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Extreme Weather Events over India in the last 100 years

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ABSTRACT
India being mainly an agricultural country the economy and further its growth purely depends on the vagaries of the weather and in particular the extreme weather events. The information on extreme weather events lie scattered in the scientific and technical papers and in the research work of many authors and if put together will help the research community for further analysis.

The authors in this paper present a factual and a brief review of the extreme weather events that occurred in India during the last 100 years (1991-2004). The socio-economic impacts of the extreme weather events such as floods, droughts, cyclones, hail storm, thunderstorm, heat and cold waves have been increasing due to large growth of population and its migration towards urban areas which has led to greater vulnerability. In recent years as per WMO review global losses from such extreme weather events is about US $ 50-100 billion annually with loss of life of about 2,50,000. Thus, greater efforts are needed to improve the forecast skill and use these better forecasts in disaster management.

INTRODUCTION

The year 1999 witnessed a super cyclone striking the eastern coast of India (Orissa State). It was a major natural disaster affecting the subcontinent in recent years. The Bangladesh Cyclone of 1971, droughts of 1972 and 1987, the heat wave in 1995 and 1998 and cold wave in 2003 killing several hundred people are still fresh in public memory. The drought and failed monsoon of 2002, in particular, an unusually dry July, is matter of concern for scientists and planners. However, many may not remember that the worst drought in India during the last century occurred in 1918.

The data on climate anomalies, extreme and disastrous weather events in respect of the subcontinent lie scattered in various published literature of the India Meteorological Department and in the scientific and technical papers documenting the research work of many authors. We have attempted to bring them systematically into the ambit of this review paper.

The aim of the paper is to review the major natural disasters and extreme weather events which occurred over the country in the last few decades (1901-2004) and discuss briefly their causes and socio-economic impacts.

Climate of India and Climate Variability

The India Meteorological Department was established as a National agency in 1875 amalgamating various provincial meteorological services which existed in the 19th century, [Kelkar (2000)]. However, instrumental data and records for a few stations in India existed since 18th century. Some of the oldest observatories include Madras now known as Chennai (September 1793), Bombay (1823) and Calcutta (December 1829). The first seismological observatory was set up in Alipore (Calcutta) in 1898. The new names for Bombay and Calcutta are Mumbai and Kolkata.

Basically, the climate of India is dominated by the summer monsoon (June to September). The entire year is, however, divided into four season : (i) Winter (January and February) (ii) Pre-monsoon or Hot Weather season (March – May) (iii) Southwest or Summer Monsoon season (June - September) (iv) Post monsoon season (October – December). Year to year deviations in the weather and occurrence of climatic anomalies / extremes in respect of these four seasons are :-

(i) Cold wave, Fog, Snow storms and Avalanches
(ii) Hailstorm, Thunderstorm and Dust storms
(iii) Heat wave
(iv) Tropical cyclones and Tidal waves

(v) Floods, Heavy rain and Landslides, and
(vi) Droughts

These are all related to the meteorological factors, whereas earthquakes, volcanoes and tsunamis are other geophysically triggered disasters and not discussed in the paper.

Cold wave

Occurrences of extreme low temperature in association with incursion of dry cold winds from north into the sub continent are known as cold waves. The northern parts of India specially the hilly regions and the adjoining plains are influenced by transient disturbances in the mid latitude westerlies which often have weak frontal characteristics. These are known as western disturbances. The cold waves mainly affect the areas to the north of 20^0N but in association with large amplitude troughs, cold wave conditions are sometimes reported from States like Maharashtra and Karnataka as well. Table 1 gives the frequencies of the occurrence of cold waves in different parts of the country for different periods. The source of the data is also given. The maximum number of cold waves occur in Jammu & Kashmir followed by Rajasthan and Uttar Pradesh. It may be seen that number of cold waves in Gujarat and Maharashtra are almost one per year though these states are located in more southern location. In recent years due to deterioration of the air quality in urban locations of India the deaths and discomfort from cold waves have been substantial, [De and Sinha Ray (2000)]. Their study showed that in states of Uttar Pradesh and Bihar the number of deaths from extreme events in the cold weather season during 1978-1999 was 957 and 2307 respectively. These two States rank the highest in terms of casualties from cold wave. The reason for this could be the poor level of development and lack of shelters to the outdoor workers and farmers.

A study by Raghavan (1967) has shown that during the period 1911-1961 most severe cold wave event occurred in Dras in March 1911. The lowest ever recorded temperature for the month of March was – 33.9°C on 22nd March, 1911. However, this was over a very small area over the mountainous region of Ladakh with the temperature going 19.7^0C below its normal minimum value. In the plains, however, the most severe cold wave occurred during 30 January – 2 February 1929 over Gujarat, Saurashtra & Kutch and Madhya Pradesh. The largest departure (-12^0C)

Table 1. Number of Cold Waves

State	Epochs				
	1901-10	1911-67	1968-77	1978-99	1901-99
Wes West Bengal	2	14	3	28	47
Bihar	7	27	8	67	109
Uttar Pradesh	21	51	8	47	127
Rajasthan	11	124	7	53	195
Gujarat, Saurashtra & Kutch	2	85	6	6	99
Punjab	3	34	4	19	60
Himachal Pradesh	-	-	4	18	22
Jammu & Kashmir	1	189	6	15	211
Maharashtra	-	60	4	18	82
Madhya Pradesh	9	88	7	12	116
Orissa	4	5	-	-	9
Andhra Pradesh	2	-	-	-	2
Assam	1	1	-	-	2
Haryana, Delhi & Chandigarh	-	-	4	15	19
Tamil Nadu	-	-	-	-	-
Karnataka	-	10	-	-	10
Telangana	-	5	1	-	6
Rayalaseema	-	3	-	-	3

Source : 1901 – 10 : Annual Summary
1911 – 67 : Bedekar FMU
1968 – 77 : Disastrous Weather Events Reports – Annual
1978 – 99 : WMO Bulletin October 2000, 49, 4, pp. 340 - 348

occurred on 1 February 1929 over western parts of Madhya Pradesh. This recorded a departure of -12^0 C of minimum temperature over considerable area in Madhya Pradesh (West) and adjoining parts of Saurashtra & Kutch, Madhya Maharashtra and Gujarat region. In recent years 1978-99 highest number of deaths from severe cold waves have been in Bihar.

West Madhya Pradesh experienced most frequent cold wave/ severe cold wave and highest number of cold wave / severe cold wave days during the decade 1971-80 (Pai, Thapliyal & Kokate 2004). In the 1st week of January 2000 the deadly cold spell resulted in the death of 363 persons of which 152 were from Uttar Pradesh and 154 were from Bihar (DWR 2000). Severe cold wave conditions prevailed over most parts of Bihar and adjoining parts of Orissa during December 2001 and claimed around 300 human lives. During the 1st to 3rd week of January 2003 the northern states were under the grip of a severe cold wave and in all 900 people died of which 813 were from Uttar Pradesh alone.

Snow storms occur during the winter months (December, January and February) over the northern hilly regions of India. Sometimes early or late snowfalls are also reported in November, March or April. An unusual case of freezing rain and snowfall was reported from Jammu and Kashmir during the month of August 1996. It resulted in death of 241 pilgrims going to Amarnath while about 9000 pilgrims from different parts of India, were stranded in the area along the route.

Fog

Immediately after the passage of a western disturbance (WD) lot of moisture is available in the atmosphere and the regional and synoptic scale conditions provide the trigger for the formation of fog. Eventhough this phenomena is not directly related to the extreme weather events it has an effect in all forms of transport and in particular aviation. This has an indirect effect on the economy of aircraft operations and air passenger inconvenience.

De & Dandekar (2001) studied the visibility trends during winter season for 25 aerodromes over a period of 21 to 31 years and concluded that most of the north Indian airports show a significant increasing trend in the poor visibility days (due to fog) amounting to 90% i.e. almost everyday. The airports in south India show only 20 to 30% days with poor visibility. The percentage frequencies of number of days with poor visibility for a number of airports are shown in Fig. 1. Rapid urbanization and increased number of automobiles in the major cities appear to be the cause of increased aerosols in the city. Increasing trend in the relative humidity and increased presence of aerosols of particulate matter are most likely causes of poor visibility.

During January 2000 due to thick fog, one truck carrying cattle skidded injuring dozens of cattles. Air and railway services were affected considerably. Delhi airport was closed for hours together disrupting flights. Thick ground fog affected vehicular traffic (DWE 2000).

On 26th and 27th December 2001 (DWE 2001) in Ferozepur and Sindh area six persons died and eight injured in an accident due to thick fog. On 10th January 2002, 4 persons died in a road accident at Phagwara (near Kapurthala) due to dense fog. At Bankura on 15th and 16th January 2002 (DWE 2002), due to dense fog, 2 buses collided (near Burjora) and 30 passengers were injured. The flights were suspended. In Darjeeling from 27th to 29th January 2002 the vehicular traffic was disrupted due to dense fog. On 28th and 29th December 2002, railway and air services came to a standstill as Delhi city and entire Ganga valley was covered under thick fog.

During 1st to 3rd week of January 2003 (DWE 2003) accident due to dense fog was reported from Haryana and Punjab in which 19 people died. Punjab and Uttar Pradesh rail / road and air traffic was badly affected due to dense fog.

Thunderstorm, Hailstorm and Dust storm

As winter season transforms into spring the temperature rises initially in the southern parts of India, giving rise to thunderstorms and squally weather which are hazardous in nature. While the southernmost part of the country is free from dust storm and hailstorm, such hazardous weather affect the central, northeastern, north and northwestern parts of the country. Records indicate that the largest size hailstone occurred in association with a thunderstorm in April, 1888 at Moradabad a town near Delhi. The hailstone measured size of a Pigeon's egg in diameter (IMD 1888). The hailstorm frequencies are highest in the Assam valley, followed by hills of Uttar Pradesh now known as Uttaranchal, South Bihar (now known as Jharkhand) and Vidarbha in the eastern parts of Maharashtra (Philip & Daniel 1976). However, thunderstorms also occur in these areas during the rest of the year as well, for example, Calcutta (Kolkata) has the highest frequency of thunderstorm in September while Delhi, Jaipur and Ahmedabad have the highest frequencies in July. In some of the worst disasters associated with

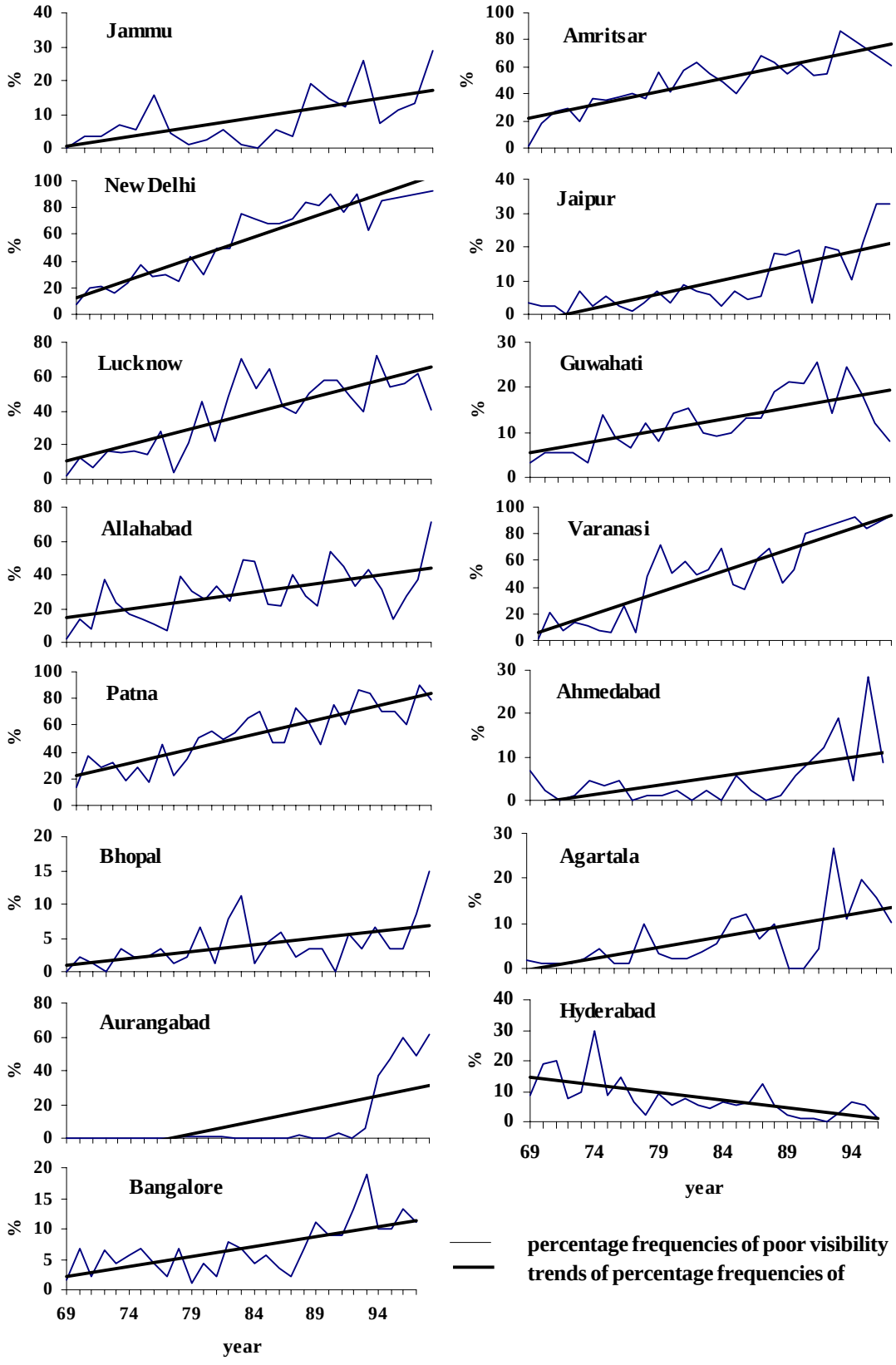

Figure 1. Percentage frequencies of number of days with horizontal visibility < 2000 m at 03 UTC during winter season with significant trends at 99% level.

hailstorms, 8 persons were killed in Kanpur (Uttar Pradesh) on 28 February 1992, and 9 persons died near Nagpur (Maharashtra) in February 1979. Thunderstorm and squally winds killed 19 people in Patna on 29 May 1997, while in Kolkata 9 people died on 26 March 1993 due to thunderstorm and lightning [De & Dandekar (2001)]. Catalouging of Disastrous Weather Events by the India Meteorological Department started in 1967. Prior to 1967, reports of deaths (loss of life) in association with thunderstorms are many.

Tornadoes are rare in India but some of them are quite devastating. In recent years, a tornado struck Delhi on 17th March, 1978 injuring over 1000 people and inflicting a damage of rupees ten million in terms of losses to properties and infrastructures. Some of other tornadoes which caused extensive damage and destruction in the country include (i) The tornado of 19th April, 1963 at Cooch Behar (West Bengal) which killed 139 people and rendered 3760 families homeless. (ii) A tornado on 1st April, 1977 at Dhaka killed 500 people and 6000 injured. (iii) 12th April, 1983 tornado at Gaighata in West Bengal killed 28 people and injured 500. (iv) 19th October, 1987 tornado at Chapra in Bihar killed 20 lives and injured 517 persons. (v) A tornado on 9th April, 1993 at Kanthi in West Bengal took a toll of 50 people and injured 180. (vi) 29th October, 1999 tornado at Midnapore and South 24 Pargana districts close to Paradeep injured 80 people.

Heat wave

Extreme positive departures from the normal maximum temperature result in heat wave during the summer season. The rising maximum temperature during the pre-monsoon months often continues till June, even in rare cases till July over the northwestern parts of the country. Raghavan (1966) made an extensive stud of the heat wave spells of the last century for the period from 1911 to 1961. His study indicated that the maximum number of heat waves occur over East Uttar Pradesh followed by Punjab, east Madhya Pradesh and Saurashtra & Kutch in Gujarat. Monthwise, maximum number of heat waves occurred during the month of June. However, individual epochs of heat wave are also noted by several authors. According to De & Sinha Ray (2000) heat wave related deaths were highest (1625) in Rajasthan, followed by Bihar, Uttar Pradesh, Orissa during the period 1978 to 1999. Notably the period roughly coincided with last two decades of the twentieth century which witnessed unprecendented high temperatures globally as a result of the global warming.

An earlier study by De & Mukhopadhyay (1998) showed that the heat wave in 1998 was linked with El-Nino of 1997. they showed that number of casualties from severe heat waves were more during years succeeding an El-Nino. However, some years like 1978, 1979, 1985, 1986, 1991, 1994 reported high number of deaths from heat waves but were not preceeded by El-Nino years. Reports indicate that 1998 was noted for severe heat wave and larger number of deaths at different parts of the world.

A recent study by Pai, Thapliyal & Kokate (2004) revealed that during the decade 1991-2000 a significant increase in the frequency, persistency and spatial coverage of heat wave / severe heat wave has been observed in comparison to that during the earlier decades 1971-80 and 1981-90. These changes might be the regional impact of the observed general increase in the global warming during the recent decade (1991-2000), which is the warmest decade during the past 140 years (WMO 2001).

The deaths due to heat wave in Orissa in 1998 has been widely reported as one of the rare extreme epochs over the country resulting in deaths of nearly 1300, of which 650 were from Orissa, [De & Mukhopadhyay (1998)]. It is of interest to note that Raghavan (1966) in his study has reported that "The severest heat wave on record in the country is that of June 1926. It lasted from the 10th to 16th. The highest value recorded was 46.1°C which occurred on 14th June, 1926. However, his studies were based on the data sets of 1911-1961. Table 2 shows the frequency of occurrence of heat waves during different epochs for different parts of the country. Alwar in Rajasthan (East) holds the record for the highest maximum temperature of 50.6^{0}C (123^{0}F) on 10 May 1956. On the other hand Kalsi & Pareek (2001) have ranked April 1999 as the warmest April of the last century for the northwestern India, while the earlier studies have focused their attention on the months of May and June. Kalsi & Pareek (2001) have considered the anomalously warm Aprils over northwest India. They identified 1892, 1921, 1931, 1941, 1958, 1973, 1988 and 1999 as anomalously warm years. They concluded, "The pronounced heating in April 1999 cannot be therefore linked with global warming and it is attributable to local anomalous circulation setting over India and its neighbourhood. Furthermore, their findings did show that April 1892, (Eliot, 1893) was relatively warmer than 1999 over northwest and central India. The occurrence and persistence of the hot spell in April 1999 thus, appears to be an unique event in the 20th century. Such a warm April was not observed during other years of the 1990's.

Table 2. Number of Heat Waves

State	Epochs				
	1901-10	1911-67	1968-77	1978-99	1901-99
		31	2	28	61
Wes West Bengal		76	9	28	113
Bihar		105	6	23	134
Uttar Pradesh		27	3	42	72
Rajasthan		43	1	7	51
Gujarat, Saurashtra & Kutch		-	2	-	2
Punjab		-	1	-	1
Himachal Pradesh		-	-	-	-
Jammu & Kashmir		26	5	35	66
Maharashtra		82	4	13	99
Madhya Pradesh		32	4	15	51
Orissa		25	8	18	51
Andhra Pradesh		21	-	3	24
Assam		-	4	19	23
Haryana, Delhi & Chandigarh		-	1	2	3
Tamil Nadu		5	-	2	7
Karnataka		-	-	-	-
Telangana		-	-	-	-
Rayalaseema		31	2	28	61

Source : 1901 – 10 : Annual Summary
1911 – 67 : Bedekar FMU
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Bedekar, V.C., M.V.Decate and A.K.Banerjee, FMU. No. IV - 6 – Heat & Cold Waves in India 1974.

In recent years heat wave induced casualties have some what increased. Abnormally high temperatures were observed during April 2002 across the country and a prolonged heat wave over northern regions of India from mid-April through the third week of May caused more than 1000 fatalities. On 10th May, the maximum temperature at Gannavaram (Vijayawada) reached 49^{0}C (WMO 2003).

During 2003 pre-monsoon months, heat wave brought peak temperatures in May of between 45^{0}C and 49^{0}C. This year's heat was particularly harsh, with a death toll of atleast 1500 people. This contrasted strongly with the unseasonably low temperatures observed in northern Indian in January and December. Maximum temperatures then were 4 to 5^{0}C below normal, which resulted in more than 2500 fatalities (WMO 2004).

Decrease in the Diurnal Temperature Range (DTR) due to urbanization is a new factor leading to human mortality and discomfort. Increased minimum temperatures in summer do not allow the necessary nocturnal cooling to neutralize the high maximum temperature during a heat wave epoch.

Tropical Cyclones

Though several studies by De & Joshi (1995, 1999); Srivastava, Sinha Roy & De (2000) and Bhaskar Rao, Naidu & Srinivasa Rao (2001) show a decreasing trend in frequency of Tropical Cyclones (TC) and Monsoon Depressions (MD) over the north Indian Ocean (The Bay of Bengal and the Arabian Sea) in recent years, their potential for damage and destruction still continues to be significant. A severe Super Cyclonic Storm with winds of upto 250 km/h, crossed the coast in Orissa on October 29, 1999. This may prove to have been the worst cyclone of the century in the Orissa region and is responsible for as many as 10,000 deaths, for rendering millions homeless and for extensive damage (WMO, 1999). Over the past decades the frequency of tropical cyclones in the north Indian ocean has registered significant increasing trends (20% per hundred years) during November and May which account for maximum number of intense cyclones (Singh, Alikhan & Rahman 2000).

De & Joshi (1995, 1999) have used the data set of tropical disturbances including tropical storm for the

period 1891 to 1990 over the Bay of Bengal and the Arabian Sea. Their analysis has shown that number of such disturbances varied from one decade to another. The maximum number of tropical disturbances (163) occurred during the decade 1941-50 and minimum number occurred in 1911-1920. The last decade of the past century had only 85 disturbances. The number of Cyclonic Storm (CS) was highest (47) during the decade 1921-30 while the number of Severe Cyclonic Storm (SCS) was highest (41) during 1971-80. Their numbers were smallest in the decade 1981-90 being 14 and 18 in the decade 1941-50 respectively. The decade 1991-2000 showed a decrease in the number of T.C. storm and MDs forming in this region. The number of TCs was 42 and that of MDs was 43 during the decade only as against a Long Term Average of 6 and 13 per year respectively.

The damage and destruction from such systems do not seem to decrease. Loss of life however, tend to show a fall as a consequence of better weather forecasts and warnings, their dissemination and disaster management strategies put in place by the National Weather Services world over in conjunction with the significant role played by the WMO through its Regional Meteorological Centers (RMCs) specially dealing with Tropical Cyclones. The Tropical Cyclone of 1970 in the Bay of Bengal killed about 2 lakh people while a similar cyclone in 1991 showed a marked decrease in number of deaths.

Some of disastrous tropical storms of the 20th century include the Orissa Super Cyclone (October 1999), Kandla cyclone (1998), Porbandar cyclone (1976), Bombay cyclone (1948). A list of such cyclonic storms are given in the Table 3. The super cyclone of 1999, and Bangladesh cyclone of 1970 rank as the most well documented storms. However, the False Point Cyclone (Orissa) which occurred in 1885 was reported to be associated with the highest storm surge of 22 ft. These storms were quite devastating for the north Bay of Bengal (Bangladesh), West Bengal (India) and Orissa (India) together with parts of Andhra Pradesh and Tamil Nadu in the south Bay of Bengal and were noted for large storm surge. The super cyclone of Orissa was preceded by a cyclonic storm crossing the Orissa coast between 15 and 19 October of the same year, but it was associated with lower damage. It is a matter of interest to note that an almost similar intensity storm crossed the Orissa coast near Paradeep during 26-31 October 1971. Yet another interesting fact is during the last 109 years four severe cyclonic storms affected the Paradeep port in the post monsoon season and two of them occurred during October, [Sridharan & Muthuchami (2002)].

The tropical cyclone intensity and frequency globally does not seem to be linked with global warming of though over regional basins its impact could be noticed, [De & Joshi (1999)].

Floods and Droughts

Floods and droughts over India are the two aspects of the weather associated with the abundance or deficit of monsoon rains. A large number of studies are available on various aspects of floods and droughts. A study by Chowdhury, Dandekar & Raut (1989) have ranked the year 1918 as the worst drought year of the last century – a year when about 68.7% of the total area of the country was affected by drought. It is of interest to note that the year 1917 had exceptionally high seasonal rainfall (Table 5). Likewise the severe drought years of 1877 and 1987 were followed by flood

Table 3. Major cyclones of India and neighbourhood

Year	Name of the country	No. of deaths	Storms surge (Height, in ft.)
1737	Hoogli, West Bengal (India)	3,00,000	40'
1876	Bakerganj (Bangladesh)	2,50,000	10'-40'
1885	False point (Orissa)	5,000	22'
1960	Bangladesh	5,490	19"
1961	Bangladesh	11,468	16'
1970	Bangladesh	2,00,000	13'-17'
1971	Paradeep, Orissa (India)	10,000	7'-20'
1977	Chirala, Andhra Pradesh (India)	10,000	16'-18"
1990	Andhra Pradesh (India)	990	13'-17"
1991	Bangladesh	1,38,000	7'-20'
1998	Porbander cyclone	1173	
1999	Paradeep, Orissa (India)	9,885	30'

years of 1878 and 1988. In the 19th century the droughts of 1877 and 1899 followed by the early droughts of the twentieth century. In the last century the drought of 1987 and 1972 are the next in order of severity. Occurrence in drought of consecutive years have been reported in 1904-05, 1951-52, 1965-66. These pair of years were associated with moderate droughts, where at least 25% of the country was affected. During 1999, 2000 and 2001 drought conditions prevailed over some parts of India, not affecting the country as a whole significantly.

During 2002 twelve out of 36 subdivisions of the country came under the grip of moderate to severe drought when abut 29% of the total area of the country was affected by drought. The seasonal rainfall departure (%) for west Rajasthan and east Rajasthan were –71 and –60 respectively. The seasonal rainfall during the summer monsoon in the country as a whole was 19 percent below normal qualifying 2002 as the first all-India drought since 1987. Rainfall deficits during July were most noteworthy, at a historical low of 51 per cent below normal. Remarkable recovery in rainfall occurred in August, which prevented the situation becoming worse (WMO 2003). However, the El-Nino episode that developed during 2002 was significantly smaller than 1997 / 1998 event.

Of all the major natural disasters, droughts account for nearly 22% of significant damages though the number of deaths is only 3% world wide (De & Joshi 1998). The occurrence of droughts during the summer monsoon season during nineteenth century led to the attempts by Blandford, the then Chief of the Indian Meteorological Service, in seasonal forecasting. The first long range forecast issued by Blanford in 1886 was based on the inverse relationship between the Himalayan snowfall during early spring and the subsequent Indian Summer Monsoon (ISM) rainfall during June to September. Repeated failure of monsoon during the beginning of the twentieth century led to introduction of multiple regression techniques in 1906, by Sir Gilbert Walker for long range forecasting of ISM rainfall. This technique used several regional and global parameters which were statistically correlated to ISM.

A comprehensive analysis of Monsoonal Droughts by Sikka (1999) has brought out several interesting facts. First the occurrence of drought on All India scale shows an epochal nature. During the years 1921 to 1964 there were only two moderate droughts in the year 1941 and 1951. Droughts were more frequent during the epochs 1890 to 1920 and from 1960 to 1990. During the last 125 years phenomenal droughts on the All India scale were only four. These years were 1877, 1899, 1918 and 1972 when the seasonal rainfall deficiencies were more than -26% below the seasonal mean rainfall. Recently Sinha Ray & Shewale (2001) studied the probability of drought on sub-divisional scale. The frequency of droughts were generally high over western and central India and northern peninsula.

The droughts during early years of twentieth century were associated with considerable losses of property and life. During 1877, 1899, 1918 the occurrence of famine and scarcity conditions prevailed resulting in deaths of thousands of persons. Later better distribution system and buffer food stock have gone a long way in reducing the adverse effects of drought. Table 4 gives the ten worst droughts that affected India. In recent years, management of drought

Table 4. Year of Drought in India

Year	Area affected ($X10^6$sq.km)	% area of the country affected	Dl value	Category
1918	2.16	68.7	3.64	Calamitous
1877	2.03	64.7	3.38	Calamitous
1899	1.99	63.4	3.31	Calamitous
1987	1.55	49.2	2.37	Severe
1972	1.39	44.4	2.05	Severe
1965	1.35	42.9	1.95	Moderate
1979	1.24	39.4	1.72	Moderate
1920	1.22	38.8	1.69	Moderate
1891	1.15	36.7	1.54	Moderate
1905	1.09	34.7	1.41	Moderate

Table 5. Flood years and their category

Year	Area affected ($X10^6$sq.km)	% of the area affected	MFI value	Category
1961	1.795	57.166	3.614	Exceptional
1917	1.427	45.446	2.668	Exceptional
1878	1.513	48.185	2.889	Exceptional
1975	1.268	40,382	2.260	Exceptional
1884	1.175	37.420	2.021	Exceptional
1892	1.162	37.006	1.987	Exceptional
1933	1.145	36.465	1.943	Exceptional
1959	1.135	36.146	1.918	Exceptional
1983	1.030	32.803	1.648	Exceptional
1916	1.025	32.604	1.635	Exceptional

has been quite systematic and mitigation measures taken in 1982 and 1987 have saved many lives from being lost. The estimated loss of crops and live stock in the country in 1982 were Rs. 5,000 crores while in 1987 these were Rs. 110 crores respectively. The difference in yield during these drought years as compared to the succeeding year a non-drought year viz : 1982 - 83 and 1987-88 were about 218.18 lakhs of tones and about 266.81 lakhs of tones respectively.

On the other hand floods have affected India with almost an equal frequency of droughts. Chowdhury & Mhasawade (1991) have studied the floods and ranked them. Their classification is shown in Table 5 giving ten worst flood years. Ramaswamy (1987) has catalogued some severe floods for the period 1923-1979. These flood events are discussed below alongwith some of the recent events.

(i) Floods in Upper Ganga and Yamuna in October 1924 caused serious damage to Uttar Pradesh and Punjab affecting 13,080 sq. km. of area. About 1100 persons and one lakh cattles were drowned and 242,400 houses were washed away.

(ii) In July 1943, 50 inches of rain in one day was recorded on the hills of Mewar and Merwara. Unprecedented flood in Ajmer and Merwara devastated 50 villages and took a toll of 5000 lives. A small industrial town Vijainagar with population 7000 lost more than half of its inhabitants.

(iii) A catastrophic flood to Yamuna in October 1955 damaged cash crops worth Rs. 35 crores. Total death toll was estimated to about 1500. The rising waters of Yamuna reached record level on 8 October 1955. About 7000 villages inundated.

(iv) Floods of Tista - Brahmaputra in October 1968 took a toll of 2700 human lives and 59,300 cattle heads in Darjeeling and Jalpaiguri. The total direct damage to engineering structures of railways was estimated to worth Rs. 4 crores and total flood damage estimated to worth 26 crores.

(v) Floods of November 1977 affected Tamil Nadu killing 500 persons. Most affected districts were Madurai, Tiruchirapalli and Pudukottai. Crop damage worth Rs. 42 crores and damage to private and public property worth Rs. 155 crores was reported.

(vi) Severe floods occurred to Godavari and Tungabhadra rivers in the 4th week of August 2000. In Andhra Pradesh alone 131 persons died, 5368 cattle lost, and 98,000 people became homeless. About 500 irrigation dams breached. Hyderabad city was flooded and many areas were under 3 meter water deep. 902 power transformers, 787 distribution transformers and 28 electric substations were damaged. 58 power stations completely flooded causing total darkness in various areas. Communication on 412 roads cut off. Crops on 1.77 lakh hectares destroyed. Total loss of property and agriculture was reported to be hundreds of cores (DWE 2000).

(vii) During July 2003 severe floods occurred to Brahmaputra and its tributaries. In Assam state alone, 38 persons died. 52,35,092 people in 4962 villages were affected. Standing crops in 2,13,184 hectares of land were badly affected. 3,635 houses fully and 1,015 houses were partially damaged (DWE 2003).

A study by Bhalme & Mooley (1980) using spectral analysis technique has found a 2.8 year cycle related to QBO and weak signal of 20 years related to double sun spot number. Sarkar (1988) noted that the intense El-Nino episodes have concurrent relationship with deficient rainfall on 60% occasions.

A recent study by Khole & De (2000) have shown that during the period 1870 - 1990, there were 11 drought years which were associated with warm ENSO events, while there were 10 droughts which were not associated with warm ENSO events. The authors defined a year with normalized rainfall departure greater than + 1 as a flood year and normalized rainfall departure less than - 1 as a drought year. Flood years on 8 occasions were associated with cold ENSO events and on 9 occasions were not associated with cold ENSO events. Though the floods and droughts were almost evenly distributed in respect of warm and cold ENSO events, yet, warm (cold) ENSO events were rarely associated with above (below) normal departures.

Most severe floods in Indian rivers in recent years

Nearly 40 million hectare of India is flood prone and every year nearly 8 million hectares of land is affected by floods. Flood producing storms have been studied from a hydrological point of view (IITM 1994). Isohytel maps of individual rain storms dating back to 1880 have been prepared. The list of major rainstorms compiled by them consists of all such rain producing systems which were associated with extensive damage and huge depth of flood waters submerging vast areas. The list contain 15 major rain storms from 1880 to present times. In addition extensive floods occurred during 1988 and 1994 and the year 2000. Table 6 gives the list with brief description of damage. A list of severe floods in Indian rivers when flood levels were 10 m and above their respective danger levels is given in Table 7.

Extreme rainfall events have also been studied by several authors in India. These events, though, records of a sort, were not generally associated with large floods. These are shown in Table 8. The data

Table 6. Major Rainstorms in India

S.No.	Date	Area	Casualty & damage
1.	17-18 Sept. 1880	NW Uttar Pradesh	150 persons lost their lives.
2.	20-22 Sept. 1900	West Bengal	60-80 cm. rain during 20-22 Sept. causing severe flooding of Damodar.
3.	19-21 Sept. 1926	Madhya Pradesh	Severe flooding of Narmada and Mahanadi. Worst affected districts Mandla and Hoshangabad.
4.	26-28 July 1927	Gujarat	Flood water rose to about 7 m. high in Sabarmati river.
5.	28-30 July 1927	Orissa	i) Severe flooding of Baitarni, water rose to height of 21 m. at Akhyapada. ii) Cuttak town cut off from rest of the country for 7 days.
6.	01-03 July 1930	Maharashtra	Damage to Agriculture and property was extensive.
7.	01-03 July 1941	South Gujarat and North Konkan	Severe flooding in Tapi,
8.	17-19 May 1943	Tamil Nadu	Very heavy rainfall in Madras. Worst affected district South Arcot.
9.	03-05 Oct. 1955	Punjab	Thousands of people evacuated due to severe flooding in rivers of Uttar Pradesh and Punjab. Near Delhi, flood water rose to danger level. Death toll was about 1500.
10.	01-03 Oct. 1961	Bihar	Extensive damage to agriculture and property.
11.	28-30 Sept. 1964	Karnataka	Vijaywada town was under 3 m. deep water.
12.	13-15 July 1965	Andhra Pradesh	Severe flooding over Nizamabad district.
13.	10-12 Aug. 1979	Saurashtra and Kutch	Severe flooding due to incessant rain over Rajkot. Morvi town worst affected.
14.	18-20 July 1981	Rajasthan	Abnormally heavy rain caused flooding in Jaipur, Tonk, Nagaur and Sawai Madhopur. Extensive damage to property and loss of lives reported.
15.	28-30 Aug. 1982	Orissa	Severe flooding to Mahanadi. Considerable damage to crops, property and loss of lives reported.
16.	July to Aug. 1st week 1988	i) Andhra Pradesh	109 people died. Paddy crop in 3 lakh hectares completely damaged.
	Aug. 3rd week to Sept. 1988	ii) Assam	167 persons died. Standing Ahu, Sali and paddy crops in 25,000 hectares damaged.
17.	June 1st & 2nd week 1994 and 14-16 July 1994	Kerala	209 human lives lost. Crop worth Rs. 144.500 crores damaged. Public utility worth Rs. 105 crores damaged.
18.	26 to 28 Aug. 2000	Andhra Pradesh Hyderabad	131 persons died. Hyderabad flooded. Many areas under 3 metre of water. Paddy, chilly crop worth hundreds of crores damaged.

Source : Severe Rainstorms of India, IITM, Pune publication

Table 7. Major Cyclones over North Indian Ocean

Year	Area affected (Maximum wind speed)	Damage / No. of deaths	Storm surge (Height in ft.) wherever observed or estimated
1920 (6-14) Jun.)	Veraval (153 kmph)	Rs. 32 lakhs / 7700 cattle perished	-
1927 (29 Oct. – 3 Nov.)	Nellore (79 kmph)	300 human lives lost. 6000 cattle perished.	-
1940 (9-20 Oct.)	Colaba (121 kmph)	Rs. 25 lakhs / heavy loss of life.	-
1942 (14-18 Oct.)	Midnapore (109 kmph)	Several lakhs of rupees / 19,000 human lives lost. 60,000 cattle perished	-
1948 (15-23 Nov.)	Bombay (151 kmph)	Several lakhs of rupees / heavy loss of life	
1949 (23-23 Oct.)	Masulipatnam (130 kmph)	Several crores of rupees / 750 lives lost, 30,000 cattle perished	-
1952 (26 Nov. – 1 Dec.)	Nagapatinam (241 kmph)	22,000 acres of fertile paddy damaged. Total loss exceeded Rs. 6 crores. 400 lives lost, 30,000 cattle perished.	-
1960	Bangladesh	5,490 lives lost	19′
1961	Bangladesh	11,468 lives lost	16′
1964 (17-24 Dec.)	Rameshwaram (119 kmph)	Rs. 8 crores / 509 persons died.	-
1967 (8-12 Oct.)	Orissa (157 kmph)	1100 lives lost, 50,000 cattle perished	-
1970 (8-13 Nov.)	Bangladesh (185 kmph)	Crop damage Rs. 47 crores / 2,00,000 persons died, 2,00,000 cattle perished.	13 ‘ – 17′
1971	Paradeep, Orissa	10,000 lives lost	7′ – 20′
1977	Chirala, Andhra Pradesh (200 kmph)	Damage worth Rs. 350 crores / 10,000 lives lost	16′ – 18′
1990	Andhra Pradesh	990 lives lost	13′ – 17′
1991	Bangladesh	1,38,000 lives lost	7′ – 20′
1998 (4-10 Jun)	Porbandar	1173 lives lost	-
1999	Paradeep, Orissa	Damage to crops over 1 lakh hectare of land / 9,885 lives lost	30′

Table 7. Most Severe Floods (in recent years) of Indian Rivers
[When flood levels were 10 meters or more above their respective Danger Levels (DL)]

Sr. No.	River	Site	State from DL	Deviation	Date
1.	Manas	Nh Crossing	Assam	11.03	13/7/84
2.	Chambal	Dholpur	Rajasthan	14.21	25/8/82
3.	Mahi	a) Dam Axis b) Vasaol	Gujarat	11.80 12.79	8/9/73 8/9/73
4.	Teesta	a) Snderson Bridge b) Coronation Bridge	West Bengal	18.10	4/10/68 ? /10/68
5.	Narmada	Garudeshwar	Gujarat	17.87	6/9/70
6.	Tapi	Burhanpur	Madhya Pradesh	11.08	? / ? / 68

Source : "Floods in the Indian Rivers and their Meteorological Aspects", O.N. Dhar & Shobha Nandargi, Memoir Geological Society of India, No. 41, 1998, pp. 1-25.

Stations in India which recorded ^{3} 75 cms of rainfall in one day (1875-1990)

Station	State	Rainfall (in cms)	Date
Bano	Bihar	81	13-9-1959
B. Ragamandala	Karnataka	84	25-7-1924
Cherrapunji	Meghalaya	104	14-6-1976
Drampur	Uttar Pradesh	77	18-9-1880
Dharampur	Gujarat	99	2-7-1941
Harnai	Maharashtra	80	5-8-1968
Jowai	Meghalaya	102	11-9-1877
Mawasynram	Meghalaya	99	10-7-1952
Naginor	Uttar Pradesh	82	18-9-1880
Navasari	Gujarat	78	2-7-1991
Purnea	Bihar	90	13-9-1879
Quilandy	Kerala	91	28-5-1961
Rewa	Madhya Pradesh	77	16-6-1882

Source : "Rainfall magnitudes that have not been exceeded in India", O.N. Dhar & Shobha Nandargi, Weather (UK), Vol. 53, No. 5, (May 1998), pp. 145-150.

are taken from a study by Dhar and Nandargi (1998). These events are occasions of one-day rainfall in excess of 75 cms. However, it is worthy of mention that the rainstorm of September 17-18, 1880 and 1 to 3 July 1941, India caused heaviest rain depths for different standard areas which have surpassed the rain depths caused by tropical storms in USA and Australia, Dhar & Mandal (1981), and Dhar & Nandargi (1998).

Landslides associated with heavy rains in Mumbai during July 2000 killing seventy persons and water logging and intense floods of Hyderabad in August 2000 are examples of urban development and its vulnerability to floods.

Droughts directly damage crops and degrade the land and desiccate the underground reservoir. Malnutrition and starvation are other impacts. Repeated droughts may lead to desertification. Floods are responsible for deaths due to spread of water-borne diseases apart from losses of crops production, landslides and damage to buildings and installations.

Present Status

The influence of weather and climate on human well being, and the inherent impact on the environment are well known. If we know the status of the climate today and the differences between this and recent past, we can begin to plan for the future. The variability attributable to national climate processes and phenomena such as the El-Nino / Southern Oscillations as well as to the effects of a warming climate that has a significant anthropogenic component, results in numerous weather and climate related disasters each year. Tropical cyclones caused loss of life and property in various parts of the world. Droughts affected the livelihood of many people. Heat waves / cold waves and associated weather phenomena caused several deaths. In France, Italy, the Netherlands, Portugal, Spain and United Kingdom over 21,000 additional deaths were related to the unrelenting heat wave of 2003 (WMO 2004).

Intergovernmental Panel on climate Change (IPCC) in its report released in January 2001, has concluded that most of the warming observed over the last 50 years is attributable to human activities (especially emissions of heat trapping gases from fossil fuels which is lively to double the risks). Further, deforestation, urbanization, industrialization, increase in automobiles, etc. add to the fury. These changes are having a lot of influence on meteorological parameters. Rao, Jaswal & Kumar (2004) studied the effects of urbanization on meteorological parameters over fifteen cities (with a population of more than one million) and concluded that in general bright sunshine hours, wind speed, total cloud amount and radiation values were showing a decreasing trend while relative humidity and rainfall had an increasing trend.

CONCLUSIONS

A study made by Ugnar (1999) has shown that losses due to extreme events are increasing steeply specially in the last decade of the twentieth century. Obassi (2001) has stated that in recent years the global loss of US $ 50-100 billion annually are caused due to these natural hazards together with the loss of life is about 2,50,000. However, these increased losses may be either due to a real increase in the frequency of the extreme weather events or due to increased vulnerability of cities, towns and the associated infrastructure and installations which have grown rapidly to meet the needs of a growing population.

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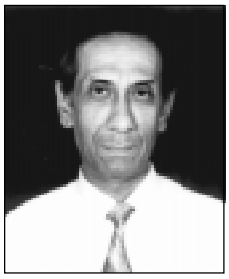

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