Analysis of Heat Waves and its Behavior during Pre-monsoon Season

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Abstract

In this work, it is examined that the decadal behavior of heat wave during 1981-1990, 1991-2000, 2001-2010 and 2011-2021, trend and magnitude of heat wave frequency in pre-monsoon season during 1981-2020. It is also observed that how many spell appeared in 2014 which was hottest year in recent time and validate the most active heat wave spell on 20-25 April 2014 with National Centre for environmental prediction (NCEP) reanalysis data of mean sea level pressure (MSLP), surface wind, relative humidity (RH), Lifting Index (L.I) and geopotential at 925hpa, 850hpa & 700hpa level. Maximum temperature data are collected from 34 stations of Bangladesh Meteorological Department for the period of 40 years during 1981-2020. Here heat wave is counted by maximum day temperature is 36°C or more according to Bangladesh Meteorological Department. Mann Kendall (MK) test and Sen's Slop estimator test are used for trend & magnitude of heat wave frequency at 5% level of significance using and spatial distribution of heat wave is conducted by Nearest Neighbor (NN) Method. During 1981-2020, heat wave frequency follows decreasing trend but not statistically significance at 5% level and decrement rate is 0.143°C/year for Mann Kendall test and 1.1803°C/year for Sen's Slop estimator test and for April it is increasing trend but insignificant at 5% level of significance and the rate of increment is 0.0175°C/year for Mann Kendall test and 0.14092°C/year for Sen's Slop estimator test. For May frequency of heat wave is increasing trend at 5% level of significance and rate of increment is 0.285°C/year for Mann Kendall test and 2.4623°C/year for Sen's Slop estimator test. Although heat wave initiates from south western part of Bangladesh in early March and it is limited on middle March in this part. At the end of March, it starts to progress north west part and central part of Bangladesh and Middle month of April it reaches south eastern part of Bangladesh. In the end of May heat wave begins to decrease when monsoon seasons start. The highest hottest year is 2014 which was ended by 4 heat wave spell such as 28 March-02 April 2014, 20-28 April 2014, 06-10 May 2014 and 12-21 May 2014. Among four heat wave spell 20-28 April 2014 is active spell which stayed long time. In this spell 20-25 April 2014 is more active which cover most part of Bangladesh and during this period the highest maximum temperature of 42.4°C was recorded at Jashore (on 24 April 2014). During 20-25 April 2014 the atmospheric situation was more favorable for occurring heat wave.

Key words: Heat Wave, Frequency, Pre-monsoon, Mann Kendall, Sen's Slop estimator, spatial distribution.

1. Introduction:

As a result of global warming, climate change has become a major research field in the perspective of different issues in where heat wave related phenomena have become a hot cake for the researcher across the world. Bangladesh is a country that is seriously threatened by climate change (Huq 2001). It is expected to bring an increase in frequency and intensity of heat waves in the future (Kirtman et al. 2013). In recent years, on heat waves related research has been established as an important research topic within the large field of current climate change research. Bangladesh is located in the sub-tropical monsoon climate region. The climatology of Bangladesh is described the following four season: 1. Northeast monsoon (December- February) or winter, 2. Pre-monsoon (March-May) or summer 3. Southwest monsoon (June-September) and 4. Post-monsoon or autumn (Khatun et al., 2016). Ahmed et al. (1996) stated that throughout the past 100 years, a rise of temperature over Bangladesh is 0.5˚C. Extreme events of weather parameters are an important aspect of climate change because the normalcy of environment is very sensitive to those parameters. Studies have indicated that a 1°C increase in global temperature will lead to reduced productivity in some cultivated crops, such as: 7.0-124.0 % in wheat, 1.0-3.8% in barley, 28% in potato, 17% in maize and soybean, and 15% in rice (Ulukan 2011). A study driven by Mearns et al. (1984) and Hansen et al. (1988) took a decision that relatively small change in the mean temperature could produce a substantial change in the frequency of temperature extremes. Karmaker et al. (2000) showed that annual mean maximum temperature will increase to 0.4˚C and 0.73˚C by the year of 2050 and 2100 severally. The definition of heat wave varies from one country to another. A heat wave is continued period of abnormally hot weather. While definitions vary across and even within countries, heat waves are generally measured relative to the usual weather in the area and relative to normal temperatures for the season. Bangladesh Meteorological Department (BMD) uses the term “heat wave” when maximum temperature reaches 36°C or more. In general, a heat wave is a period of excessively hot weather, which may be accompanied by high humidity. The World Meteorological Organization (WMO) defines a heat wave as 5 or more consecutive days of prolonged heat in which the daily maximum temperature is higher than the average maximum temperature by 5°C (9°F) or more (https://www.britannica.com/science/heat-wave- meteorology). Productivity of numerous kinds of plants, vegetables and other things are greatly depended on the behavior of temperature in different parts of the world. Photosynthesis, respiration, organ initiation and their relative growth, and dry matter production and its distribution are dependent on temperature and solar radiation (Ewing et al. 1990, Atkin et al. 2000a,b, Loveys et al. 2002, Mazurczyk et al. 2003, Ulukan 2008, Cosmulescu et al. 2010, Şenyiğit and Akbolat 2010).

The north, northwest and central parts of the country were found to experience severe heat waves in this duration. Compared with the previous four decades, there was mentionable increase in heat waves/severe heat waves (HW/SHW) days over the country during the recent decade 2001-2010 Karmakar.et al (2019) has explored the mean frequency of maximum temperature and found that Rajshahi has the highest mean frequency of maximum 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. Mishra et al. (2017) in a study mentioned that heat waves with great impacts have increased in the recent past and further it will continue to increase under future warming. According to their estimate, if the global mean temperature is limited to 2°C above pre-industrial conditions, the frequency of severe heat waves will rise by 30 times the current climate by the end of 21st century. Heat-related deaths occur when a rapid rise in environmental temperatures and the body is not able to cool itself through the increment of blood circulation and perspiration. Due to the geographical position of Bangladesh, especially the coastal region phases a lot of natural disasters irrespective of time, places, colors for which every year Bangladesh government has to pay deep attention and as a result GDP hamper drastically. Heat waves were responsible for 4 of the 10 deadliest natural disasters in 2015, with South Asian heat waves ranking third and fourth by mortality (UNISDR et al. 2015). In the 21st century the Mediterranean area is expected to be one of the dominant and vulnerable climate change “hot spots” [Giorgi, 2006; Diffenbaugh et al., 2007] that will face a large number of extremely hot temperature events, an increase of summer heat wave frequency and duration [e.g., Türkeş et al., 2002; Founda et al., 2004; Kostopoulou et al. 2005; Della-Marta et al., 2007] and increasing summer temperature variability [Xoplaki et al., 2003; Jones et al., 2008]. Domroes et al. (2005) reported increasing mean temperature trends in northern Egypt over the period 1941-2000. Fan and Wang (2011) studied climate change by looking at the monotonic trends in annual and seasonal air temperature indices across Shanxi province in China, and found that there have been warming trends in temperature over the period 1959-2008. Karaburun et al. (2011) also analyzed the spatiotemporal patterns of temperature change in Istanbul, Turkey for the period of 1975 to 2006, and observed that warmer temperature trends generally prevailed for seasonal and annual temperature indices. At a given temperature, high humidity increases the level of heat stress on a person. This effect can be accounted for with the heat index, which combines the influence of relative humidity and temperature to give an ‘‘apparent’’ temperature and is employed operationally in many countries (McGregor et al. 2015). The environmental parameters that influence the human heat balance capacity include ambient temperature and humidity, the radiation regime, and wind speed (Driscoll 1985). In our study, it is found that the highest maximum temperature of 42.4°C was recorded at Jashore (on 24 April 2014) which is absolutely a matter of great concern for the inhabitant of this region. Decade with maximum number of HW spells and minimum number of HW spells are traced out in the decade of 2001-2010 and 1981-1990 respectively while doing an analysis in the duration of 1981-2020. The central-western and southwestern part of Bangladesh are mostly affected by the HW situation and it got maximum in the month of April.

In this study we examine the changing characteristics of heat waves across Bangladesh using historical meteorological data over a four-decade period (1981-2020). Mann Kendall (MK) test and Sen’s Slop estimator test are used for investigating trend and magnitude of heat wave frequency at 5% level of significant in pre-monsoon season. The atmospheric conditions are observed with the mean sea level pressure (MSLP), relative humidity (RH), surface wind, Lifting Index (L.I), Geopotential height at 925hpa, 850hpa &700hpa level which are favorable for associating hot weather.

2. Data and Methodology:

2.1 Data

Here daily data on maximum temperature are used to investigate the climatology of maximum temperature (Tmax), frequency of heat wave with maximum temperature ≥36°C have been studied for Pre-monsoon season in Bangladesh. Daily maximum temperature (Tmax) for the month of March to May for the period of 1981-2020 are used for 34 stations over Bangladesh-by-Bangladesh Meteorological Department (BMD). Due to statistical analysis data has been prepared by taking mean of daily data to monthly data.

National Centre for environmental prediction (NCEP) reanalysis data are used for observing atmospheric condition when more active heat wave spell sweeping over Bangladesh during 20-25 April 2014. Here, mean see level pressure (MSLP), Surface wind, Relative humidity (RH), Lifting Index (L.I) and geopotential at 950hpa, 850hpa & 700hpa level are conducted to validate of atmospheric condition which are associated with heat waves over Bangladesh and neighborhood.

2.2 Mann Kendall (MK) trend test

The non-parametric Mann-Kendall (MK) experiment (Kendall, 1975; Mann, 1945) is huge generally used for tendencies classifying in climatologic and weather data in time series analysis. Here, there are two benefits of using MK experiment. (1) It is a non-parametric test where data do not necessary to be normally distributed. (2) The trial has little sensitivity to unexpected due to inhomogeneous time series analysis (H. Tabari et al, 2011). The MK test statistic (S) is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(T_j - T_i), \quad (1)$$

$$Sign(T_j - T_i) = \begin{cases} 1 \; if \; T_j - T_i > 0 \\ 0 \; if \; T_j - T_i = 0 \\ -1 \; if \; T_j - T_i < 0. \end{cases} \quad (2)$$

Where, T_j and T_i are the yearly values in years j and i, j > i respectively.

If n < 10, the value of $|S|$ is shares straight to the theoretical distribution of S derived MK. The two tailed experiment is used. At definite likelihood level H_0 is rejected in favor of H_1 if the original value of S equals or exceeds a certain value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the lowest S which has the possibility less than α/2 to execute in case of no trend. A positive (negative) value of S designates an upward (downward) trend. For n ≥ 10, the statistic S is almost normally distributed with the mean and variance as follows:

E(S) = 0. (3)

The σ^2 for the S statistic is expressed by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18}. \quad (4)$$

Where t_i represents the number of ties to extent i. The synopsis term in the numerator is used only if the data series contains tied values. The standard test statistic Z_s is considered as bellows:

$$Z_s = \begin{cases} \frac{S-1}{\sigma} \; for \; S > 0 \\ 0 \; for \; S = 0 \\ \frac{S+1}{\sigma} \; for \; S < 0. \end{cases} \quad (5)$$

The test statistic Z_s is used a quantity of meaning of trend. In detail, this experiment statistic is used to experiment the null hypothesis, H_0. If $|Z_s|$ is greater than $Z_{\alpha/2}$, where α denotes the special implication level (e.g., 5% with $Z_{0.025} = 1.96$) then the null hypothesis is inacceptable suggesting that the trend is important.

2.3 Sen's Slop estimator test:

Non-parametric technique (Sen, 1968) was used to assessment the degree of tendencies in the data at time series analysis. The gradient of "n" pairs of statistics can be first projected by using the below equation:

$$\beta_i = \textbf{Median} \left[\frac{X_j - X_k}{j-k}\right] \; \forall \; (k < j) \quad (6)$$

In this formula, X_j and X_k represent values statistics at time j and k, separately, and time j is after time k (k ≤ j). The median of "n" values of β_i is the Sen's slope estimator experiment. A negative β_i value signifies a declining tendency; a positive β_i value signifies an accumulative tendency over time.

If "n" is an even number, then the slope Sen's estimator is computed by using the following equation:

$$\beta_{med} = \frac{1}{2}(\beta_{[n/2]} + \beta_{[(n+2)/2]}) \quad (7)$$

If "n" is an odd number, then the slope Sen's estimator is calculated by using the below formula:

$$\beta_{med} = \beta_{[(n+1)/2]} \quad (8)$$

Finally, β_{med} is verified by a two tailed experiment at 100(1-α) % assurance level, and the true gradient of monotonic tendency can be projected by using a nonparametric experiment (Partal and Kahya, 2006).

2.4 Nearest Neighbor (NN) Method

Spatial patterns or spatial distribution of data are generated by NN method. NN procedures are among the most popular methods used in statistical pattern recognition (Holmes et. al. 2002). The models are conceptually simple and empirical studies have shown that their performance is highly competitive against other techniques such as Kriging, Inverse distance a power, triangulation with linear interpolation etc. It turns out that whether or not the data are regular or irregular is unimportant once anybody define what is known as NS.

Let $\mathcal{R} = \{s_i : i = 1, 2, \dots n\}$ where$\mathcal{R} \subset \mathcal{R}^d$, for d a positive integer, be the set of all sites making up a finite lattice. Two sites are said to be neighbors if the response variables at these sites depend on each other directly. Let $N_i = \{S_k ; S_k \text{ is a neighbor of } s_i\}$, $i = 1,2, \dots n$. Then the set $G_{\mathcal{R}} = \{S_i, N_i : 1,2, \dots, n\}$ is defined as a NS for $\mathcal{R}$, with the following two properties:

1. $s_i \notin N_i, i = 1, 2, \dots, n$ (a site is not a neighbor of itself)
2. $s_j \in N_j \Rightarrow s_j \in N_i, \forall_i, j = 1, 2, \dots, n$.

Example of NS: Suppose a realization $y = \{y(s_i): i = 1,2, \dots n\}$ is taken from a regular $n_1 \times n_2$ grid of sites in $\mathcal{Z}^2$ (the two dimensional integer space) where $n = n_1 \times n_2$ the number of sites in the lattice is. For this setup, a two dimensional coordinate (j, k) corresponds naturally to each sit S_i. Hence, this two dimensional lattice $\mathcal{R}$ and corresponding realization can be defined by:

$$\mathcal{R} = \{(j, k); j = 1,2, \dots, n_1 \text{ and } k = 1,2, \dots n_2\}.$$

$$y = \{y_{jk}; j = 1,2, \dots, n_1 \text{ and } k = 1,2, \dots n_2\}.$$

The first-order neighborhood system consists with the horizontal and vertical adjacent units. Precisely, this neighborhood system is defined with the sites for which the following criteria is satisfied.

$$N(j,k) = \left\{(j', k'): (j - j')^2 + (k - k')^2 = 1\right\}.$$

The second-order neighborhood system for a given site (i, j) is defined the sites for the following criteria is satisfied

$$N(j,k) = \left\{(j', k'): (j - j')^2 + (k - k')^2 \leq 2\right\}.$$

The same idea can be extended for defining a neighborhood system of higher order. Lattice or areal data units are neighbors if they are within a distance d. Distance based neighboring suggests that one can create distance bins such as $(0, d_1], (d_1, d_2], (d_2, d_3]$, and so on, to extend the concept neighborhood system in terms of first-order neighborhood, second-order neighborhood, third-order neighborhood respectively. In this type of neighborhood, those units who are within $(0, d_1]$ distance from unit i are said to be first order neighbor of unit i, those units who are within $(d_1, d_2]$ distance from unit i are said to be second order neighbor of unit i and so on.

3. Results and Discussions

3.1 Frequency of heat wave in pre-monsoon season over Bangladesh during 1981-2020:

Based on the records of maximum temperature, the decadal analysis of HW reveals that the highest no. of HW recorded in decade of 2001-2010 during the observation period of 1981-2020 in pre-monsoon season. But it was lowest in the decade of 1981-1990. Monthly distribution of HW indicates that the country average maximum number of HW of 5.2 was recorded in in March in 1986. In April and May, it was highest of 14.8 and 5.2 in 2014 during the observed period. The highest number of HW was recorded in 2014 but the lowest number of HW was recorded in 2018.

3.2 Trend of Heat Wave frequency in Pre-monsoon season during 1981-2020

In Table 1 represent the magnitude of heat wave frequency for March, April and May during 1981-2020 which is obtained from the Mann-Kendall test and the slope estimator from Sen. For March, yearly frequency of heat wave follows decreasing trend (Fig 1.1) which is statistically insignificant at 95% level of significance for both of the tau(τ) value of Mann-Kendall and the slope estimator from the Sen (z) these are -0.143 and -1.1803(Table 1). In April the heat wave frequency follows increasing trend (Fig 1.2) which is statistically insignificant at 95% level of significance for both of the tau (τ) value of Mann-Kendall and the slope estimator from the Sen (z) these are 0.0175 and 0.14092 (Table 1). And also, for May the heat wave frequency indicates increasing trend (Fig 1.3) which is statistically significant at 95% level of significance for both of the tau (τ) value of Mann-Kendall and the slope estimator from the Sen (z) these are 0.285 and 2.4623 (Table 1).

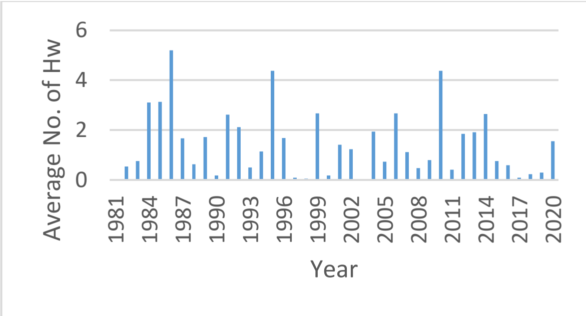

Fig 1.1: Average no. of heat wave over Bangladesh at March during (1981-2020)

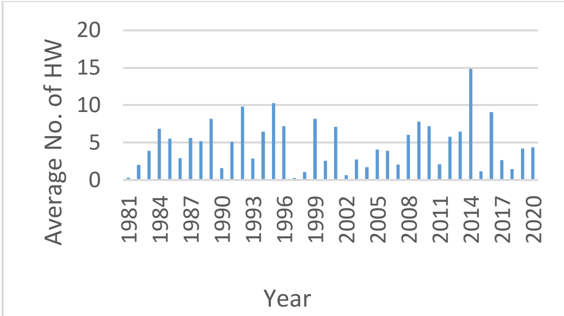

Fig 1.2: Average no. of heat wave over Bangladesh at April during (1981-2020)

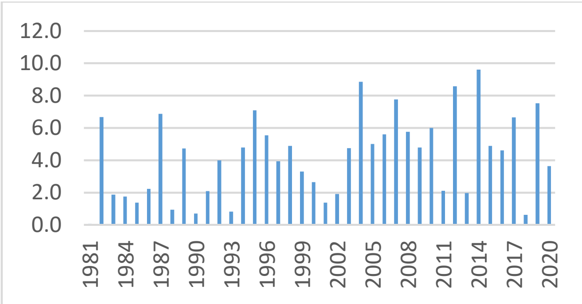

Fig 1.3: Average no. of heat wave over Bangladesh at May during (1981-2020)

Table 1: Trend of Heat Wave frequency in Pre-monsoon season

Month	**Mann-Kendall (τ)**	**Sen's slope(z)**	**Two sided (p) - value**
March	-0.143	-1.1803	0.23789
April	.0175	0.14092	0.88793
May	0.285	2.4623	0.013805

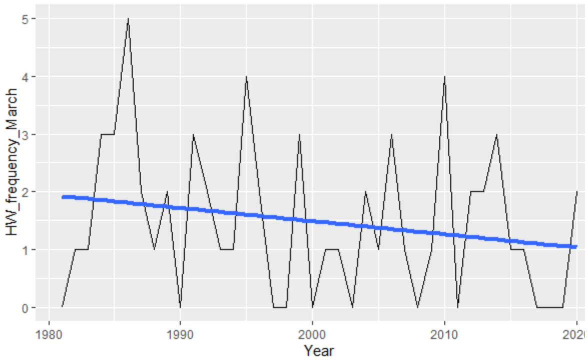

Fig 2.1: Trend analysis of Heat Wave frequency in March during 1981-2020

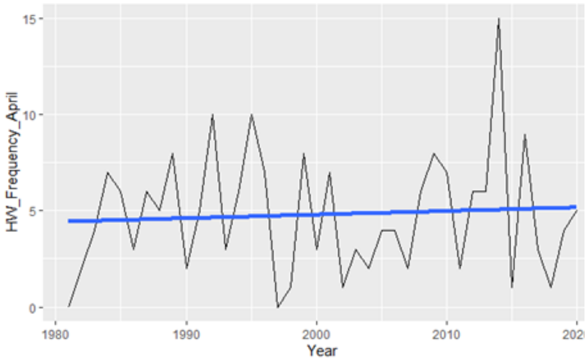

Fig2.2: Trend analysis of Heat Wave frequency in April during 1981-2020

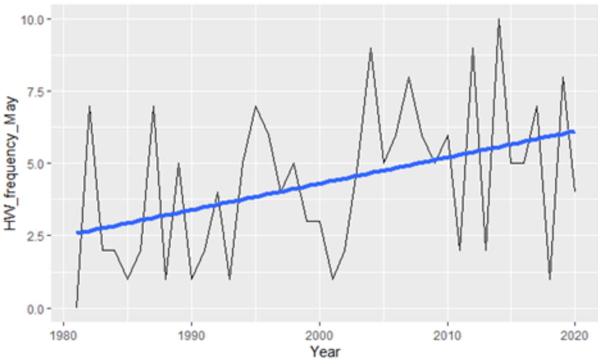

Fig 2.3: Trend analysis of Heat Wave frequency in May during 1981-2020

3.3 Spatial distribution of Heat Wave in pre-monsoon season over Bangladesh

3.3.1 Weekly evolution of HW in Bangladesh during 1981-1990

For understanding the evolution and progression process during pre-monsoon season, weekly average no. of HWs are calculated. Accordingly, pre-monsoon season has been divided into 9-periods with 10 days each from the first day of March. It has been found that the HW situation appears in Bangladesh first over Jashore-Satkhira region in W1 period. Then it is found to expand north and southwards over western border region of Bangladesh in W2. During W4 and w5 periods it become vigorous with peak intensity over western part of Bangladesh when it is found to expand up to central part also. Then during W6 to W9 periods it is found to become weak and its existence is found mainly over western part of Bangladesh. The average maximum temperature of the HW prone area during W1, W2, W3, W4, W5, W6, W7, W8 and W9 are 32.8°C, 35.1°C, 36.1°C, 37.1°C, 37.3°C, 36.9°C, 36.2°C, 35.9°C and 37.2°C respectively. The evolving process of this HW in Bangladesh is illustrated in Fig.2.1 (1(a)-1(i)).

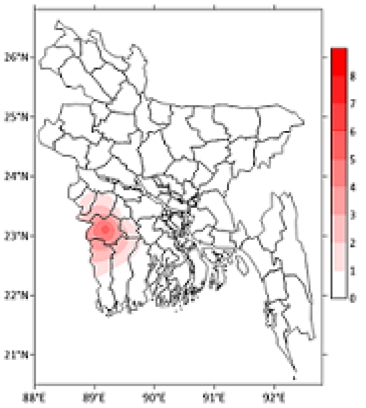

Fig.3.1 (a): No. of HW in W1 (Mar 01-10)

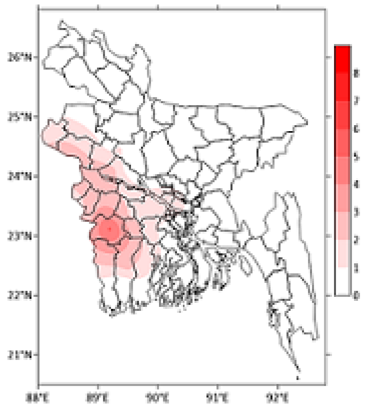

Fig.3.1(b): No. of HW in W2 (Mar 11-20)

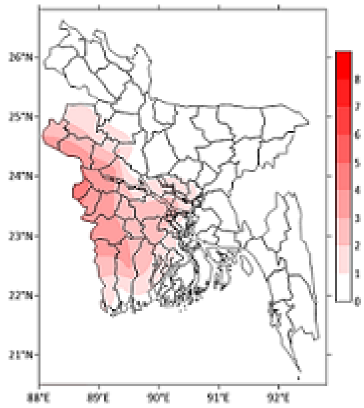

Fig.3.1(c): No. of HW in W3 (Mar 21-31)

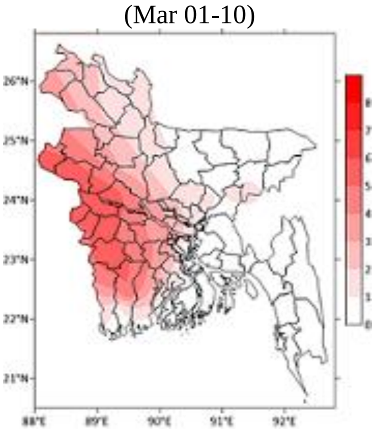

Fig.3.1(d): No. of HW in W4 (Apr 01-10)

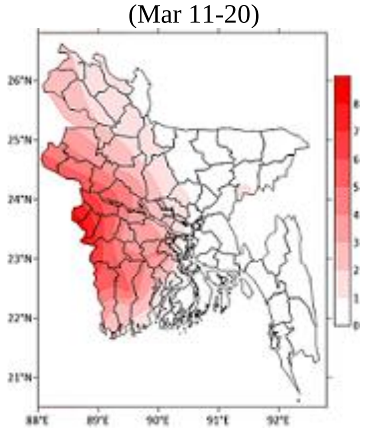

Fig.3.1(e): No. of HW in W5 (Apr 11-20)

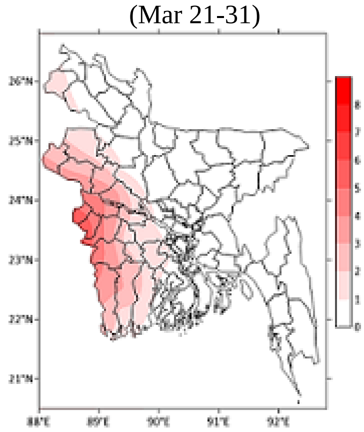

Fig.3.1(f): No. of HW in W6 (Apr 21-30)

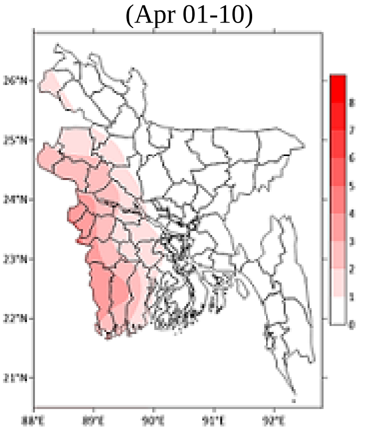

Fig.3.1(g): No. of HW in W7 (May 01-10)

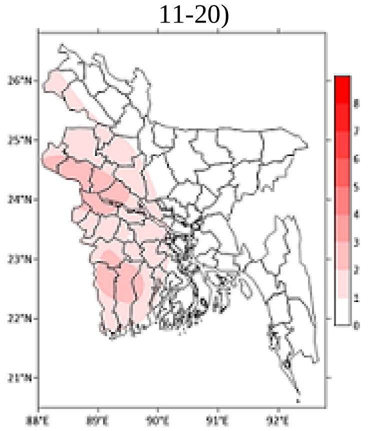

Fig.3.1(h): No. of HW in W8 (May 11-20)

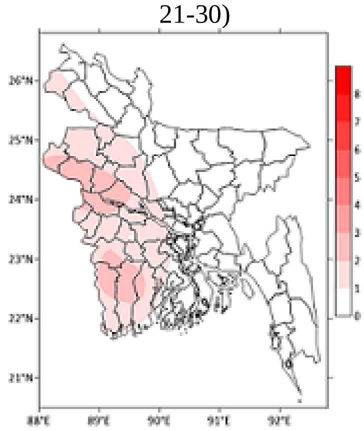

Fig.3.1(i): No. of HW in W9 (May 21-31)

3.3.2 Weekly evolution of HW in Bangladesh during 1991-2000

The evolution and progression process of HW during pre-monsoon season of 1991-2000 has been depicted in Fig.2.2 (a-i). It has been found that the HW situation appeared in Bangladesh first over Jashore-Satkhira region in W1. Then it expanded towards north and south over the nearby area in W2 and further extended over the surrounding areas W3. HW area covered west-central part in W4. Then it covered more parts over central and northern parts during W5. During these periods it is found to become strong with the records of higher maximum temperature. After that it is found to be weakened and shrink and finally persisted over extreme western part of Bangladesh. The average maximum temperature of the HW prone area during W1, W2, W3, W4, W5, W6, W7, W8 and W9 are 37.7°C, 38.7°C, 38.7°C, 38.8°C, 35.7°C, 36.7°C, 38.9°C, 38.2°C and 38.5°C respectively.

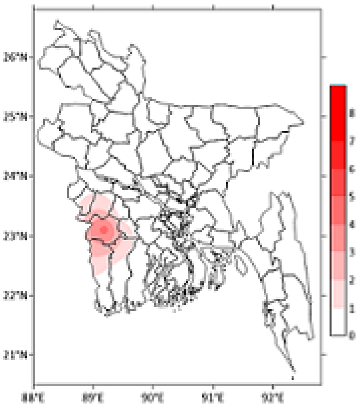

Fig.3.2(a): No. of HW in W1 (Mar 01-10)

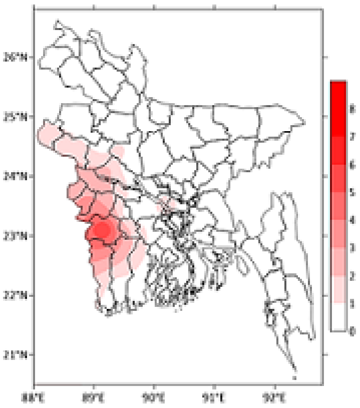

Fig.3.2(b): No. of HW in W2 (Mar 11-20)

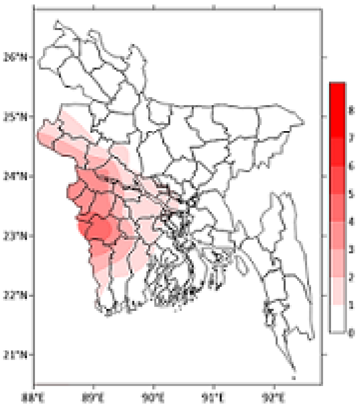

Fig.3.2(c): No. of HW in W3 (Mar 21-31)

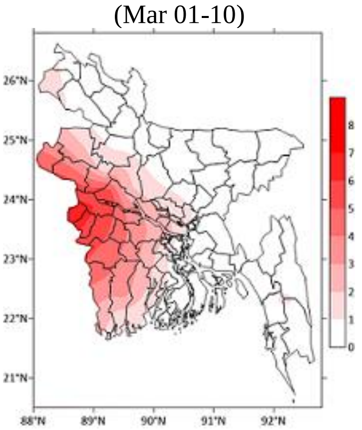

Fig.3.2(d): No. of HW in W4 (Apr 01-10)

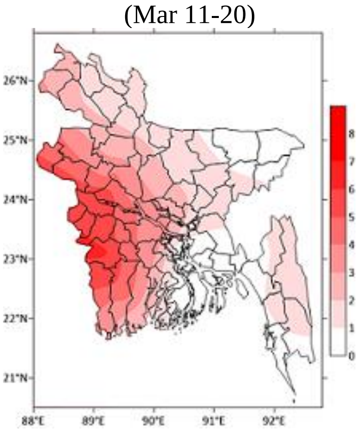

Fig.3.2(e): No. of HW in W5 (Apr 11-20)

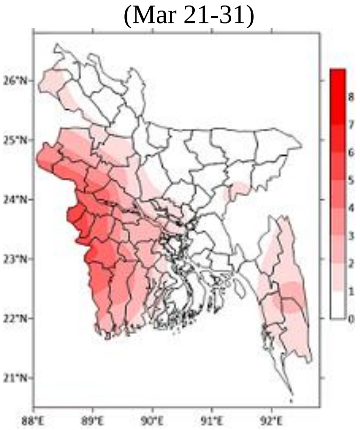

Fig.3.2(f): No. of HW in W6 (Apr 21-30)

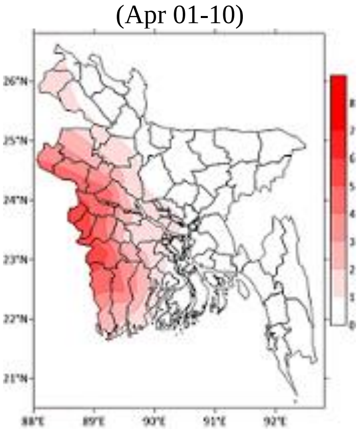

Fig.3.2(g): No. of HW in W7 (May 01-10)

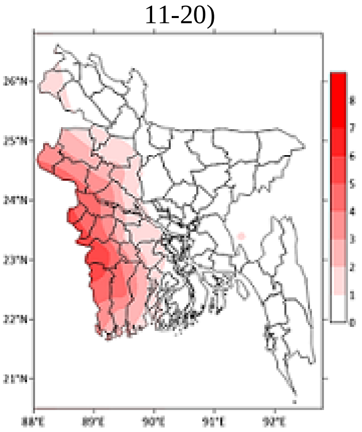

Fig.3.2(h): No. of HW in W8 (May 11-20)

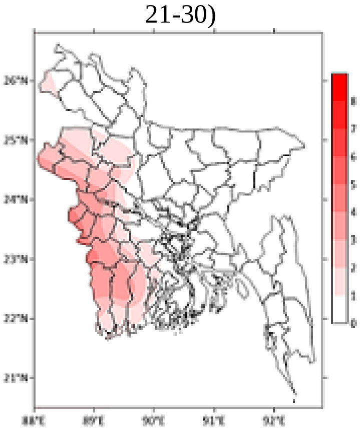

Fig.3.2(i): No. of HW in W9 (May 21-31)

3.3.3Weekly evolution of HW in Bangladesh during 2001-2010

The evolution and progression process of HW during pre-monsoon season of 2001-2010 has been illustrated in Fig.3.3 (a-i). It has been found that the HW situation appeared in Bangladesh first over Jashore-Satkhira region in W1. It also appeared in Bangladesh over Jashore-Satkhira region and southeast hilly region in W2. Then it expanded towards north and south over the nearby area in W3 and covered west-central part in W4.Then it enlarged over southeast hilly region W6 across central part of Bangladesh. During these period it is found to become strong with records of higher maximum temperature. After that it is found to be weakened and shrink and finally persisted over extreme western part of Bangladesh. The average maximum temperature of the HW prone area during W1, W2, W3, W4, W5, W6, W7, W8 and W9 are 34.7°C, 35.5°C, 37.1°C, 37.4°C, 38.2°C, 38.7°C, 38.2°C, 38.3°C and 38.2°C respectively.

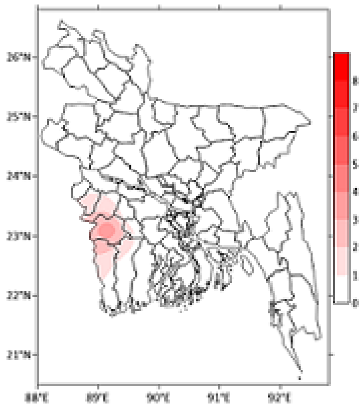

Fig.3.3(a): No. of HW in W1 (Mar 01-10)

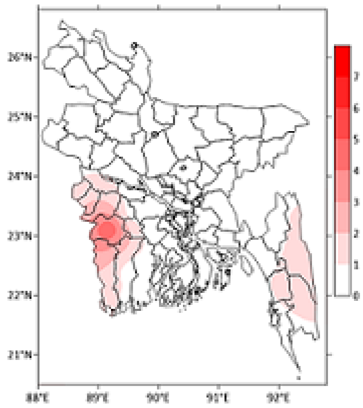

Fig.3.3(b): No. of HW in W2 (Mar 11-20)

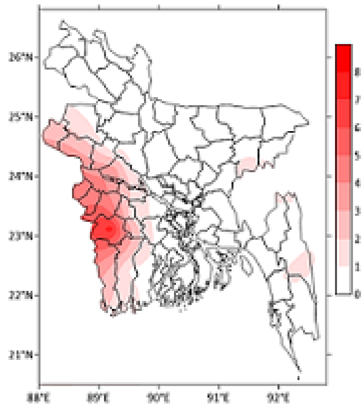

Fig.3.3(c): No. of HW in W3 (Mar 21-31)

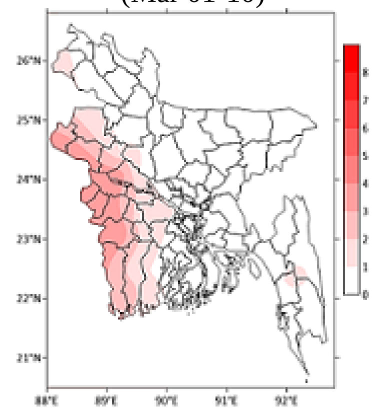

Fig.3.3(d): No. of HW in W4 (Apr 01-10)

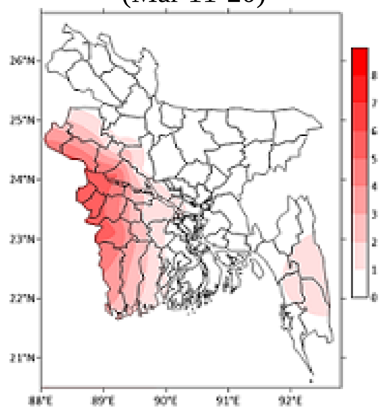

Fig.3.3(e): No. of HW in W5 (Apr 11-20)

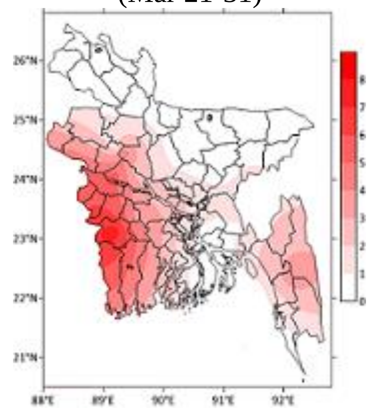

Fig.3.3(f): No. of HW in W6 (Apr 21-30)

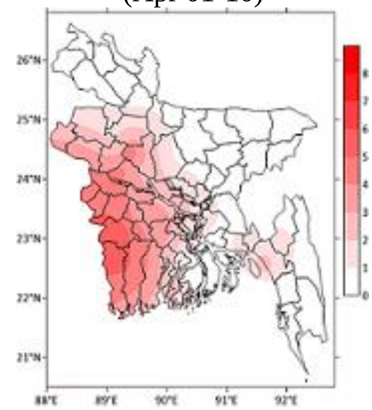

Fig.3.3(g): No. of HW in W7 (May 01-10)

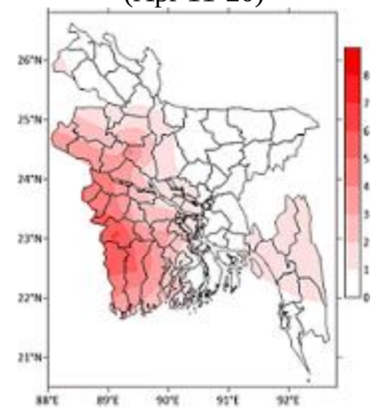

Fig.3.3(h): No. of HW in W8 (May 11-20)

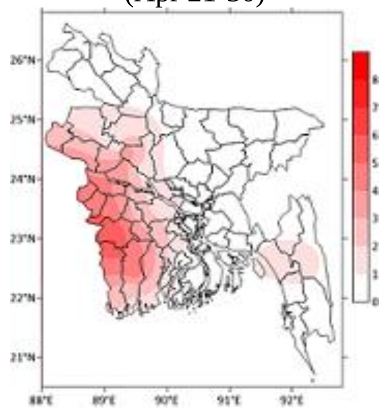

Fig.3.3(i): No. of HW in W9 (May 21-31)

3.3.4Weekly evolution of HW in Bangladesh during 2011-2020

The evolution and progression process of HW during pre-monsoon of 2011-2020 has been illustrated in Fig.3.4 (a-i). It has been found that the HW situation appeared in Bangladesh first over Jashore-Satkhira region in W1 and W2. Then it expanded towards north-south with west-central and eastern hilly region of Bangladesh in W3. It covered more parts over central and southern parts during W6. During this period it is found to become strong with the records of higher maximum temperature. After that it is found to weakened and shrink and finally persist over extreme western part of Bangladesh. The average maximum temperature of the HW prone area during W1, W2, W3, W4, W5, W6, W7, W8 and W9 are 33.7°C, 34.8°C, 36.8°C, 37.3°C, 37.7°C, 38.0°C,37.9°C, 37.8°C and 37.6°C respectively.

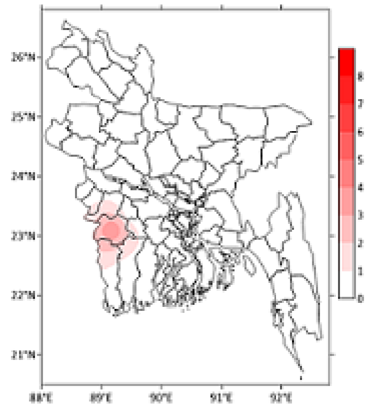

Fig.3.4(a): No. of HW in W1 (Mar 01-10)

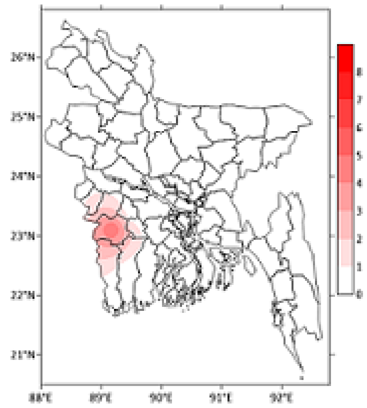

Fig.3.4(b): No. of HW in W2 (Mar 11-20)

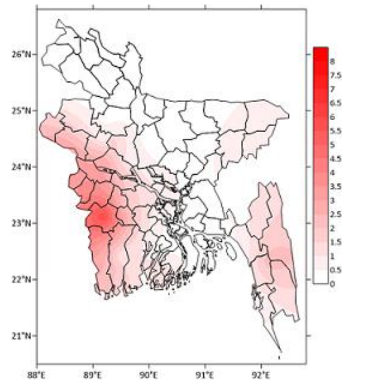

Fig.3.4(c): No. of HW in W3 (Mar 21-31)

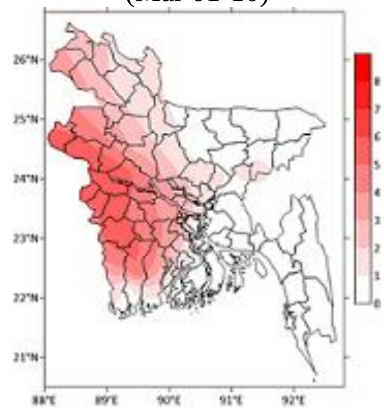

Fig.3.4(d): No. of HW in W4 (Apr 01-10)

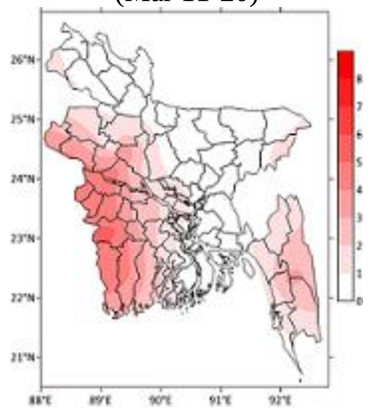

Fig.3.4(e): No. of HW in W5 (Apr 11-20)

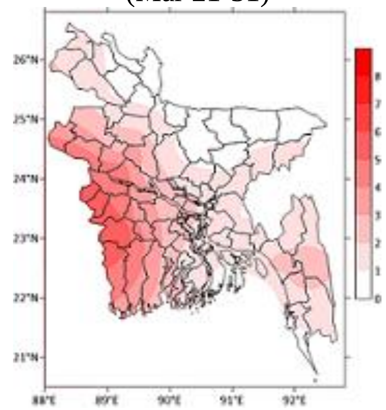

Fig.3.4(f): No. of HW in W6 (Apr 21-30)

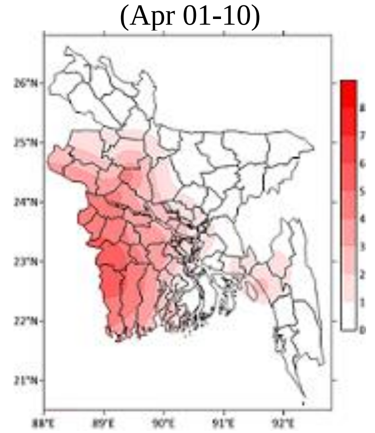

Fig.3.4(g): No. of HW in W7 (May 01-10)

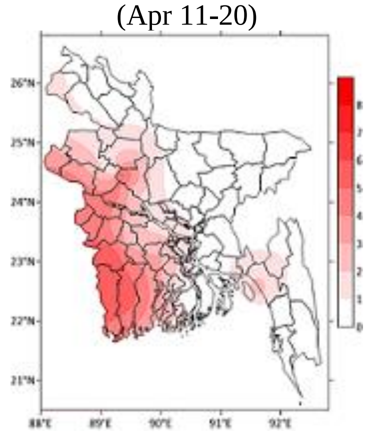

Fig.3.4(h): No. of HW in W8 (May 11-20)

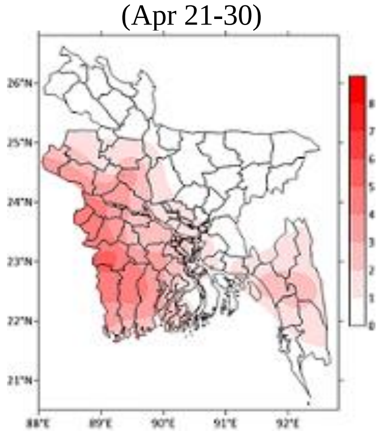

Fig.3.4(i): No. of HW in W9 (May 21-31)

4. Heat wave spell analysis in 2014 over Bangladesh

4.1 Heat Wave spell during 27March – 03 April 2014

Heat wave spell was initiated from 27 March 2014 over west-southwest part of Bangladesh, which expanded towards east-southeast of Bangladesh across central part on 29 March. On 29-30 march 2014 it persisted over southwestern part as a moderate HW and central to east-southeast as a mild HW, when highest maximum temperature of 39.6°c was recorded at Rajshahi. After that it began to weak but it was also rigid and intolerable condition for west- southwest border side locality of Bangladesh. The evolve process of HW during this period over Bangladesh is depicted in Fig. 4.1 (a-h).

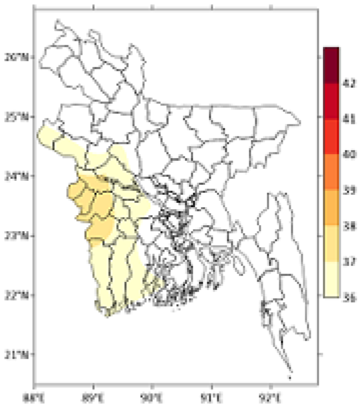

Fig.4.1(a): HW_27_Mar_2014

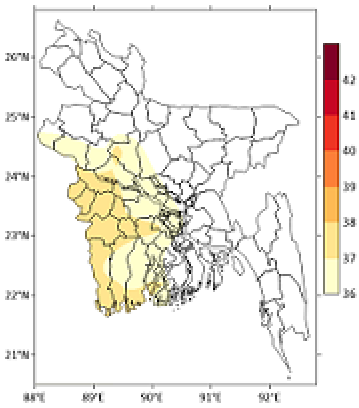

Fig.4.1(b): HW_28_Mar_2014

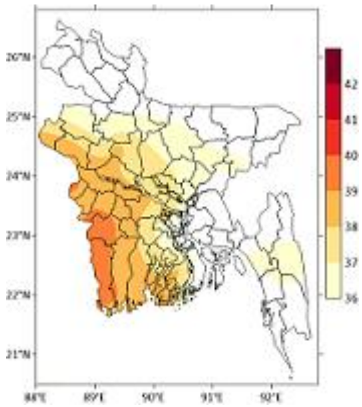

Fig.4.1(c): HW_29_Mar_2014

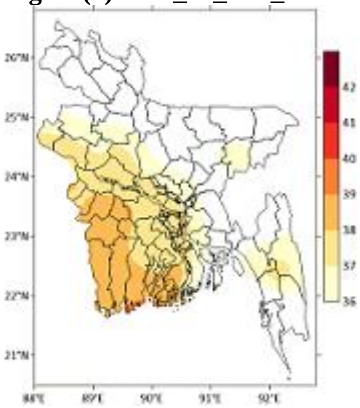

Fig.4.1(d): HW_30_Mar_2014

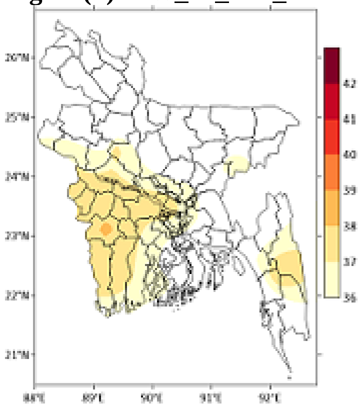

Fig.4.1(e): HW_31_Mar_2014

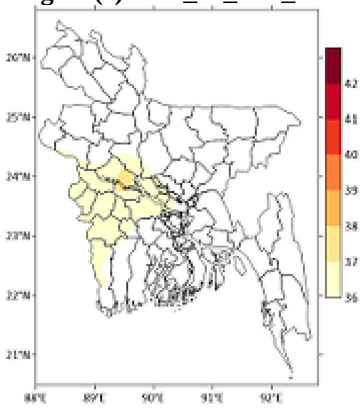

Fig.4.1(f): HW_01_Apr_2014

4.2 Heat Wave spell during 10 - 28 April 2014

A long-durable strong heat wave (HW) spell recorded in Bangladesh during 14-28 April 2014, which covered most part of Bangladesh during 20-25 April. Analysis shows that this HW initiated over Chuadanga- Jashore- Satkhira region on 10 March 2014. It gradually enlarged north and southeastwards first and then southeastwards over southern part of Bangladesh till 19 April. After that it progressed and covered whole country on 20 April 2014 and persisted till 25 April when its intensity was the maximum. During this period the highest maximum temperature of 42.4°C was recorded at Jashore (on 24 April 2014). Then its intensity decreased and the coverage area is shrunk but persisted over southwestern part as a severe condition in addition to the central part and Rangamati region as mild/moderate HW. After that the strength of HW weakened from moderate to mild and the HW situation observed over western border regions and adjoining area of Bangladesh. Thus, there were consecutive HW days with high intensity persisted over southwestern part with some part of central part and Rangamati region of Bangladesh. This situation leads strong feelings of HW in the mentioned area, especially over southwestern part and Rangamti region and it was unbearable to the locality. The life cycle and evolution process of this HW in Bangladesh is illustrated in Fig. 4.2(a-t).

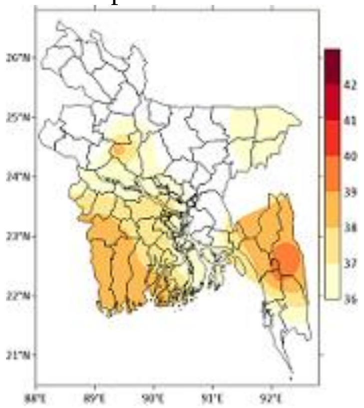

Fig.4.2(j): HW_19_Apr_2014

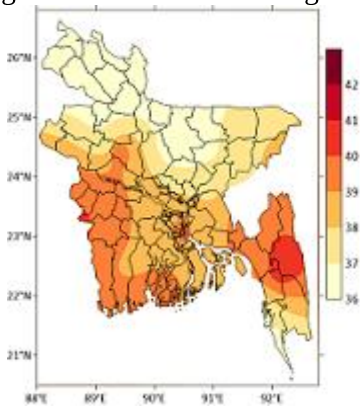

Fig.4.2(k): HW_20_Apr_2014

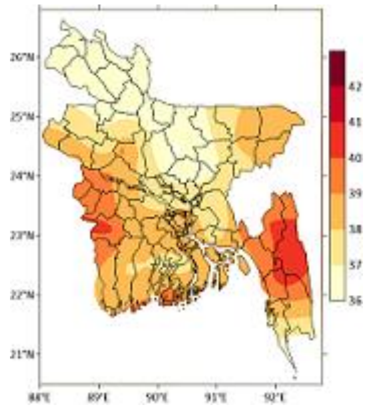

Fig.4.2(l): HW_21_Apr_2014

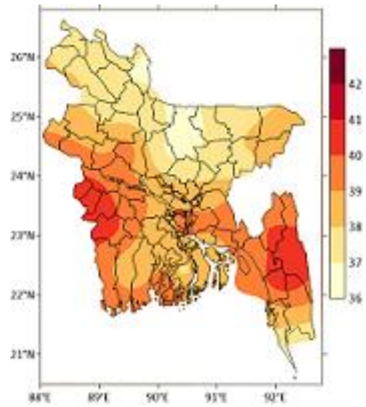

Fig.4.2(m): HW_22_Apr_2014

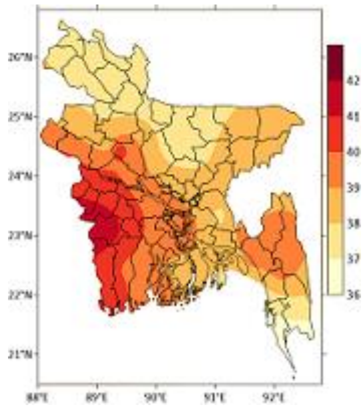

Fig.4.2(n): HW_23_Apr_2014

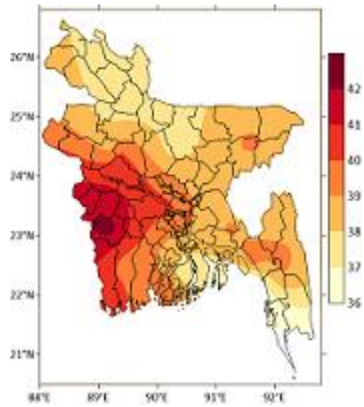

Fig.4.2(o): HW_24_Apr_2014

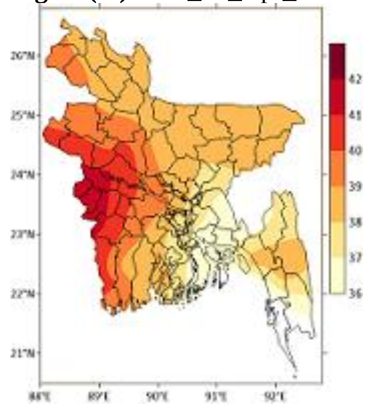

Fig.4.2(p): HW_25Apr_2014

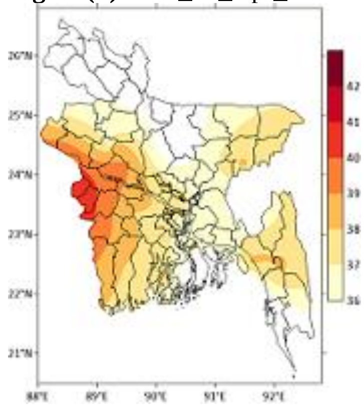

Fig.4.2(q): HW_26Apr_2014

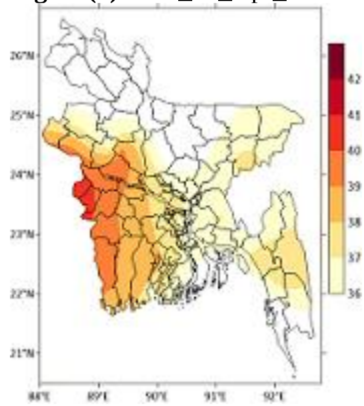

Fig.4.2(r): HW_27Apr_2014

4.3 Heat Wave spell during 06 - 10 May 2014

This HW spell began over western part of Bangladesh on 06 May 2014, which expanded towards north and over Khulna and Rangpur regions. It continues on 06-10 May 2014 over west-central part of Bangladesh, when highest

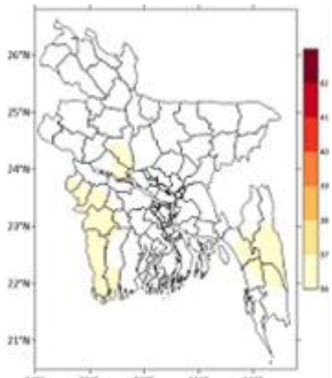

Fig.4. 3(a): HW_06_May_2014

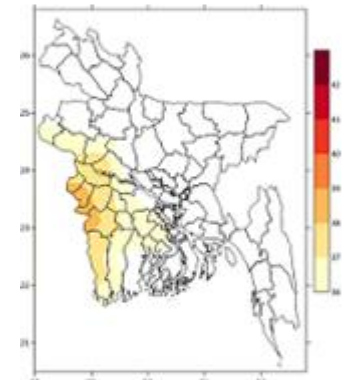

Fig.4.3(b): HW_07_May_2014

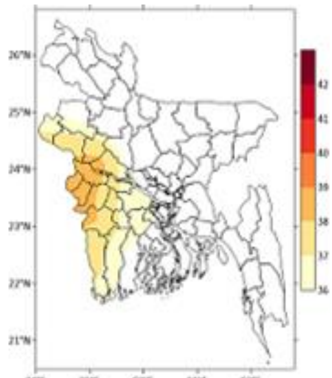

Fig.4.3(c): HW_08_May_2014

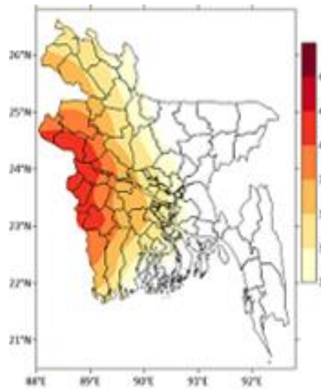

Fig.4.3(d): HW_09_May_2014

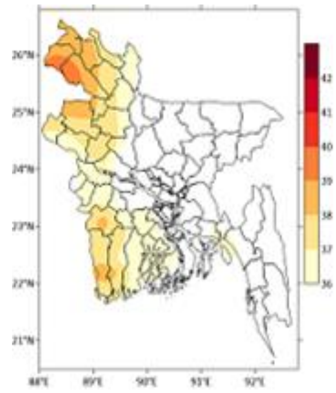

Fig.4.3(e): HW_10_May_2014

maximum temperature of 41.2°C was recorded at Rajshahi on 09 May. It persisted as a moderate HW west border region of Bangladesh, which was terrible situation of its locality. The evolve process of HW during this period over Bangladesh is depicted in Fig.4.3 (a-e).

4.4 Heat Wave spell during 12 - 21May 2014

As per the record, a strong and long-durable heat wave (HW) spell recorded over Bangladesh during 12-24 May 2014, which had strong influence over west-central part of Bangladesh. Analysis reveals that the HW spell initiated over Satkhira-Jashore region on 12 May 2014, when the highest maximum temperature of 42.2 □C was recorded at Chuadanga. After that the coverage of HW zone extended towards north and south over Khulna, Rajshahi and Dinajpur regions. Then, it extended towards east and covered the nearby area of its eastside but concentrated mainly over western part of Bangladesh till 17 May 2014. The strength of HW situation then weakened but concentrated over southwestern border regions and adjoining areas of Bangladesh. During 19-23 May it extended up to southeastern part of Bangladesh across central part and persisted as a moderate HW over this area, with its high focus over southwestern part. Therefore, there were consecutive HW situation with high temperature and severe situation of HW persists over southwestern part of Bangladesh, which leads strong feelings of HW of this area. As a whole, the HW situation was terrible over southwestern part of Bangladesh and it was

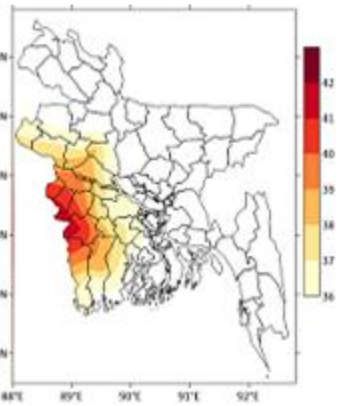

Fig.4.4(a): HW_12_May_2014

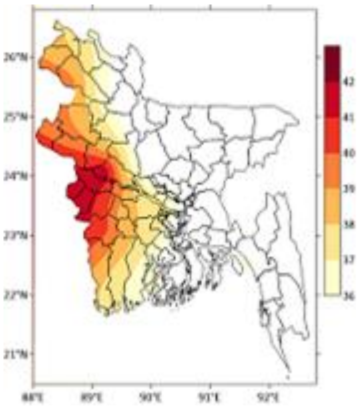

Fig.4.4(b): HW_13_May_2014

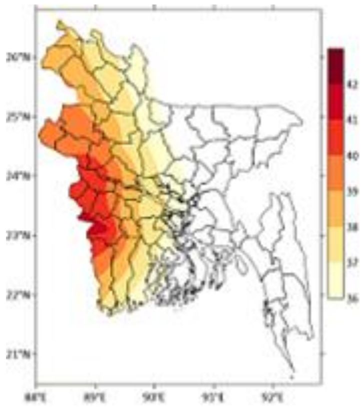

Fig.4.4(c): HW_14_May_2014

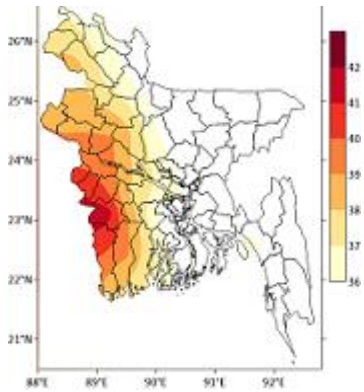

Fig.4.4(d): HW_15_May_2014

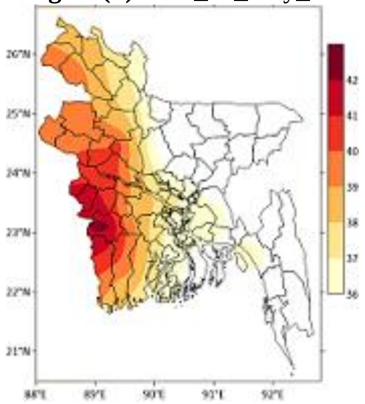

Fig.4.4(e): HW_16_May_2014

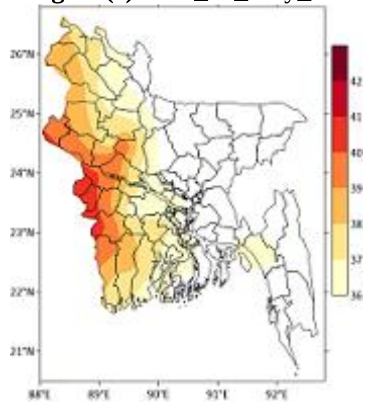

Fig.4.4(f): HW_17_May_2014

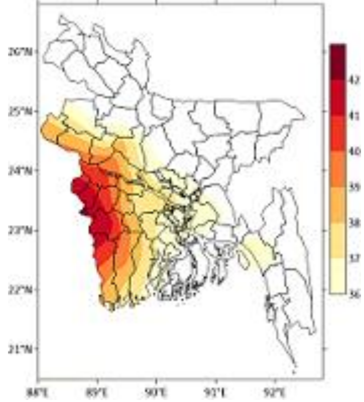

Fig.4.4(i): HW_20_May_2014

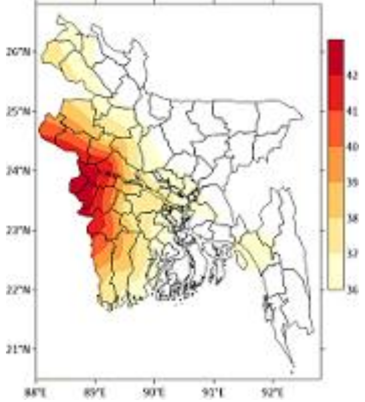

Fig.4.4(j): HW_21_May_2014

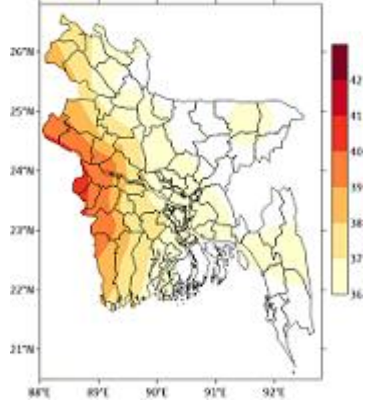

Fig.4.4(k): HW_22_May_2014

intolerable to the locality. The evolve process of HW during this period over Bangladesh is depicted in Fig.4.4 (a-m).

5. MSLP distribution during 22 April – 25 April 2014

Spatial distribution of the MSLP at 0000UTC indicates that there was pressure trough persists over the West Bengal and adjoining area during 22-25 April 2014, which has been extended from west during this HW spell. But with the progress of time, it extended up to western part of Bangladesh and finally reached up to eastern side of Bangladesh covering most part of Bangladesh on 24 April 2014 (Fig. 24 April 2014). After that it retreated and shrink and become less dominant. This situation helped the heat low to be organized more for carrying moisture from the Bay of Bengal and unbearable to the locality.

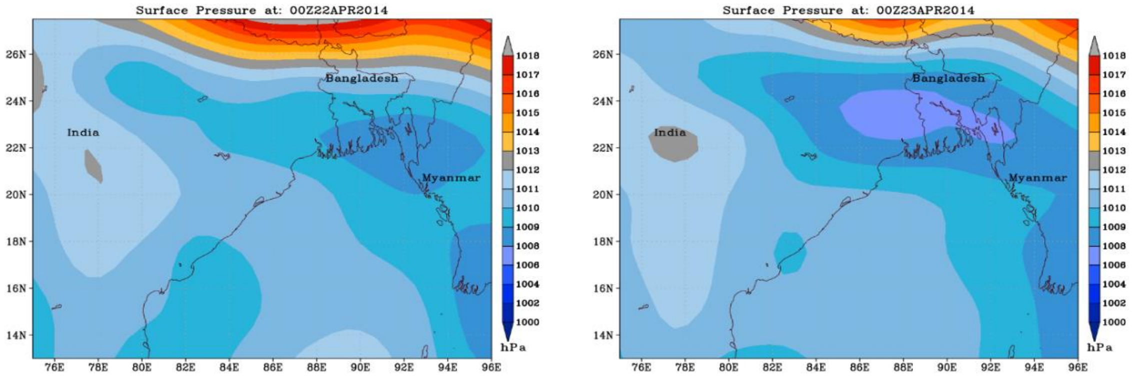

Fig4.5 (a-b): Surface pressure at 22-25 April 2014

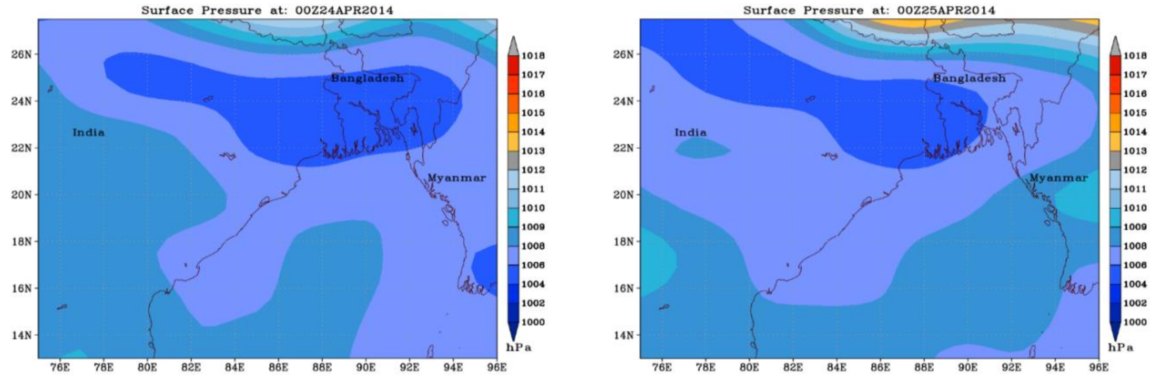

Fig4.5(c-d): Surface pressure at 22- 25 April 2014

6. Surface wind analysis 22 April – 25 April 2014

Spatial distribution of surface wind 22 - 25 April 2014(00utc) shows that strong dry westerly wind and weaker moist laden south westerly wind are observed and gradually a feeble low-pressure system are experience over

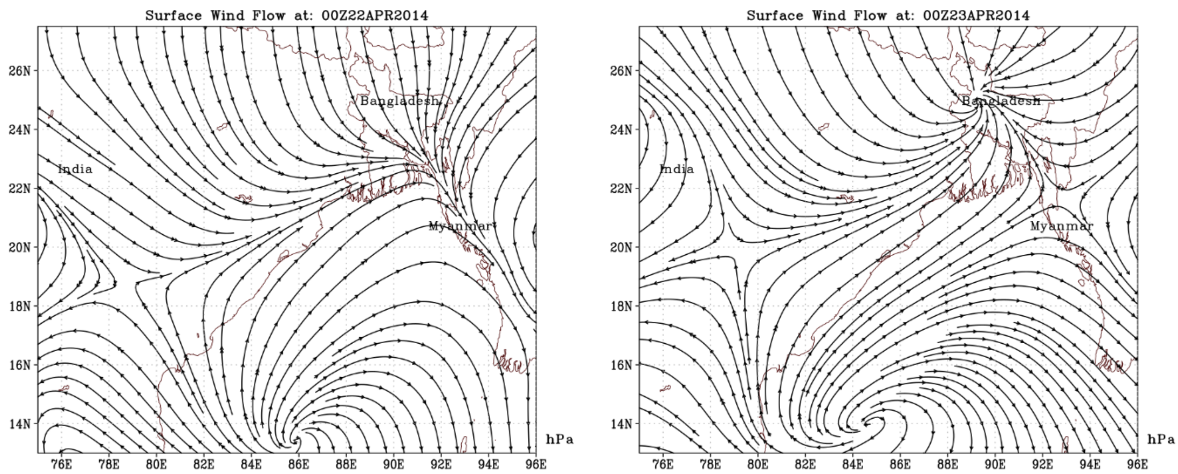

Fig.4.6(a-b): Surface wind flow at 22-23 April 2014

north western part of Bangladesh and it progress up to north eastern portion which also cover somewhat part of Assam. In the same duration a anti cyclonic circulation are form South- west Bay this general circulation prohibits the entrance of enough moisture from the Bay of Bengal and as a result atmospheric humidity be lessened.

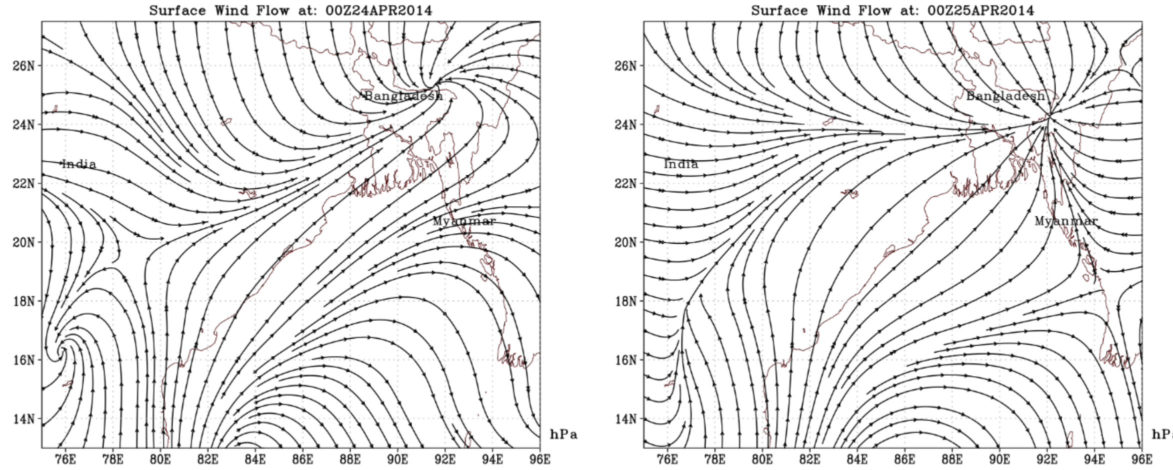

Fig.4.6(c-d): Surface wind flow at 24-25 April 2014

7. Relative Humidity analysis 22 April – 25 April 2014(06utc)

Spatial distribution of relative humidity at 0600 UTC on 22nd April-25th April 2014 shows that the lower relative humidity at that time was in the range of 20-35 % and there was a trough of RH insist over West Bengal and adjoining area that is extended from western part of Bangladesh during this heat wave spell, it passes Bangladesh through the central portion. During this period southern part experienced more relative humidity than that of the remaining part of Bangladesh.

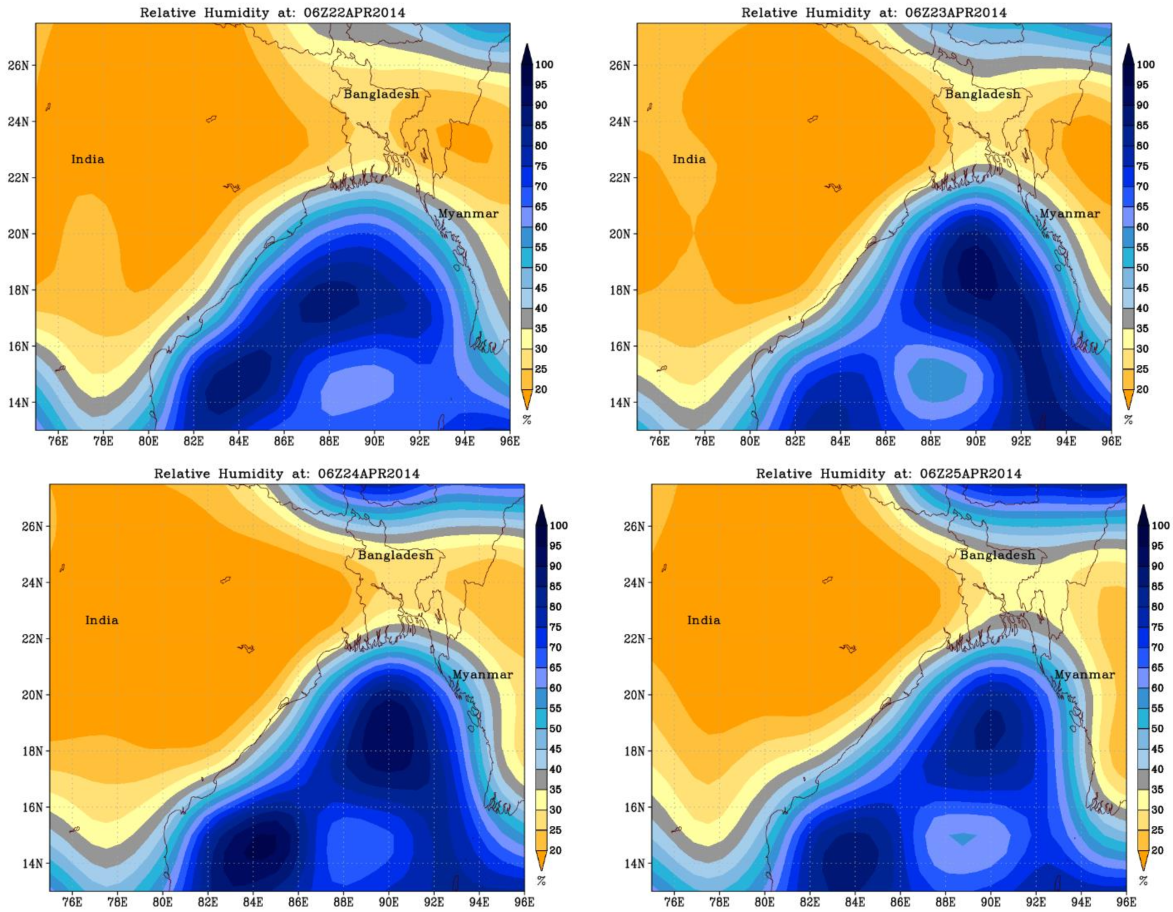

Fig. 4.7: Relative humidity at 22-25 April 2014

8. Conclusion

Based on this study, during 1981-2020 recent time the highest no. of heat wave recorded at April in 2014 and lowest no. of heat wave recorded in 2018. For March, frequency of heat wave follows decreasing trend with rate of decrement is 0 .143 for Mann-Kendall and 1.1803 for Sen's Slope estimator. For April, frequency of heat wave follows increasing trend with rate of increment is 0.0175 for Mann-Kendall and 0.14092 for Sen's Slope estimator. And for May, frequency of heat wave follows increasing trend with rate of increment is 0.0175 for Mann-Kendall and 0.14092 for Sen's Slope estimator 0.285 and2.4623. The trends of heat wave frequency in March and April are statistically insignificance at 95% level of significance and the trends of heat wave frequency in May are statistically significance at 95% level of significance. The spatial distribution of every decade it is seen that heat wave starts from south western part of Bangladesh (Jashore-Satkhira) then it gradually expands north western part to central part of Bangladesh. In last two decade it is also see heat wave are expanding to south-eastern part of Bangladesh. In 2014 among 4 heat wave spell in 20-25 April are more prominent heat wave over Bangladesh which cover about whole Bangladesh. In 20-25 April 2014 the highest maximum temperature is recorded at 24 April 2014 which was 42.4°C at Jashore. Atmospheric condition was more favorable for occurring heat wave during 20-25 April 2014. During this heat spell a pressure trough insist over west Bengal and adjoining area which reached up to eastern side of Bangladesh. Strong dry westerly wind and weaker moist laden south westerly wind entranced Bangladesh region and a trough of low relative humidity 20-35% persisted over west Bengal and Bangladesh region.

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