Cold wave condition over Bangladesh for the period of 1988-2017

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Abstract

When temperature plunges 10°C or less and continue for some period considered as cold wave. Wind enters into the country through the Himalayan foot hills and drops the day-night temperature and makes the cold feelings. Cold wave is a weather phenomenon which has widespread impact on socio-economic infrastructure, industrialization, agriculture, livestock, and forestry and also on human health. On the basis of this, different parts of Bangladesh experience different intensity of cold waves. This study examines the variation of the frequency and categories of the cold waves over the country for 30 years and also finds out the special events, extreme events, the highest duration of cold waves for the month of December-February. Among the 35 stations, It is also analyzed which stations are less significant and which are more significant for cold waves. Duration wise variation is also examined. Comparative analysis of cold wave duration and cold wave frequency of whole year for the period (1988-2017) is analyzed. Mann Kendall test also used to find out the significance level of different duration and different categories of cold waves. Understanding the nature, frequency and duration of cold waves is useful for the climate prediction and better forecasting. This analysis is also supporting to manage the cold related diseases. These results can be used as an argument for public-health interventions to prevent cold-related deaths. Furthermore, predictability of these cold waves exists from daily weather to seasonal time scales, offering opportunities for a range of preparedness measures.

Keywords: Minimum temperature, Cold wave, Duration, Frequency, GIS, Bangladesh

1. Introduction

Bangladesh rarely experiences very severe cold wave but, in some years, moderate to very severe cold waves move through the northern part of the country and when it moves through the central part to southern part its intensity gradually decreases. These cold waves and heat waves affect the health and livelihoods of the people, especially the children, women and elderly people. The cold waves and heat waves enter Bangladesh through west-northwest region of the country mainly; cold wave is also found to enter through the Srimangal-Sylhet region [1] Analyses of climate model simulations and observations revel that when extreme cold waves move through the land or it spends some times to cross the land or continent even in consideration of warming condition of 21st century. When the intensity analysis is grid based and the frequency of extreme cold events are categories in three indices and also annually calculated. In this aspect consecutive three days are considered when the average daily temperature is calculated the annual maximum of consecutive frost days, and the total number of frost days [2]. In recent years Bangladesh has experienced numerous winter events during the winter According to record, the minimum temperature falls significantly in the Northern and the Southern part of the country in January 2010.At the same time dense fog and cold wind sweeps over that part of the country. In January 2011, it was examined from the archived minimum temperature of Meteorological Department that during this time temperature fall 2 to 5 degrees Celsius lower than the normal average temperature (about 10°C) compare to the previous years which causes the significant rise in respiratory illnesses, and in some cases deaths. Some prior arrangement should be made and preparatory measures should be taken by the respective departments, Bangladesh is a disaster-prone country of an area of about 147,570km2 with population near about 160 million. The country has to face many different geo-hazards and hydro meteorological hazards/disasters due to its geographical location and the weather pattern. Long coastal belt and shallow bathymetry also make the land cyclone prompt area. It is one of the most vulnerable countries of Southeast Asia. Almost every year country faces different types of natural disasters , most notables are floods, cyclones, droughts, tidal surges, tornadoes, Nor 'wester, earthquakes, river erosion, fire, infrastructure collapse arsenic contamination of ground water, water logging, water and soil salinity, cold wave, building collapse, epidemic and various forms of pollution etc. [3] The peculiar geographical location with the Bay of Bengal (BoB) in the south and the Himalayan range in the north has made the deltaic Bangladesh most vulnerable in the world in respect of disasters of hydro meteorological origin. [4] According to the IPCC re-port (IPCC 2012), warm days/nights and their frequency and duration have increased since 1950sand it is projected that there will be more frequent hot temperature and fewer cold temperature extremes over most of the land areas of Asia [5]. A huge portion of the population of the country is living under poverty line not having adequate capacity to cope with extreme weather events such as severe cold waves. Though the cold condition is not so much bitter but in some respective months, especially December to middle of the February the northern part of the country experience

the bitterness of cold waves. Both aged and children suffer from various cold related diseases. Mostly they suffer from pneumonia, diarrhea, asthma and other cold related diseases due to cold waves. As the dense fog arises in the river basin areas, so transports mainly ferry, vehicle and also aircrafts face obstacles in their way. Sometimes Meteorological Department issues signal so they are forbidden to move anywhere for the mentioned periods. Therefore, some prior arrangement should be made and preparatory measures should be taken by the respective agencies to protect the affected peoples [6]. In the northern town of Tetulia, on the border with India, temperatures dropped to 4.5 °C, the lowest ever recorded in the area where temperatures usually hover at about 8°C at this time of the year. Ordinarily this temperature would not be low enough to cause deaths, but impoverished laborers and their families who lack appropriate shelter and clothing are falling victim. Experts' opinion, climate change has its very adverse consequences, it may responsible for breakout the multifarious diseases and also the changing weather pattern may affect the human lifestyle and also the infrastructure.

2. Data and study area

In this study, data on temperature of all 35 weather stations in Bangladesh were collected from the Bangladesh Meteorological Department (BMD). Temperature data included daily, monthly average and annual mean minimum temperatures for the period 1988-2017.

3. Methodology

Climatic Sub-regions and Bangladesh Meteorological Stations

In this study the daily minimum temperature of 35 meteorological observatory of Bangladesh Meteorological Department has been shown (fig.-1), used to describe the cold waves over Bangladesh. To explain and find out the nature and characteristics of cold wave, the data set were primarily classified according to their intensity as mild, moderate, severe and very severe cold waves. After that these classes were again classified according to their duration as 1, 2,3,4,5 and more than 5 days. These data sets were analyzed by using GIS software and MS-Excel spreadsheet. The programming language FORTRAN has used for data management. Spatial distribution and Mann Kendall test has been done to find out the characteristics of cold waves. Let (X_1,Y_1) ,..., (X_n, Y_n) be a bivariate random sample of size n. The Pearson correlation coefficient provides an optimal measure of the degree of association between the X's and the Y 's when the sample is drawn from abivariate normal distribution. The Pearson correlation coefficient is reasonably robust for many other distributions as well. The Kendall correlation coefficient, denoted by τ, provides a more general non-parametric measure of monotonic association. It is said to be monotonic since making a monotonic transformation on either the X's or the Y 's does not change the numerical value of τ. Kendall's rank correlation coefficient (Kendall, 1970, equation 1.5) may be written,

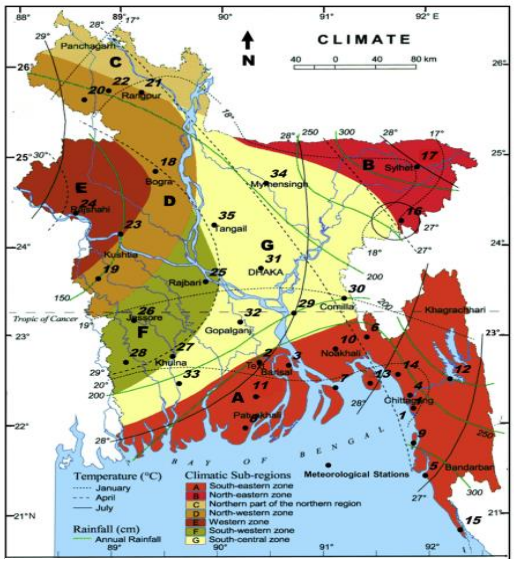

Fig. 1: Climatic Sub-regions and Bangladesh Meteorological Stations

$$\tau = \frac{S}{D} \quad \text{..... (2)}$$

where S, is the Kendall score given by

$$S = \sum_{i>j} sign(Xj - Xi)\, sign(Yj - Yi), \quad \text{..... (1)}$$

where sign (•) denotes the sign function and D is the maximum possible value of S. In the case where there are no ties among either the X's or the Y 's,

$$D = \left\{\frac{n}{2}\right\}.$$

More generally, if there are n_x distinct ties of extent t_i , $i = 1,....,n_x$ among the X's and n_y distinct ties of extent u_i , $i = 1,\ldots,n_y$ among the Y 's then

$$D = \sqrt{\left(\left(\frac{n}{2}\right) - T\right)\left(\left(\frac{n}{2}\right) - U\right)}.$$

Where,

$$T = \frac{1}{2\sum_{i=1}^{nx} ti(ti-1),}$$

And

$$U = \frac{1}{2}\sum_{i=1}^{ny} ui(ui - 1).$$

In the case where there are no ties in either ranking, it is known (Kendall, 1975, p.51) that under the null hypothesis, the distribution of S may be well approximated by a normal distribution with mean zero and variance,

$$Var(S) = \frac{1}{18}n(n-1)(2n+5),$$

provided that $n \geq 10$. Valz and McLeod (1990) have given a simplified derivation of this formula for Var (S). In the case of ties, the variance of S is more complicated,

$$Var(S) = \left\{\frac{1}{18}n(n-1)(2n+5) - \sum ti(ti-1)(2ti+5) - \sum ui(ui-1)(2ui+5)\right\} + \frac{1}{9n(n-1)(n-2)}\left\{\sum ti(ti-1)(ti-2)\right\}\left\{\sum ui(ui-1)(ui-2)\right\} + \frac{1}{2n(n-1)}\left\{\sum ti(ti-1)\right\}\left\{\sum ui(ui-1)\right\}.$$

This study also tried to find out the exceptional cases where severe and very severe cold waves are found in January. In this study only considered the months are December, January and February and considerable period (1988-2017).

4. Results and Discussion

4.1 Mild cold wave

Calculated the total number of cold waves of 35 observatories, for the month of December, January and February. Considered the mild cold wave duration of single day for the period of (1988-2017), represented graphically in Fig. 2a. Number of cold waves is much higher in January, secondly in December and it is the lowest in February. During this period, the highest number of cold waves was observed in the year 1997 & 2011 and it is notable that cold waves occurred in January, 70 times in the category of 1 day duration.

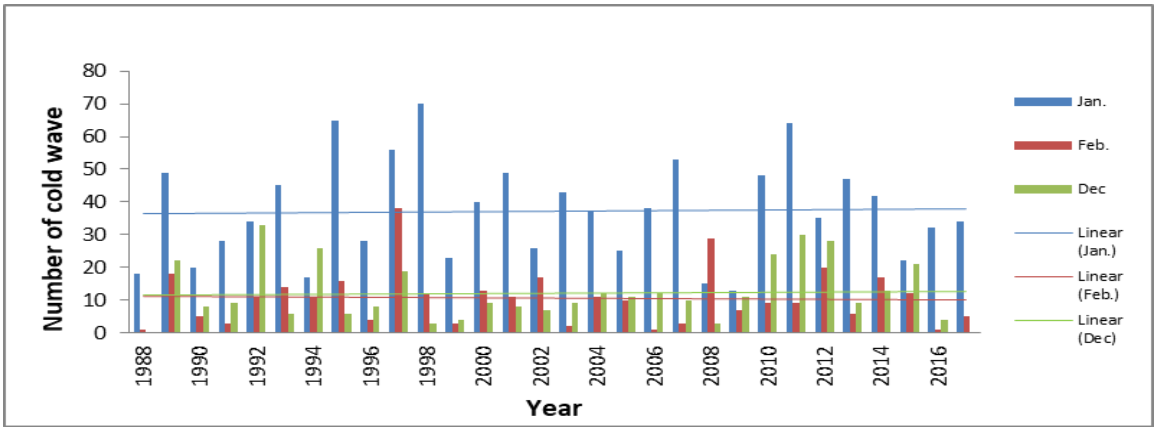

Fig. 2a: Number of mild cold wave Duration 1 day

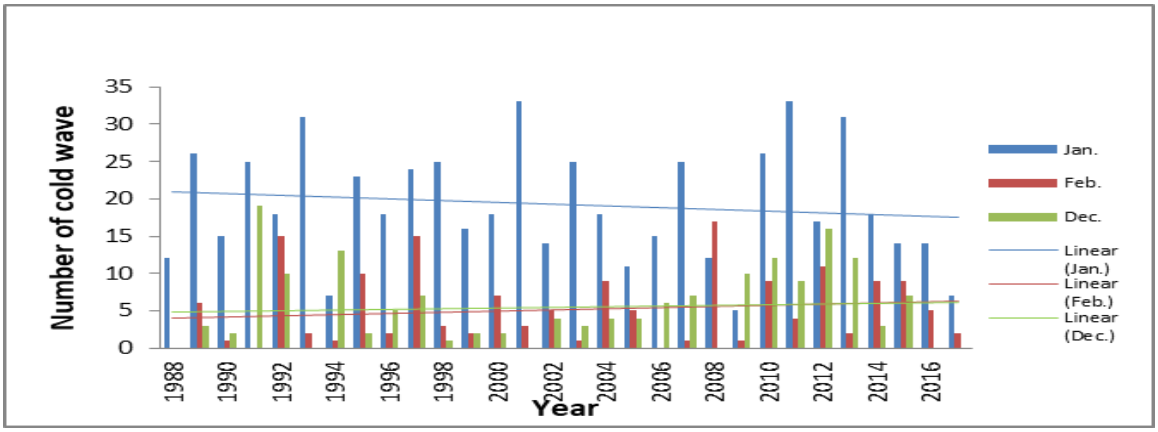

Fig. 2b: Number of mild cold wave duration 2 day

Following the same method, for mild cold waves, it is also analyzed for the duration of 2 consecutive days and graphically presented in Fig. 2b. The graphical presentation reflects that cold wave of 2 days duration occurred more frequently in January than December and much less times in February. This category of cold waves occurred maximum times in January at 2011 and some other significant years are 1997, 2010, 2011 and 2013.

Next step has been taken to find out the characteristics of mild cold waves for duration 3 days and graphically presented in Fig. 2c. In January, cold waves occurred 283 times where it occurred 102 times in December and 50 times in February during the mentioned period.

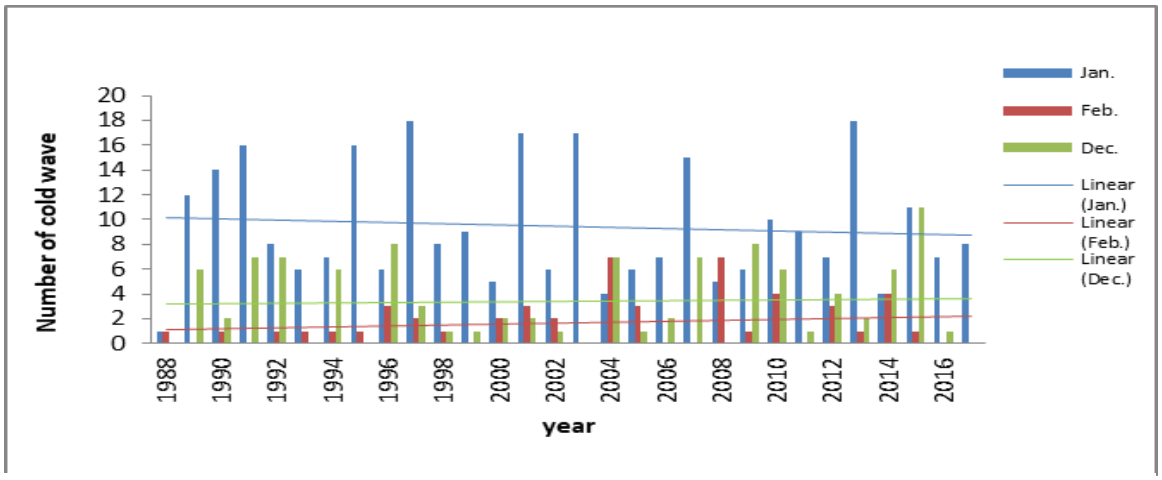

Fig. 2c: Number of mild cold wave duration 3 day

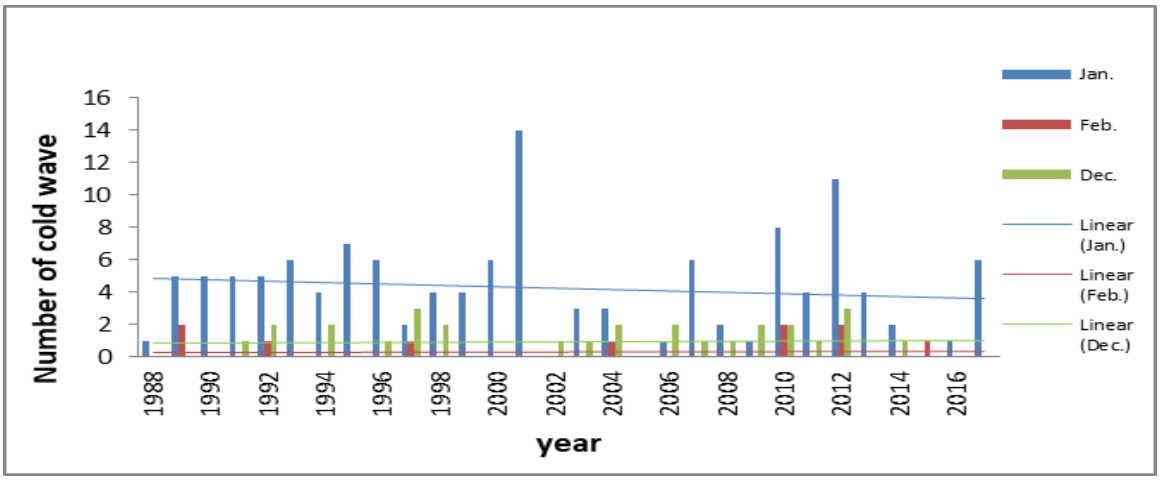

Fig. 2d: Number of mild cold wave duration 4 day

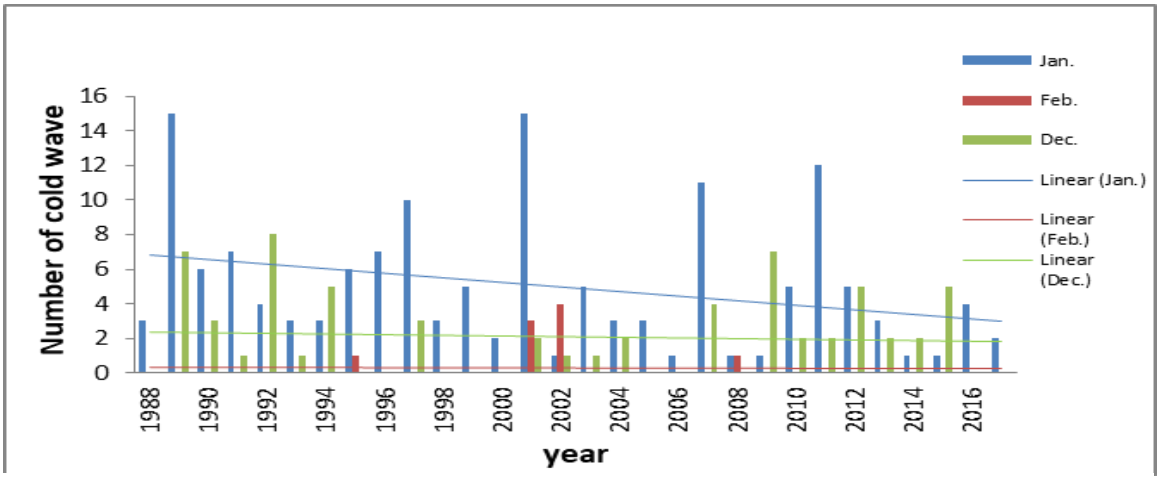

Fig. 2e: Number of mild cold wave duration equal to or more than 5 day

Following the previous steps authors also completed searching to find out the specialty of mild cold waves for the duration of 4 consecutive days and come to the conclusion which is exposed in graphical presentation in Fig. 2d. Annual analysis indicates that cold waves occurred maximum 14 times in January 2001. Number of occurrences is very less in December and it significantly less in February compared to January.

Number of mild cold waves for 5 and more than 5 consecutive days calculated for the mentioned period and it is clearly visualized in fig- (2e) that in January cold waves occurred more frequently than December and it is much less in February. It is also surprising that the number of occurrences of this category is little bit greater than the category of 4 consecutive days.

4.2 Moderate cold wave

Similar study has done for the moderate cold waves considered the months of December, January and February. Considered period (1988-2017) for the duration of 1,2,3,4 and 5 and more than 5 days. Number of cold waves is very less in this category compared to the mild cold wave. Number of moderate cold waves for single day duration, considerable period (1988-2017) has been examined, summarized and shown in fig- 3(a). The number of cold wave (387) which is much higher in January than December (75) and lowest in February (63) among the 3 months. Cold waves occurred maximum times in the year 2011 and some other significant years are 1989, 1993, 1995,1997,2011,2012.

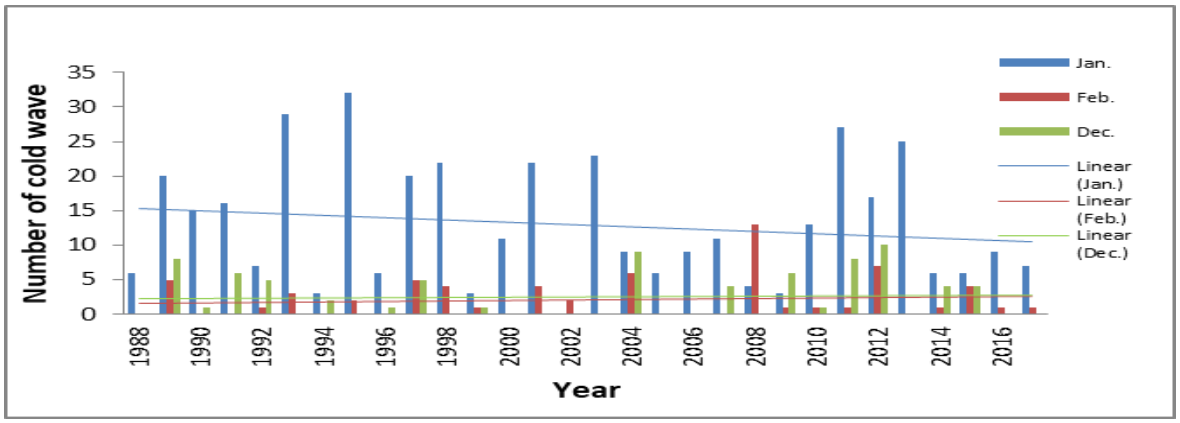

Fig. 3a: Number of moderate cold wave duration 1

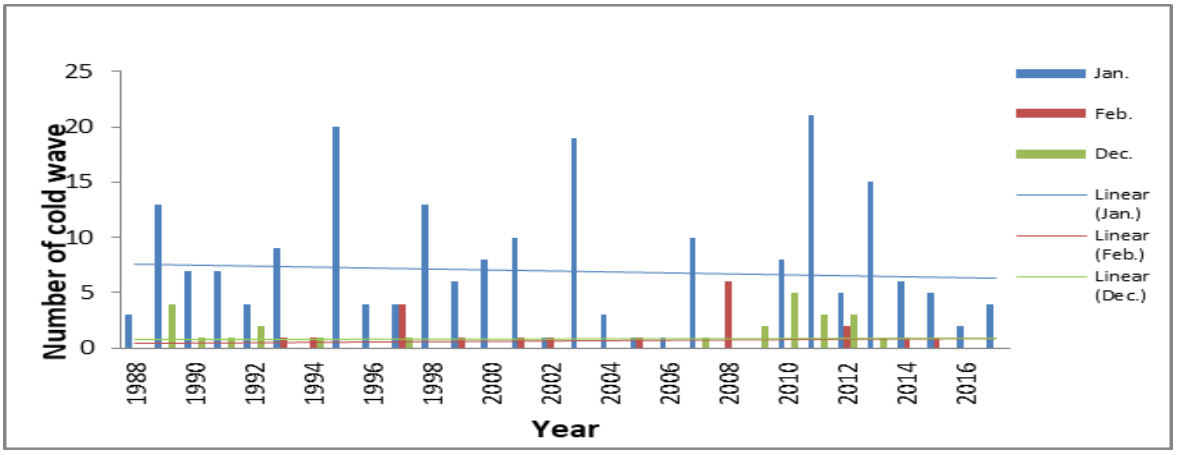

Fig. 3b: Number of moderate cold wave duration 2

Duration 2 days for moderate cold waves also showed a similar characteristic like duration 1 day. Numbers of cold waves are much higher in January (209), then December after then in February. The number of cold waves is a little bit higher in December (25) than February (20). Most significant years in this category are 2011 and 1995 shown in fig- 3(b).

Category of 3 days duration, the calculation indicates that in this category of moderate cold waves occurred much less than category 2 days duration as shown in fig- 3c. Moderate cold waves occurred only 103 times in January, in December 10 times and then in January 4 times. Some significant years in this category are 1989, 2011, 2013.

The finding of moderate cold wave duration 4 days indicates something different from other categories. In February, the country experienced no cold wave during the mentioned period. In January this situation occurred 43 times and in December number only 8 times of occurrence observed and that shown in fig. 3(d).

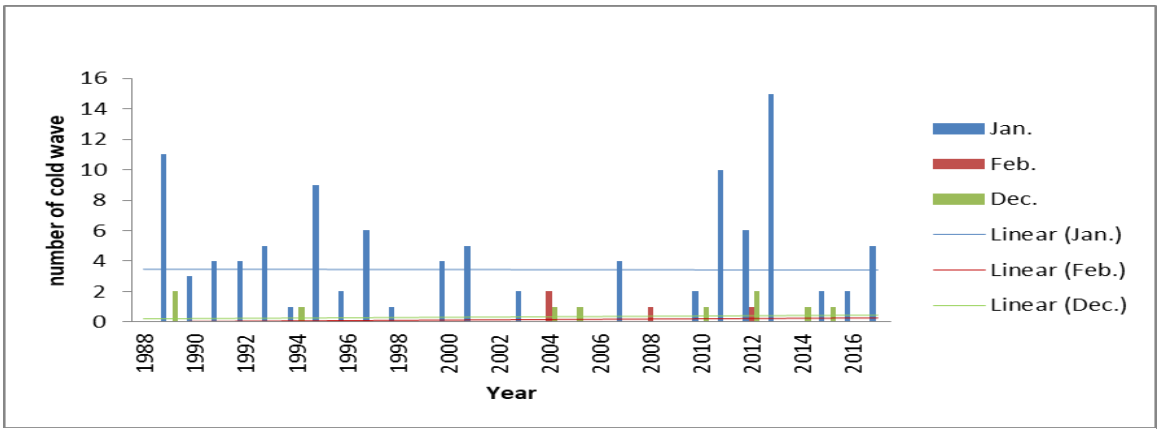

Fig. 3c: Number of moderate cold wave duration 3

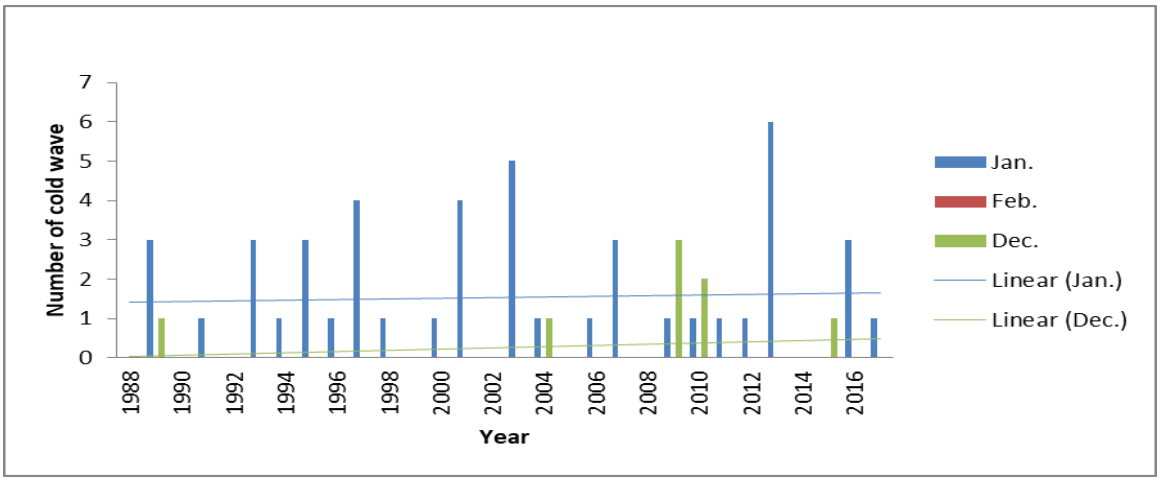

Fig. 3d: Number of moderate cold wave duration 4

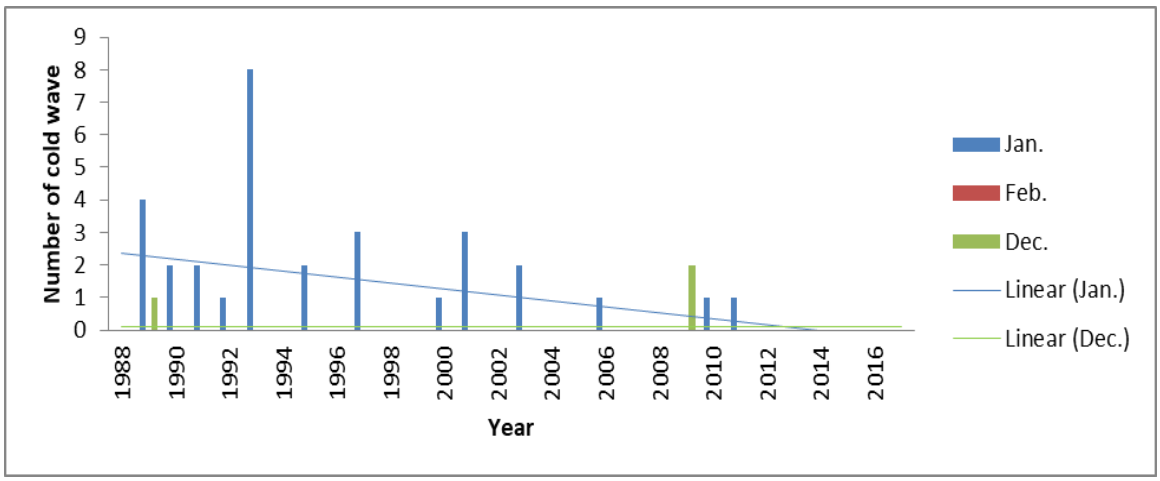

Fig. 3e: Number of moderate cold wave duration 5 day or more

Moderate cold wave 5 days duration also examined like other categories which shown in fig- 3(e). In this category numbers of occurrence are very occasional. In January the numbers of occurrences are 31 times and in December are 4 times but in February no cold wave of this category has occurred.

4.3 Severe Cold wave

As cold conditions are not so bitter in this country, the number of severe cold waves is much less than other categories even for 1 day duration. In January occurrences of severe cold waves of 1 day duration are 102 times,

in December 7 times and in February 5 times. Significant years are in this category 1995 and 2013 as exposed in fig- 4(a).

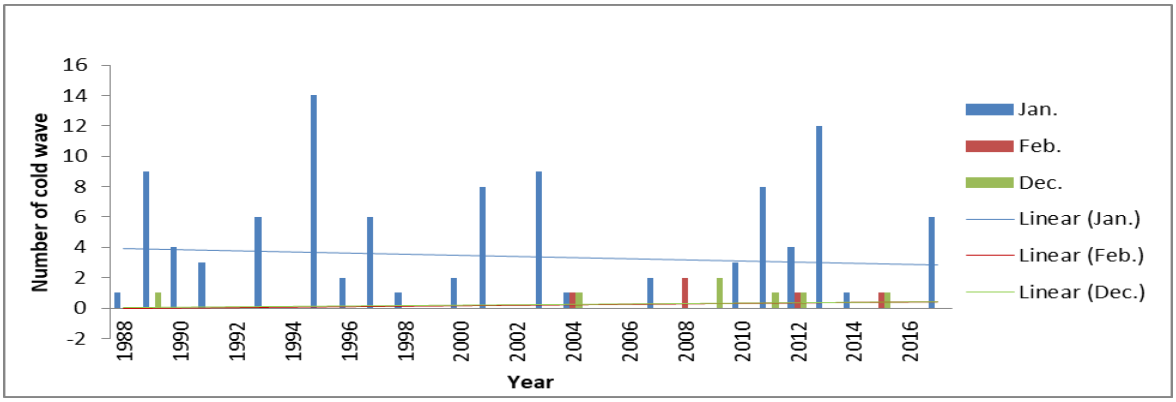

Fig. 4a: Number of severe cold wave duration 1 day

If we look at the graphical presentation of duration 2 category in fig- 4(b), then it is clearly visualized that there is no cold wave in February and December and the number of events in January is only 38 times. This type of cold wave occurred maximum 7 times in 1993 and 2003.

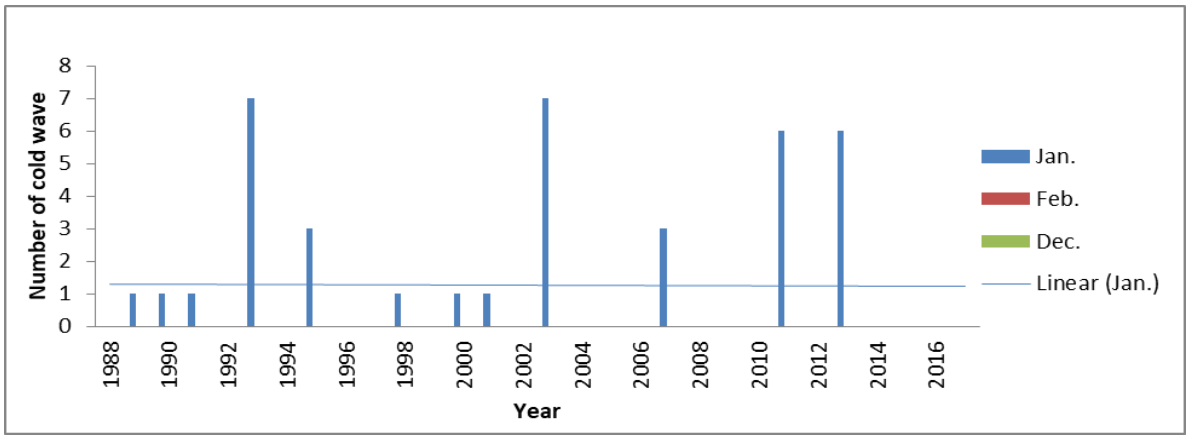

Fig. 4b: Number of severe cold wave duration 2 day

In this category the number of events decries significantly as shown in fig- 4c. Maximum times occurred in January, counted number of events are 18, it occurred only once in February and No event occurred in December. In this category no year can be mentioned as significant.

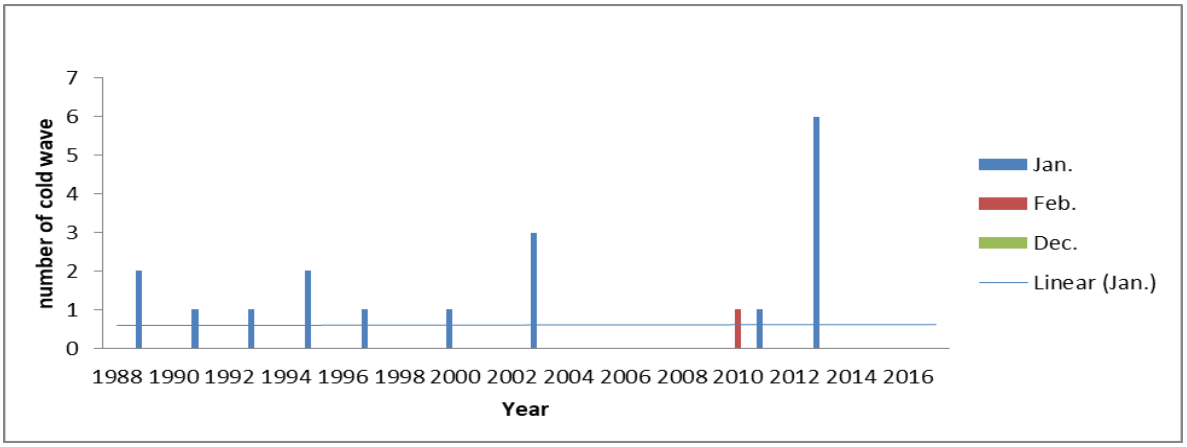

Fig. 4c: Number of severe cold wave duration 3 day

Duration 4 of this category, no observation was recorded in February and December but only in January the recorded number of events is 4 as presented graphically in fig- 4(d).

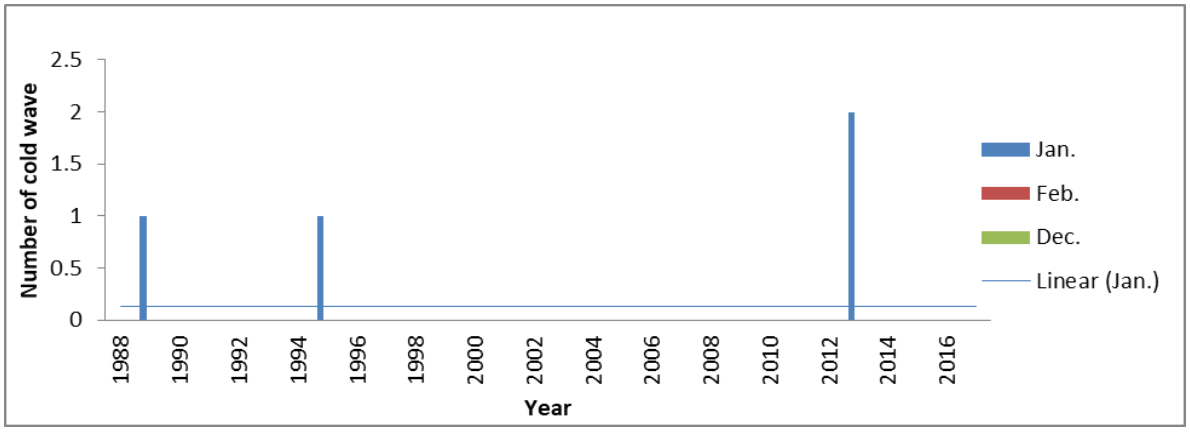

Fig. 4d: Number of severe cold wave duration 4 day

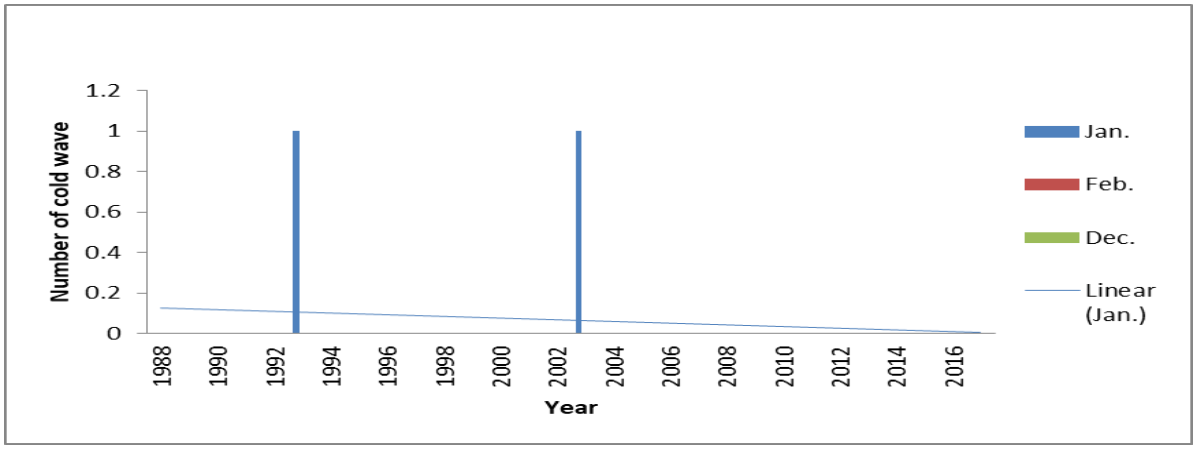

Fig. 4e: Number of severe cold wave duration 5 day

5 days duration of severe cold wave is very occasional in Bangladesh which happened only two times during this period, first time reordered in 1993 and second time was in 2003 as presented in fig- 4e.

4.4 Very severe cold wave

This category of cold wave is very rare in Bangladesh. Only few events occurred during the mentioned period. According to the spatial distribution of December the compared scenario of duration and frequency has shown in fig- 5a and fig-5b for the mentioned period, the most intensified areas are extreme northern, north western and some regions of the North Eastern part. It is moderately intensified in the Central part and less intensified in the Southern part of the country. In December Srimangal experienced the highest duration and frequency of cold waves, Dinajpur, Ishurdi, Jessore and Chuadanga also experienced cold waves of long duration and high frequency. On the other side, cold waves never swept over the stations Kutubdia, M. Court, Sandwip and Teknaf during this period.

Table 1: List of very severe cold wave is presented in Authors has taken another step to find out the intensive area over the country

Station	St.Year	St.Mon	St.Date	End.Year	End.Mon	End.Date	Duration
Srimangal	1995	1	4	1995	1	4	1
Srimangal	2007	1	17	2007	1	17	1
Srimangal	2013	1	10	2013	1	10	1
Sylhet	2013	1	9	2013	1	9	1
Dinajpur	2013	1	9	2013	1	9	1
Ishurdi	2013	1	9	2013	1	9	1
Rajshahi	2013	1	23	2013	1	23	1
Rangpur	2013	1	10	2013	1	10	1
Sayedpur	2013	1	9	2013	1	11	3
Chuadanga	2013	1	9	2013	1	9	1

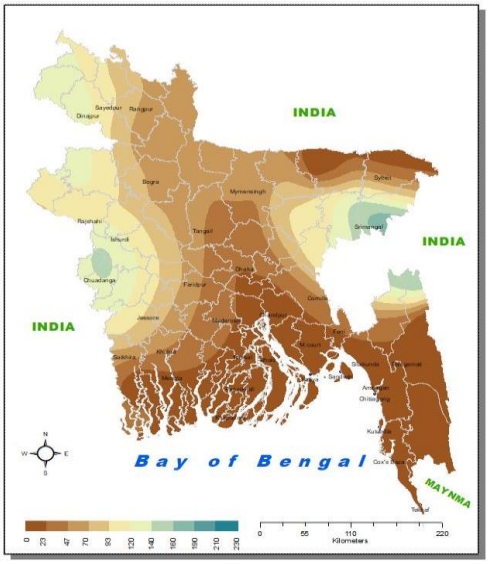

Fig. 5a: Spatial distribution of cold wave duration for the month of December.

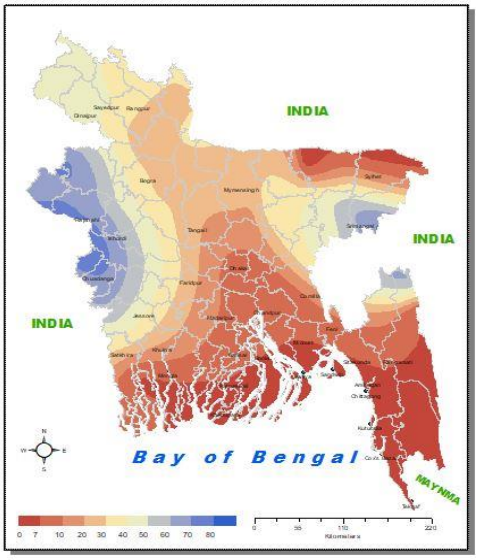

Fig. 5b: Spatial distribution of cold wave frequencyfor the month of December.

It is also analyzed to compare the duration and frequency of cold condition over the country for the month of January.

In January the intensity of cold condition is much more intensified in Northern, Northwestern and extended up to Mymensingh near to the central part of the country. Intensified areas are also recognized in some parts of the Northeastern region of the country. Central part of the country can be considered as moderately intensified and the Southern part of the country is less intensified compared to the other zones of the country shown in fig-6a and fig-6b. Cold waves occurred with highest frequency & longest duration in Rajshahi and other notable areas for prominent cold conditions are Srimangal, Dinajpur, Ishurdi, Sayedpur, Jessore and Chuadanga. It is also to be noticed that among the 13 observatories of the southern part, Cox's Bazar experienced no cold wave during this period in January.

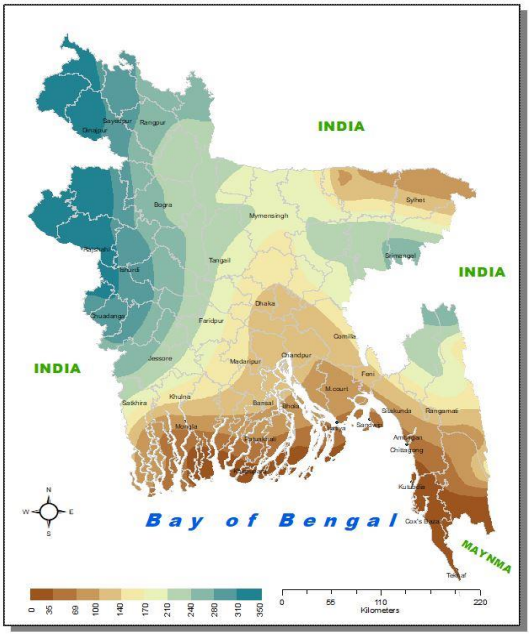

Fig. 6a: Spatial distribution of cold wave duration for the month of January.

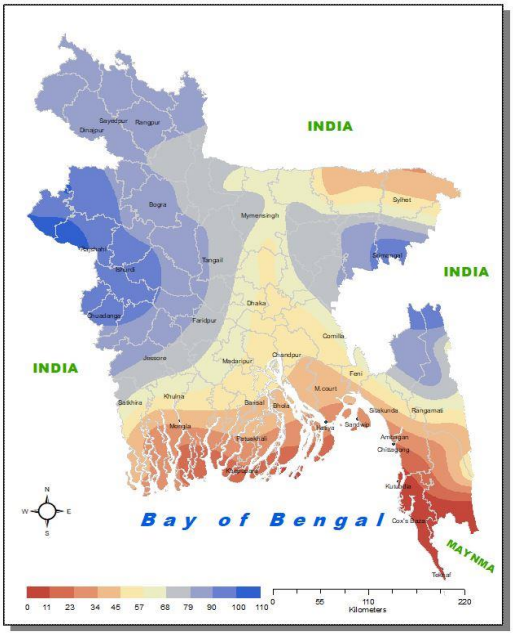

Fig. 6b: Spatial distribution of cold wave frequency for the month of January.

This type of analysis is also done to locate the intensified areas for the month of February and which is shown in the compared pictures of fig-7(a) and fig-7(b).

Fig. 7a: Spatial distribution of cold wave duration for the month of February

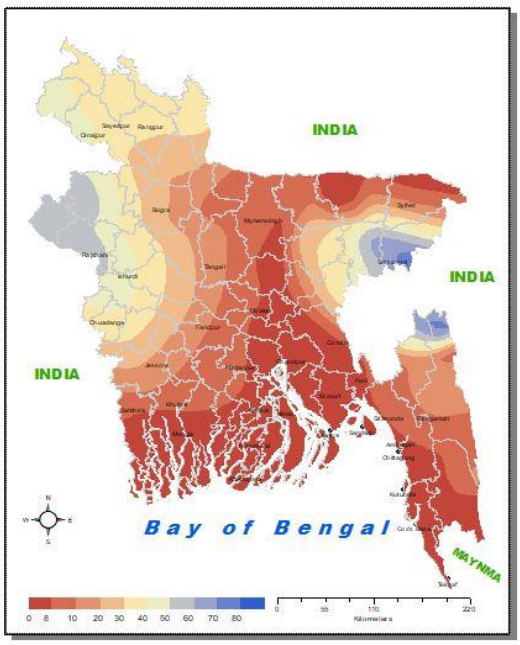

Fig. 7b: Spatial distribution of cold wave frequency for the month of February

It is clear from the spatial distribution of the coupled figures, representing the duration and frequency of cold wave, the Northern, Northwestern and some areas of Northeastern regions are most intensified and from the central part the intensity is gradually decreasing. This distribution also exposed that the Southern part is less intensified compared to the other parts of the country. In this month Srimangal, Dinajpur and Rajshahi received cold waves of long duration and more frequent. On the other hand, no cold wave swept over Mongla, Kutubdia, Cox's bazar and Chittagong (Ambagan).

Table 2a: Using Mann Kendall test and finding the significance level of duration- 1and 2days and Kendall Rank Correlation:

Class	Month	Duration_1			Duration_2		
		Tau	P value	Significant Level	Tau	P value	Significant Level
Mild	Jan	0.00461	0.49288	Not significant	-0.114	0.199545	Not significant
	Feb	-0.0492	0.360185	Not significant	0.165	0.11062	Not significant
	Dec	0.112	0.20018	Not significant	0.117	0.193995	Not significant
Moderate	Jan	-0.073	0.295415	Not significant	-0.0799	0.277285	Not significant
	Feb	0.106	0.229025	Not significant	0.0874	0.285005	Not significant
	Dec	-0.0316	0.417555	Not significant	-0.0619	0.34199	Not significant
Severe	Jan	-0.0893	0.261295	Not significant	-0.165	0.131445	Not significant
	Feb	0.264	0.044164	Significant	1	0.5	NO Data
	Dec	0.192	0.10758	Interesting subgroup	1	0.5	NO Data

Table 2b: Using Mann Kendall test and finding the significance level of duration-3, 4, 5 and more than 5 days Kendall Rank Correlation:

Class	Month	Duration_3			Duration_4			Duration_5 or more		
		Tau	Pvalue	Significant Level	Tau	Pvalue	Significant Level	Tau	Pvalue	Significant Level
	Jan	-0.033	0.408	Not significant	-0.14 2	0.152	Not significant	-0.27	0.022	Highly Significant
	Feb	0.091	0.264	Not significant	0.0109	0.481	Not significant	-0.03	0.428	
Mild	Dec	0.02	0.45	Not significant	0.0575	0.352	Not significant	-0.01	0.493	
Moderate	Jan	-0.054	0.351	Not significant	0.0321	0.418	Not significant	-0.39	0.003	Highly Significant
	Feb	0.163	0.15	Not significant	1	0.5	NO Data	1	0.5	NO Data
	Dec	0.147	0.171	Not significant	0.125	0.211	Not significant	-0.08	0.309	Not significant
Severe	Jan	-0.177	0.12	Not significant	-0.1	0.267	Not significant	-0.12	0.24	Not significant
	Feb	0.134	0.209	Not significant	1	0.5	NO Data	1	0.5	NO Data
	Dec	1	0.5	NO Data	1	0.5	NO Data	1	0.5	NO Data

Mann Kendall test has done and Table-2 indicates the significant level of different categories of cold wave.

Conclusion

i. Maximum duration of very severe cold wave for 3 consecutive days was at January 2013 in Sayedpur
ii. Very severe cold conditions observed only in January.
iii. Highest duration of cold wave for the period of (1988-2017) observed at Rajshahi 1989 and it started from 10th January continued 26 consecutive days up to 4th February.
iv. According to Mann Kendall test, 5 or more than 5 consecutive days, the number of severe cold waves is highly significantly decreasing for every category mild, moderate and severe.
v. According to Mann Kendall test, Severe cold condition for the month of February for a single day are significantly increasing.
vi. Considering the month February and category severe cold wave, no cold condition found that belong 2 or more than 2 consecutive days.
vii. Highest duration and frequency (1988-2017) was found at srimangal except January when maximum duration found at Rajshahi but frequency maximum was at Srimangal.
viii. During this period Cox's Bazar did not experience temperature conditions below 10° C.
ix. Cold wave condition was comparatively intensive in Northern, North western and Northeastern part of the country.

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