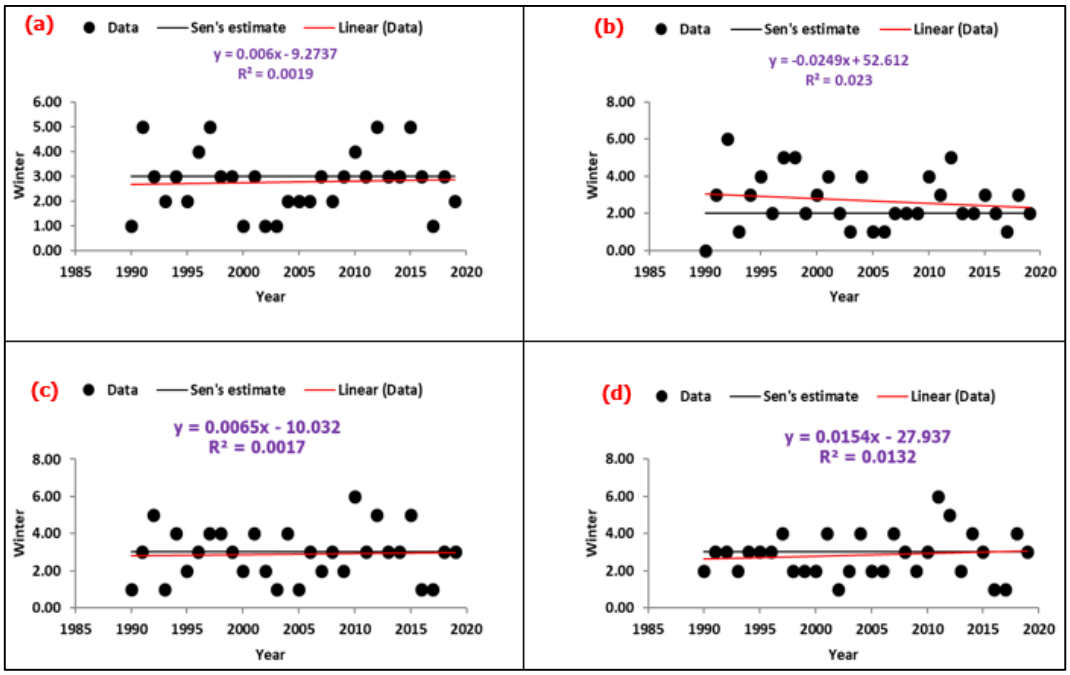


Fig 10(a-d): Trend analysis of CW frequency at (a) Chuadanga, (b) Dinajpur, (c) Ishurdi and (d) Jashore

3.13 Trend analyses of frequency of the hottest HW station using Mann-Kendal test

The trend analysis of the frequency of HW and CW at Rajshahi from 1990 to 2019 is shown in Figure 11. The highest number of HW frequency occurred during pre-monsoon at Rajshahi in Bangladesh (Figure 4.1.11(a)); it indicates that the trend is increasing a little bit. In winter, that station (Figure 11(b)) has indicated that the trend of CW is decreasing. In both cases, this station has not given any significant value.

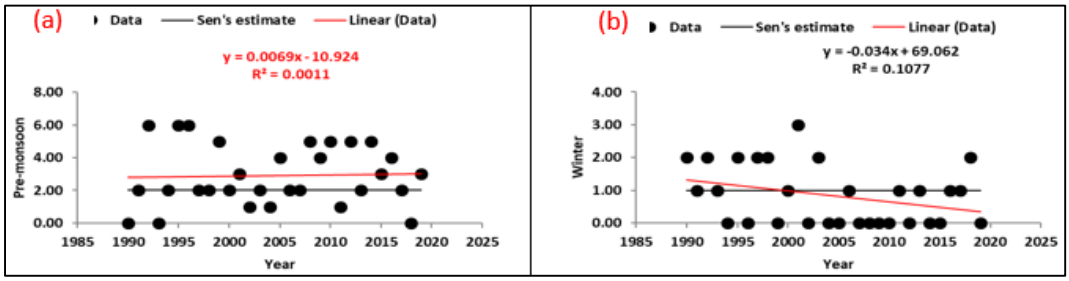


Fig 11(a-b): Analysis of (a) HW and (b) CW Frequency at Rajshahi

3.14 Trend analysis of frequency of the coldest CW station using Mann-Kendal test

The trend analysis of the frequency of CW and HW at Srimangal from 1990 to 2019 is shown in Figure 11. The highest number of CW frequencies occurred during winter at Srimangal in Bangladesh (Figure 12(a)); the trend of that station has increased a little bit. In Pre-monsoon, that station (Figure 12(b)) has indicated that the trend of HW is increasing a little bit. In both of the cases, this station has not given any significant value.

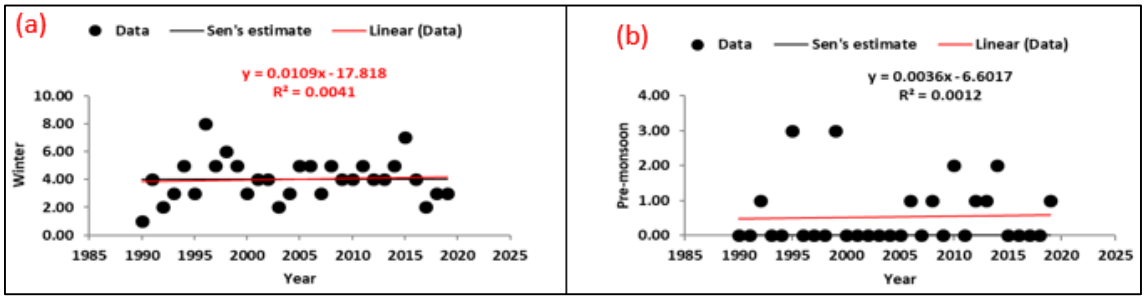


Fig 12(a-b): Analysis of (a) CW and (b) HW frequency at Srimangal

3.15 Analysis of the spatial distribution of HW and CW frequency

Figure 13(a-b) shows the spatial distribution of CW and HW frequency. It shows the coldest areas which are Srimangal and northwestern parts of Bangladesh in winter (Table 1) and the hottest area which are the southwestern and middle-western parts of Bangladesh in pre-monsoon (Table 2).

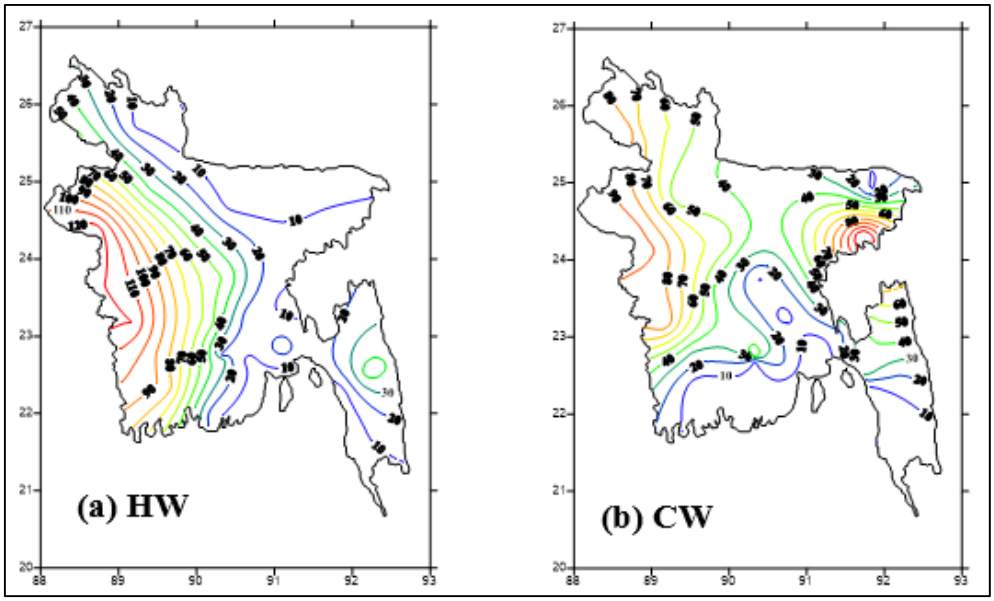


Fig 13(a-b): Spatial distribution of HW and CW frequency (Spell)

3.16 Analysis of the spatial distribution of hot days and cold night's duration

Figure 14(a-b) shows the spatial distribution of the duration of cold nights and hot days. It shows the coldest areas which are Srimangal and the northwestern part of Bangladesh in winter (Table 2) and the hottest area which are the southwestern and middle-western parts of Bangladesh in pre-monsoon (Table 1).

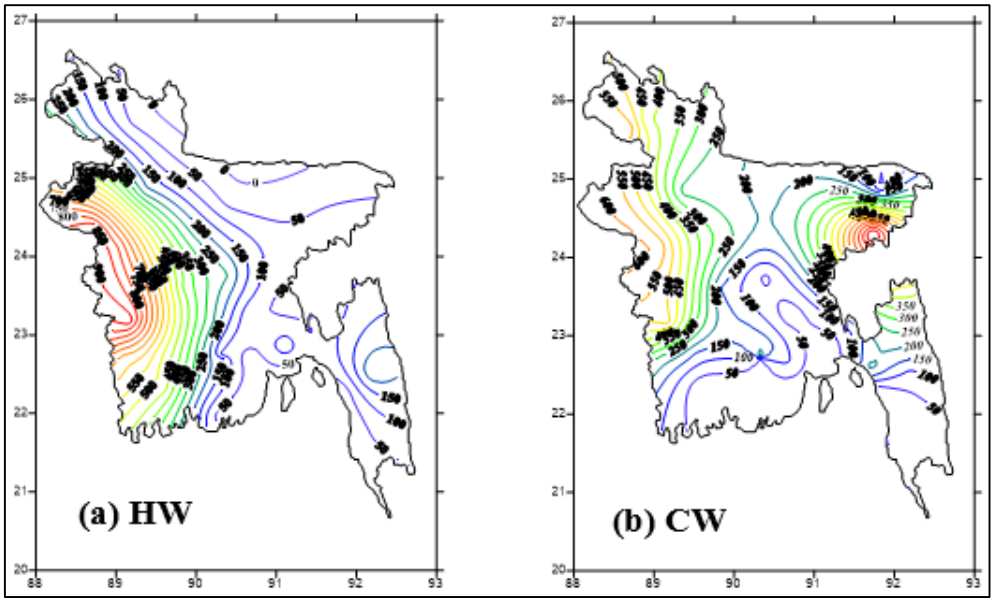


Fig 14(a-b): Spatial distribution of duration of hot days and cold nights

Conclusion

The foot hill of Himalaya is warmer in pre-monsoon and its temperature is varies 40^0 – 48^0 C. 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. In winter season, the Sun shifted southwards and Indian sub- continent get incline solar insulation. The duration of the night is higher than that of the day. That is why Indian sub-continent becomes cooler than that of the southern part. North Easterly monsoon is active and wind blows from the foot hill of Himalaya towards Bangladesh. Lower solar insolation, less moisture and ridge of sub-continental high and Backing are responsible for Cold Wave condition.

Due to the geographical location, Bangladesh experiences HW in pre-monsoon and CW in winter. So, it is very important to predict these Extreme temperature condition time and location specific to minimize casualties.

In the present study, all categories of Cold Wave (CW) and Heat Wave (HW) days (Duration) and frequencies (Spells) have been studied for the winter (December to February) and Pre-monsoon (March to May) over most of the stations (34) of Bangladesh for the period 1990-2019. The highest numbers of cold wave and Heat wave days are found in Srimangal (803 days) and Jashore (927 days) of all types of events and Frequency are found Srimangal (114) for CW and Rajshahi (127) for HW during winter and Pre-monsoon season respectively. January is the highest cold month and April is the highest warm month in Bangladesh. Cold day in Bangladesh is decreased of all divisions except Barisal. The highest 5 coldest places are Srimangal, Ishurdi, Rajshahi, Chuadanga and Dinajpur and the highest hottest places are Jashore, Chuadanga, Rajshahi, Ishurdi and Satkhira on the basis of duration. Kutubdia and Teknaf had no CW or HW; Cox's Bazar had no CW at all. Among 30 years, 1995 is the highest coldest year and 2009 is the lowest cold day recorded year and 2014 is the highest hottest year and 2018 is the lowest hot day recorded year. By Mann-Kendall test, the HW trend of Mymensingh station has given only significant and decreasing value. From spatial distribution, it shows coldest areas which are Srimangal and Northwestern part of Bangladesh and hottest area which are Western and Middle-western part of Bangladesh.

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