ASSESSMENT OF CLIMATIC EXTREMES OVER NORTHEAST AND WEST COAST REGIONS OF INDIA

OCJENA KLIMATSKIH EKSTREMA U REGIJAMA SJEVEROISTOČNA I ZAPADNA OBALE INDIJE

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Extreme weather and climate variability have become a subject of big concern worldwide. In response, efforts have been made to evaluate the trends in climatic parameters in two geographical regions of India – Northeast (NER) and West coast region (WCR) for the period 1901-2009. This paper studies trends in cyclones and depressions, floods and droughts, thunderstorms, hailstorms, the number of fog and poor visibility days in the research areas. A detailed analysis indicates a mixed trend for cyclones and depressions, flood and drought events. Moderate and severe cold waves also show a significant decreasing trend. The same behaviour is observed in the frequency of heat waves too. There is a significant increase in thunderstorm and hailstorm frequency. During the winter season, fog and poor visibility days show a positive correlation in Imphal, Kailashahar and Agartala. It can be concluded that in the midst of global warming and climate change, the climate response is mixed for both regions.
Keywords: cyclones, depressions, floods and droughts, thunderstorms

Ekstremno vrijeme i klimatska varijabilnost postali su predmet rasprava i brojnih istraživanja na svjetskoj razini. Kao doprinos istraživanju promjena klimatskih obrazaca, nastojalo se ocijeniti trendove klimatskih parametara u dvije geografske regije Indije – Sjeveroistočna regija (NER) i Zapadna obala (WCR) za razdoblje 1901. – 2009. Ovaj rad istražuje trendove ciklona i depresija, poplava i suša, grmljavinskog nevremena, tuče i broja dana s maglom i lošom vidljivosti u proučavanim područjima. Detaljna analiza upućuje na miješani trend za ciklone i depresije, poplave i suše. Umjereni i jaki valovi hladnoće također pokazuju značajan trend opadanja. Jednake značajke opažene su i kod učestalosti toplinskih valova. Postoji značajan porast u učestalosti grmljavinskog nevremena i tuče. U zimskom razdoblju dani s maglom i smanjenom vidljivosti pokazuju pozitivnu korelaciju u Imphalu, Kailashaharu i Agartali. Može se zaključiti da je u jeku globalnog zatopljenja i klimatskih promjena, učinak na klimu raznolik za obje regije.
Ključne riječi: ciklone, depresije, poplave i suše, olujno nevrijeme

Introduction

Globally speaking, public awareness about extreme weather events and climate variability which causes heavy losses of lives and property has risen because of media reports on natural catastrophes. There is also a general perception that the number of extreme events has increased worldwide (*An annual review of natural catastrophes*, 2003) and may be changing in frequency and intensity as a result of human influences on climate (*Climate Change 2007: The Physical Science Basis*, 2007). Several studies documented events related to extreme weather on cyclone, drought/floods, hailstorm, thunderstorm, heat/cold waves and fog days.

Some of the climate scientists (*The Regional Impacts of Climate Change: An Assessment of Vulnerability*, 1998; Walsh, 2004) confirmed that there are no distinct changes in tropical cyclone frequency and tracks associated with global warming. Indian researchers discovered significant decreasing trends of tropical cyclones (De, Joshi, 1999; Kumar, Dash, 2001) while J. R. Kumar and S. K. Dash (2004) discovered no trends. G. McCabe et al. (2004) and E. R. Cook et al. (2004) studied drought in relation to warmer temperature in the USA, while C. Schar et al. (2004) and N. Nicholls (2004) studied it in relation to greenhouse gas in Europe and Australia. M. P. Shewale and S. Kumar (2005) found out that drought affected areas in India have increased due to a decrease in monsoon rainfall. D. Dutta (2003) studied floods in relation to changes in land use while N. S. Reynard et al. (2001) worked on the influence of extremes in rainfall. Some scientists studied a decreasing trend in the frequency of cold days (Manton et al., 2001; Wibig, Glowicki, 2002) as well as the increase in the number of extremely hot days (Salinger, Griffiths, 2001). U. S. De and R. K. Mukhopadhyay (1998) and D. S. Pai et al. (2004) studied heat/cold waves over India. Several researchers collected and analysed records related to the frequency, intensity, duration, persistence and trend of fogs in the country (De, Rao, 2001; Jayanthi, Stella, 2001; De, Rao, 2004; Jenamani, 2007). Some of the researchers (Kandalgaonkar et al., 2002; Manohar, Kesarkar, 2004; Mohapatra et al., 2004; Kandalgaonkar et al., 2005) studied thunderstorm characteristics in the Indian region. However, there are few studies with regard to hailstorm in the country namely, A. Chowdhury and A. K. Baneerjee, (1983) and K. K. R. Chakrabarty and S. K. Bhowmik (1992).

Occurrences of extreme events of severe high and low temperatures, heavy rainfall etc., claim thousands of lives as well as cause extensive damage to national and regional economy. Therefore, possible long term changes in the intensity of such events are of great concern. The assessment of extreme weather is important since NER (Northeast region) and WCR (West coast region) are prone to these hazards. This paper is focused on studying the extremes in climate in both regions.

In the light of the above, two regions characterised by the extreme weather, the west coast and northeast region of India (Fig. 1) were selected to study the changing patterns of climatic elements.

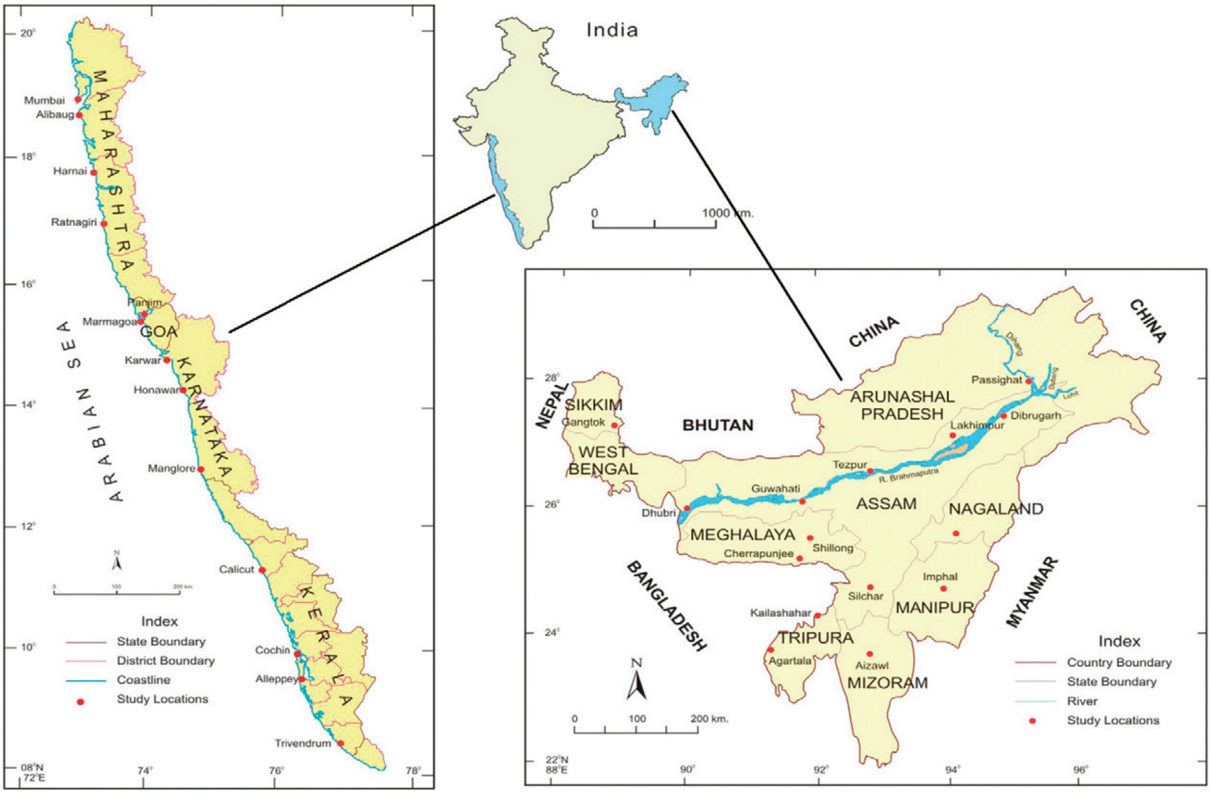

Figure 1 Study area

The first step was to examine the annual and seasonal extreme weather patterns in terms of cyclones and depressions, floods and droughts, cold and heat waves, thunderstorms, hailstorms, number of fog and poor visibility days in the study areas. Therefore, an attempt was made to assess the decadal trends on annual and seasonal scale over the last century. Many researchers investigated climatic parameters on spatial and temporal scale. However, this study was carried out based on political boundaries characterised by homogeneity in climatic phenomena. It analyses intra and inter regional climatic trends.

Data and methods

Using monthly data for winter (January-February), pre-monsoon/summer (March-May), monsoon (June-September) and post-monsoon (October-December) season annual values were calculated. In order to determine the significance of a trend, linear regression and correlation coefficients were computed and student t-test was used for calculation of significant levels (0.05 and 0.01%).

Monthly frequency data (1901-2009) on cyclone and depression were collected from Indian Meteorological Department (IMD) publications. In order to identify the flood year when rainfall exceeds $\mu + \sigma$ (i.e. mean + 1 SD), drought year when rainfall is less than $\mu - \sigma$ (i.e., mean -1 SD). In order to determine flood/drought behavior on a larger scale, 4 meteorological subdivisions in the NER and 3 in the WCR were selected for this study. The monthly number of fog and poor visibility days (less than 1 km) during the period 1970-2009 recorded at 3 GMT during the winter season (November to February) were used. Due to paucity of the data only 7 stations in the NER were used while fogs are rare in the WCR. The frequency of cold and heat waves was identified by using daily maximum and minimum temperature data for the months April to June and November to February during the period 1970-2009. Even though cold waves do not occur in the WCR one station was used for representative purposes while two stations were used for the NER. The criteria for heat and cold waves are given in Tab. 1.

Thunderstorm and hailstorm frequencies (1974-2005) for the states of Assam and Kerala were noted from the Record-Disastrous Weather Events published by IMD, Pune (Annual publications from year 1974 to 2005). The frequencies were based on the economic damage and human casualties associated with thunderstorms/hailstorms in the study area.

Table 1 The criteria for heat and cold waves in NER and WCR

Heat wave	**Normal maximum temperature**	**Moderate heat wave**	**Severe heat wave**
	40 ºC or lower	5 ºC to 6 ºC above the normal	7 ºC or above
Cold wave	**Normal minimum temperature**	**Moderate cold wave**	**Severe cold wave**
	10 ºC or higher	lower than 5 ºC to 6 ºC	-7 ºC or below
	lower than 10 ºC	Cold wave: -3 ºC to -4 ºC.	5 ºC or lower

Results

Cyclones and Depressions

The analysis of decadal frequencies of cyclones and depressions for the NER and WCR are depicted in Fig. 2 (a-d) and the total frequency is reported in Tab. 2. The analysis of cyclone/depressions frequency in the NER reveals a significant decreasing annual trend as well as a post monsoon season trend (Fig. 2 a-b).

In order to find any changes over a long period, two periods were identified: 1901-1950 and 1951-2000, and compared (Tab. 2). The third period, from 2001-2010, was disregarded as the data range is short.

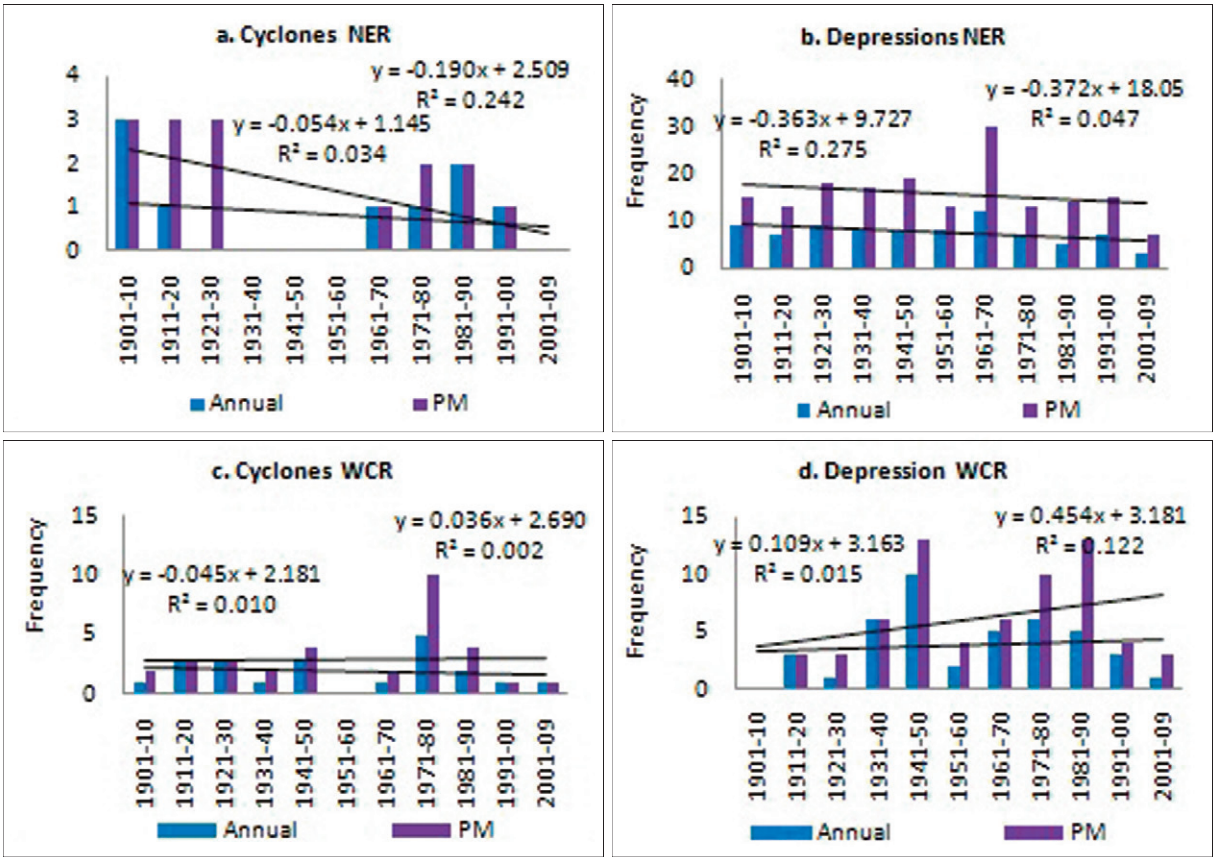

Figure 2 (a-d) Cyclones and depressions

Table 2 Total frequency of cyclones and depressions

	Cyclones				Depressions			
NER	S	MON	PM	Annual	S	MON	PM	Annual
1901-1950	4	1	4	9	18	23	41	82
1951-2000	0	1	5	6	19	27	39	85
2001-2010	0	0	0	0	3	1	3	7
Total	4	2	9	15	40	51	83	174
WCR	S	MON	PM	Annual	S	MON	PM	Annual
1901-1950	3	0	11	14	1	4	20	25
1951-2000	2	6	9	17	4	12	21	37
2001-2010	0	0	1	1		2	1	3
Total	5	6	21	32	5	18	42	65

Note: S – summer; MON – monsoon; PM – post-monsoon

The table above shows that there is very little variation between the two periods in the year as well as during the seasons, which means that there is a secular trend. It is also surprising to see that in the midst of global warming, the frequency of cyclones and depressions forming in the Bay of Bengal shows a decreasing trend. A study by S. K. Dash et al. (2004) shows a decrease in the horizontal and vertical wind shears of the mean monsoon flow over India and decrease in the moisture and convection over the Bay of Bengal. A recent study by L. Dong and T. Zhou (2014) reported an increase of the sea surface temperature over the Indian Ocean affecting the hydrological cycle, atmospheric circulation, and global climate change. However, there was a decrease in the trend of cyclones and depressions frequency in the studied area in spite of warming of the sea surface.

In the WCR (Fig. 2 c-d), annual and post monsoon cyclonic frequency shows a mixed trend. As for the depressions, there is an increasing trend in a year and in post monsoon season and it is significant for the former. The total frequency during the last century for the WCR is shown in Tab. 1. The table indicates that there is very little variation in cyclonic frequency between 1901-1950 and 1951-2000; however, there is a great difference in frequency of depressions between the two periods. It is also reported that the total frequency of cyclone and depression is high in the NER (174) unlike the WCR (65). However, the relationship is inversely proportional: frequencies of cyclones are higher in WCR, and depressions in NER.

Subdivisional Monsoon Flood and Drought Years

The flood/drought years have been identified in respect to the subdivisions in the NER namely Arunachal Pradesh (AP), Assam and Meghalaya (AM), Nagaland, Manipur, Meghalaya, Mizoram and Tripura (NMMT) and Sub-Himalayan West Bengal (SHWB) and the decadal analysis for the NER are reported in Tab. 3.

Table 3 Flood/drought years during monsoon season

	Flood				Drought			
Decadal	**AP**	**A/M**	**NMMT**	**SHWB**	**AP**	**A/M**	**NMMT**	**SHWB**
1871-1880		2	1	1		2		2
1881-1890		3		1		2	4	2
1891-1900			1			2	3	3
	0	**5**	**2**	**2**	**0**	**6**	**7**	**7**
1901-1910		1		2			1	2
1911-1920	2	2	1	2				
1921-1930	3	1	3	2				1
1931-1940	1	2	4	2				
1941-1950	1		3		1			1
	7	**6**	**11**	**8**	**1**	**0**	**1**	**4**
1951-1960			4	3	2		1	1
1961-1970	2		2	2	6	2	1	
1971-1980		1			1	2	2	4
1981-1990	3	1		1		1	3	1
1991-2000	2	2		2	2	4	3	1
	7	**4**	**6**	**8**	**11**	**9**	**10**	**7**
2001-2010					4	8	4	1
Total	14	15	19	18	16	23	22	19

Table 4 Flood/Drought years during monsoon season

	Flood			Drought		
Decadal	KG	CK	Kerala	KG	CK	Kerala
1871-1880	1	1	1	2	2	
1881-1890	2	1	4		1	1
1891-1900	3	2	4	1	2	1
	6	**4**	**9**	**3**	**5**	**2**
1901-1910		1	1	2	1	
1911-1920	1	1	1	3	5	1
1921-1930		1	2	2	1	
1931-1940	1		2		1	
1941-1950		1	1	1	1	1
	2	**4**	**7**	**8**	**9**	**2**
1951-1960	5	2	1		1	2
1961-1970	2	1	2	2	1	2
1971-1980	1	2	1	1	1	1
1981-1990	1	2				5
1991-2000		4		1		2
	9	**11**	**4**	**4**	**3**	**12**
2001-2010	1	1		2	1	4
Total	18	20	20	17	18	20

Note: KG – Konkan/Goa, CK – Coastal Karnataka

The table above shows variations in flood years over the NER during the last 139 years. It is also observed that from 1911 to 1940, all the subdivisions experienced flood years. The table also indicates that there were only a few drought years in the period from 1911 to 1940 for all the subdivisions. In order to see whether any sudden change was observed, the study period was divided into four: 1871-1900, 1901-1950, 1951-2000 and 2001-2010. The results show that when 1901-1950 and 1951-2000 are compared, there is a sudden decrease in flood years for Assam/Meghalaya and NMMT and an increase in drought during the last half of the century. Monsoon rainfall was also analysed in all the subdivisions to determine its trend. The results show that there was a decrease in monsoon rainfall in both subdivisions. However, it is significant at 0.01% in A/M (-11.37x + 1647) which can be compared to the increase in drought during the last half of the century. Decadal frequencies of flood years over WCR are depicted in Tab. 4.

The table clearly shows that there is variability in floods for Konkan/Goa (K/G) while Coastal Karnataka (CK) experienced floods during each decade except for the decade 1931-1940. It is observed that not a single flood year was reported since 1981 for Kerala. The table also indicates that the frequency of droughts has increased over Kerala during the period 1941-2010. On the other hand, in CK the period from 1981-2000 was without a drought. The table also shows that in the period 1951-2000 there were more flood years for Konkan/Goa and CK unlike Kerala when compared with the period 1901-1950. Like the NER, the increase and decrease in flood years over the study regions was studied considering the monsoon rainfall trend. The decrease in drought years over CK is also supported by significant (0.01%) increase in rainfall trends (y = 2.503x + 2782) while an increase in drought years over Kerala is mainly because of significant (0.01%) decrease in rainfall (y = -4.314x + 2228).

Fogs and Poor Visibility Days

In order to establish the link between fog days and poor visibility days, the data were subjected to correlation analysis and the scatter plots are presented in Fig. 3.

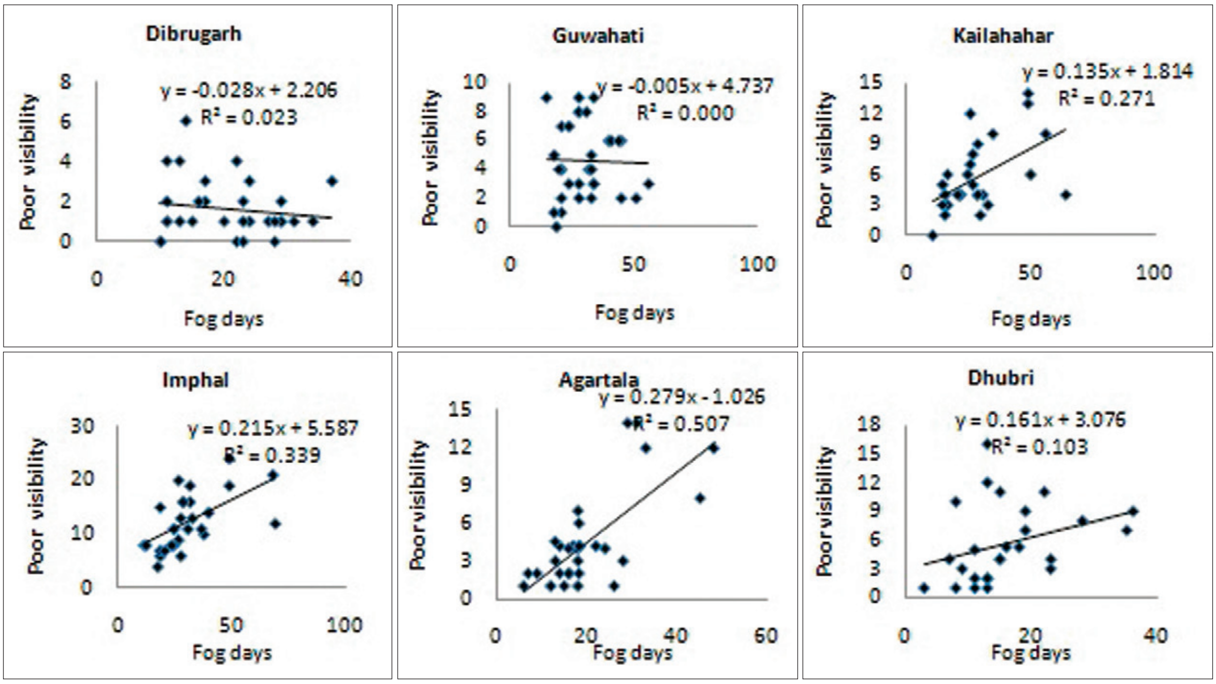

Figure 3 Fog and poor visibility (NER)

The analyses indicate that a significant relationship exists between fog and poor visibility days at Kailashahar, Imphal and Agartala. The increase in the fog frequency and poor visibility appears to be related to meteorological factors like calm or variable wind, temperature inversion, stable atmospheric conditions and moist atmosphere which contribute to thickening of fog. The figures indicate a negative correlation between Dibrugarh and Guwahati. The negative correlation can be attributed to the significant increase in the minimum temperature at Dibrugarh ($y = 0.057x + 9.794$) and Guwahati ($y = 0.008x + 11.07$) during the winter season for these cities.

Cold and Heat Waves Frequency

The following paragraph attempts to study the variations and patterns in the frequency of cold waves in the NER. The annual cold/heat wave frequencies are shown in Tab. 5.

Table 5 Cold and heat wave frequency

NER							WCR	
	Gangtok		Guwahati	Gangtok	Guwahati		Mumbai	
Decade	MCW	SCW	MCW	MHW	MHW	SHW	MCW	HW
1971-1980	14	0	10	8	17	4	16	1
1981-1990	81	22	9	3	7	1	7	2
1990-2000	9	1	3	2	18	4	11	0
2001-2009	4	0	1	0	11	1	6	1

Note: MCW – Moderate cold wave, SCW – Severe cold wave, MHW – Moderate heat wave, SHW – Severe heat wave; HW – Heat wave

Table 6 Cold and heat wave slope value

Station	MCW	R^2	SCW	R^2
Gangtok	y = -10.2x + 52.5	0.132	y = -2.1x + 11	0.062
Guwahati	y = -3.3x + 14.0	0.926		
Mumbai	y = -2.6x + 16.5	0.545		
Station	**MHW**	**R^2**	**SHW**	**R^2**
Gangtok	y = -2.5x + 9.5	0.899		
Guwahati	y = -0.7x + 15.0	0.030	y = -0.6x + 4	0.2
Mumbai	y = -0.2x + 1.5	0.1		

Tab. 5 indicates the following: 79% of the cold waves occurred during the period 1981-1990. The annual cold wave frequency at Gangtok is high during the period 1981-1990; this finding is also comparable with Samui and Gupta (1992). The frequencies of moderate as well as severe cold waves decreased. The frequency of cold wave in Gangtok is much higher than in Guwahati. The significant decrease in cold wave (Tab. 6) can be attributed to the increase in minimum temperature at Gangtok (y = 0.071x + 3.768) and Guwahati (y = 0.008x + 11.07) during the winter season. The increase in minimum temperature at Gangtok can be attributed to urbanization. Hence, the increase ($y = 2574.e^{0.478x}$) in population during the study period 1951-2001 can be seen. For Guwahati, meteorological factor like increase in medium cloud (0.014x/year; 1951-2006) has an influence over the minimum temperature. Thus, increased urbanization and a cloud cover are some of the factors that lead to the decrease in cold waves over the study areas.

The annual frequencies of heat waves at Gangtok and Guwahati are depicted in Tab. 5. The table above reveals that there is a decrease in moderate heat wave at Gangtok while at Guwahati moderate and severe heat waves shows variability. The table also indicates that Gangtok did not experience severe heat wave and that frequency of moderate heat wave is lower than the one for Guwahati. The table also shows that more occasions of moderate and severe heat waves were observed during the decade 1971-1980 (17) and 1991-2000 (18) for Guwahati. The decrease in heat wave at Gangtok (Tab. 6) can be attributed to the decrease in maximum temperature (y = -0.035x + 20.82) and with an increase in forest cover (y = 44.06x + 2867). The frequency of heat wave shows a decreasing trend in the northeast region; this in fact is in conformity with that of Pai et al. (2004) which shows that the entire subdivisions from NER did not experience heat waves and severe heat waves.

The WCR is represented by Mumbai. The moderate cold wave shows variability in the study period. The highest frequencies were reported during the decade 1971-1980 (16) and 1990-2000 (11) (Tab. 5). On closer analysis, Mumbai never experienced a severe cold wave in the period from 1971 to 2009. It is clear from the table that in all periods there were only 4 occasions of a heat wave of which only one was severe, and the decade 1991-2000 did not experience a single heat wave. It is also observed that heat wave occasions for Mumbai are very few.

Thunderstorm and Hailstorm Frequency

The annual thunderstorm frequency during the period 1974-2005 for the NER was represented by Assam while the WCR is represented by Kerala and are reported in Tab. 7.

Tab. 7 indicates that for the state of Assam, there were 95 occasions of thunderstorms in a span of 31 years. The table clearly indicates that the thunderstorms activity depicts increasing trend significant at 0.01%. It also reveals that maximum frequencies of events are observed during the decade 1991-2000 followed by 2001-2005. This study period covers till 2005, thus fewer frequencies were reported during the period 2001-2005 as compared to the decade 1991-2000. The analysis of thunderstorm also shows increasing in annual significant at 0.01% for the state of Kerala (Tab. 7). Decadal wise frequencies indicates that

Table 7 Thunderstorms frequency

	Assam		Kerala	
Decadal	Annual	Summer	Annual	Summer
1974-1980	9	9	8	7
1981-1990	22	19	2	2
1991-2000	35	24	12	12
2001-2005	29	15	9	5
Total	95	67	31	26
	Annual	R^2	Summer	R^2
Assam	y = 7.3x + 5.5	0.711	y = 2.3x + 11.0	0.219
Kerala	y = 1.3x + 4.5	0.160	y = 0.4x + 5.5	0.015

Table 8 Hailstorms frequency

Decadal	Annual	Summer
1977-1980	4	3
1981-1990	15	12
1991-2000	41	36
2001-2005	27	21
Total	87	72
Annual	y = 9.5x – 2.0	R^2 = 0.594
Summer	y = 7.8x - 1.5	R^2 = 0.512

maximum frequency for Kerala was observed during the decade 1991-2000 (12) while the least was noticed in the decade 1971-1980 (8). The same behaviour is observed during the summer season which accounts for more than 80% of annual thunderstorms.

The decadal frequency of hailstorms in annual and summer season over the state of Assam are reported in Tab. 8.

The annual and seasonal frequency shows significant (0.01%) increase in the hailstorms activity. Further, the analysis of the decadal data reveals that there were in all 87 hailstorms in a span of 28 years. The table clearly shows that maximum frequency of hailstorms is observed during decade 1991-2000. Since hailstorms and fogs occur rarely in WCR it was not possible to convert them into frequency and therefore they have not been considered.

Conclusions

The findings have raised a number of important questions regarding changes in extreme events. Observational studies based on relatively short time periods namely, thunderstorms/hailstorms and cold/heat waves, have shown significant changes. However, for long time periods such as cyclones/depressions making land fall in the NER has in fact declined, except in depressions for the WCR. This is the most challenging problem concerning climate change as the cyclones/depressions show a decreasing trend which is not consistent with global warming climatic changes. Therefore, the climate change caused by enhanced greenhouse gas has little impact on the trends. There is some evidence that this is coming out from the WCR namely the increase in floods years over Konkan/Goa (K/G) and Coastal Karnataka (CK).

The above findings are too complex for a precise interpretation of the changes in extreme climatic events. Therefore, it can be concluded that extremes in climate showed mixed result in both regions in the last century. These variations might be due to some other factors (anthropogenic/non climatic) which influence the climatic patterns. One of the biggest problems in performing analyses of extreme climate events for most of the NER is the inability to access high-quality, long-term climate data from a reduced number of meteorological stations. Hence, dense network of stations and records for long periods are required to show a clear trend and lead to precise conclusions.

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BIBLIOGRAPHY

An annual review of natural catastrophes, Munich Reinsurance Company, Munich, 2003, pp. 48.

Chakrabarty, K. K., Bhowmik, S. K. (1992): *Study of unusual hailstorm over Bombay*, Mausam, 44, 292-295.

Chowdhury, A., Banerjee, A. K. (1983): *A study of hailstorm over Northeast India*, Vayu Mandal, 13, 91-95.

Climate Change 2007: The Physical Science Basis, (ed. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor M., Miller, H. L.), Intergovernmental panel on climate change, Cambridge University Press, Cambridge, 2007, pp. 996.

Cook, E. R., Woodhouse, C. A., Eakin, C. M., Meko, D. M., Stahle, D. W. (2004): *Long term aridity changes in the Western United States*, Science, 5698, 1015-1018.

Dash, S. K., Jenamani, R. K., Shekhar, M. S. (2004): *On the decreasing frequency of monsoon depressions over the Indian region*, Current Science, 86/10, 1404-1411.

De, U. S., Joshi, K. S. (1999): *Interannual and interdecadal variability of tropical cyclones over the Indian seas*, The Deccan Geographer, 37/1, 5-21.

De, U. S., Mukhopadhyay, R. K. (1998): *Severe heat wave over the Indian subcontinent in 1998 in perspective of global climate*, Current Science, 75/12, 1309-1311.

De, U. S., Rao, G. (2001): *Visibility over Indian airports during winter season*, Mausam, 52/4, 717-726.

De, U. S., Rao, G. S. P. (2004): *Urban climate trends – The Indian Scenario,* Journal of Indian Geo-physical Union, 8/3, 199-203.

Dong, L., Zhou, T. (2014): *The Indian Ocean Sea Surface Temperature Warming Simulated by CMIP5 Models during the Twentieth Century: Competing Forcing Roles of GHGs and Anthropogenic Aerosols*, Journal of Climate, 27/9, 3348–3362.

Dutta, D. (2003): *Analysis of floods disaster trends in Asia*, in: Watershed Hydrology, (ed. Singh, V. P., Yadava, R. N.), Allied publisher Pvt Ltd, New Delhi, 512-520.

Jayanthi, N., Stella, S. (2001): *On the increasing trend in the fog menace of Chennai Airport*, Tropmet 2001, Meteorology for sustainable development, 510-516.

Jenamani, R. K. (2007): *Alarming rise in fog and pollution causing a fall in maximum temperature over Delhi,* Current Science, 93/3, 314-322.

Kandalgaonkar, S. S., Tinmaker, M. I. R., Kulkarni, M. K., Nath, A. (2002): *Thunderstorm activity and sea surface temperature over the island stations and along the east and west coast of India*, Mausam, 53/2, 245-248.

Kandalgaonkar, S. S., Tinmaker, M. I. R., Nath, A., Kulkarni, M. K., Trimbake, H. K. (2005): *Study of thunderstorm and rainfall activity over the Indian region*, Atmosfera, 18/2, 91-101.

Kumar, J. R., Dash, S. K. (2001): *Inter decadal variations of characteristics of monsoon disturbances and their epochal relationship with rainfall and other tropical features*, International Journal of Climatology, 21/6, 759-771.

Kumar, J. R., Thapliyal, V., Dash, S. K. (2004): *Decadal and epochal variation of frequency and duration of monsoon disturbances and their secular relationship with rainfall over India*, Mausam, 55/3, 397-408.

Manohar, G. K., Kesarkar, A. P. (2004): *Climatology of thunderstorm activity over Indian region: I. A Study of East-West contrast,* Mausam, 54/4, 819-829.

Manton, M. J., Della-Marta, P. M., Haylock, M. R., Hennessy, K. J., Nicholls, N., Chambers, L. E., Collins, D. A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T. S., Lefale, P., Leyu, C H., Lwin, T., Maitrepierre, L., Outprasitwong, N., Page, C. M., Pahalad, J., Plummer, N., Salinger, M. J., Suppiah, R., Tran, V. L., Trewin, B., Tibig, I., Yee, D. (2001): *Trends in extreme daily rainfall and temperature in Southeast Asia and the south Pacific*, International Journal of Climatology, 21/3, 269-284.

McCabe, G. J., Palecki, M., A., Betancourt, J., L. (2004): *Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States,* Proceedings of the National Academy of Sciences, 101/12, 4136-4141.

Mohapatra, M., Koppar, A. L., Das, A. T. (2004): *Some climatological aspects of thunderstorm activity over Bangalore City*, Mausam, 55/1, 184-189.

Nicholls, N. (2004): *The changing nature of Australian droughts*, Climate Change, 63/3, 323–336.

Pai, D. S., Thapliyal, V., Kokate, P. D. (2004): *Decadal variation in the heat and cold waves over India during 1971-2000*, Mausam, 55/2, 281-292.

Reynard, N. S., Prudhomme, C., Crooks, S. M. (2001): *The flood characteristics of large UK rivers: Potential effect of changing climate and land use*, *Climatic Change,* 48/2-3, 343-359.

Salinger, M. J., Griffiths, G. M. (2001): *Trends in New Zealand daily temperature and rainfall extremes*, International Journal of Climatology, 21/12, 1437-1452.

Samui, R. P., Gupta, D. C. (1992): *Severe winter associated with cold waves at two hill station in Sikkim*, Vayu Mandal, 22, 52-56.

Schar, C., Vidale, P. L., Luthi, D., Frei, C., Haberli, C,. Liniger, M. A., Appenzeller, C. (2004): *The role of increasing temperature variability in European summer heat waves*, Nature, 427/22, 332-335.

Shewale, M. P., Kumar, S. (2005): *Climatological features of drought incidences in India,* Meteorological Monograph, Climatology 21, National Climate Centre, Pune, pp. 22.

The Regional Impacts of Climate Change: An Assessment of Vulnerability, (ed. Watson, R. T., Zinyowera, M. C., Moss, R. H.), Intergovernmental panel on climate change, Cambridge University Press, Cambridge, 1998, pp. 517.

Walsh, K. (2004): *Tropical cyclones and climate change: unresolved issues,* Climate Research, 27/1, 77-83.

Wibig, J., Glowicki, B. (2002): *Trends of minimum and maximum temperature in Poland,* Climate Research, 20/2, 123-133.