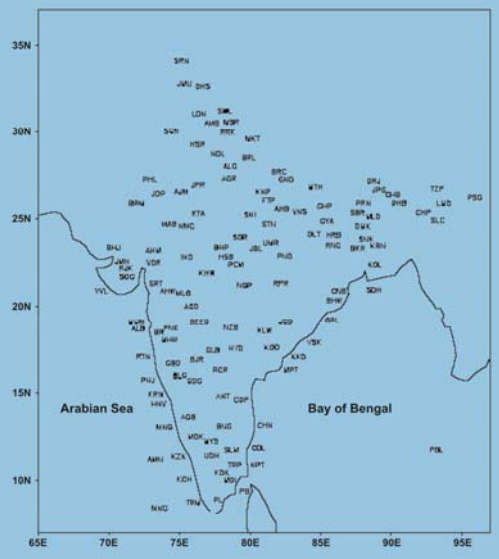
ISSN 0252-1075
Contribution from IITM
Research Report No. RR-123

Alarming Rise in the Number and Intensity of Extreme Point Rainfall Events over the Indian Region under Climate Change Scenario



R.M. Khaladkar, P.N. Mahajan
and
J.R. Kulkarni

August 2009

Indian Institute of Tropical Meteorology
Pune - 411 008, India

ISSN 0252-1075
Contribution from IITM
Research Report No. RR-123

Alarming Rise in the Number and Intensity of Extreme Point Rainfall Events over the Indian Region under Climate Change Scenario

R.M. Khaladkar, P.N. Mahajan
and
J.R. Kulkarni

AUGUST 2009

Indian Institute of Tropical Meteorology
Dr. Homi Bhabha Road, Pashan Pune - 411 008
Maharashtra, India

E-mail : lip@tropmet.res.in Fax : 91-020-25893825
Web : http://www.tropmet.res.in Telephone : 91-020-25904200

Contents

Alarming Rise in the Number and Intensity of Extreme Point Rainfall Events over the Indian Region under Climate Change Scenario

R.M. Khaladkar, P.N. Mahajan and J.R. Kulkarni

ABSTRACT

The rainfall is an important parameter for the well being of around 1000 million people of the Indian regions. However, certain extreme rainfall events occurring in different seasons cause disastrous situation over some parts. In view of this, we have scanned the daily rainfall data of 165 stations across the region to find out their extreme point rainfall events (highest 24-hour rainfall) and examined whether there is any change in the number and the intensity of such events during past four decades. The study reveals that their number has gone up considerably after 1960 with an alarming rise in the intensity thereafter. It is further noticed that the major cities, hill stations and the islands are affected with a heavy downpour. The conspicuous feature is that from the mid 90s, the regional as well as the world records were established over this part of the globe on different time scales. It is conjectured that these events may be associated with the global and the regional warming under the climate change scenario. In the event of their continuation, there would be severe impact on societal and environmental issues warranting appropriate precautionary measures in near future to safeguard the interest of the vast population of this region.

1. Introduction

India is fortunate to enjoy the heavy rainfall spells in all the seasons due to both tropical and extra-tropical weather systems. The summer or the southwest monsoon season (June-September) is the main rainy season contributing about 75-80 % of the annual rainfall. Although, the contributions from other seasons, viz. the winter (January-February), pre-monsoon (March-May) and the post or north-east monsoon (October-December) to all India rainfall are not very significant, they are quite important for the particular regions. Main weather systems which bring rainfall to the region are monsoon low pressure areas, depressions, thunderstorms, tropical cyclones, western disturbances etc. (Pant and Rupa Kumar, 1997). The typical orography of the region also influences the intensity and distribution of the rainfall.

In view of the paramount importance of the rainfall from economic, societal and scientific points, extensive work has been carried out over the years on its various facets like trends, disaster events, spatio-temporal variability, seasonal contributions etc. (e.g. Sinha Ray and De, 2003; Sen Roy and Balling, 2004; Francis and Gadgil, 2006; Guhathakurta and Rajeevan, 2008). Goswami et al. (2006) used grid point data at 100 km resolution (Rajeevan et al., 2006) and demonstrated a significant increasing trend in the frequency and the magnitude of extreme monsoon rain events in central India over the past 50 years. These instances are attributed to the warming global surface (Goswami et al., 2006) and the tropical Indian ocean (Ajayamohan and Rao, 2008). The information of the peak rainfalls intensities at the stations is instrumental for the planning of urban development, disaster management and for studying the environmental aspects pertaining to water runoffs in the vicinity of the stations. Therefore, present study is carried out using the station data. The domain is whole of Indian region and all the seasons are considered.

2. Criterion for extreme point rainfall event

The rainfall of 10 cm/day may be an extreme for the northwest region, whereas it may not be a significant amount for the northeast region or along the west coast of India during summer monsoon. Even in summer monsoon season, west coast of India gets heavy rainfall spells in the first fortnight of June while the northern part of the country is devoid of the rainfall. Therefore for this study, the magnitude of extreme point rainfall event (EPRE) is not taken as a fixed threshold for all the stations but it is different for each station and varies according to the month. Considering the climatological data, the magnitude of the EPRE at the station is defined as its highest 24-hour rainfall reported in a particular month during the entire period of the data availability. Accordingly, it may increase for certain stations, if their previous EPRE are exceeded in the course of time. This definition is adopted in order to examine whether there was any change in the number and intensity of the EPRE in the recent decades and if so, which parts of the region are affected most.

3. Data and methodology

Total 165 stations well spread across the region with the data availability of at least 50 years up to 1980 are considered (Source : *Climatological Tables of Observatories in India: 1951-1980, IMD, 1999*). Only the cases with the minimum rainfall of 10 cm/day are taken into account to give weightage to the high rainfall values. The rainfall data after 1980 are compiled from different IMD publications.

The instances of EPRE at the stations are classified chronologically according to the decades. The high rainfall events occurred at the stations after 1980 are compared with those of the earlier period to assess whether the previous EPRE are exceeded in recent decades. Subsequently, the extreme rainfall events occurred on different time scales are also discussed in the paper.

4. Results

In order to compare the intensity of EPRE in different periods, three time slots are considered viz. (1) Period up to 1980 (2) 1981- 2000 and (3) 2001-2009.

Accordingly, the outcome of comparative study is briefly presented below.

4.1.1. Period up to 1980

The conspicuous feature is that most of stations have reported their highest 24-hour rainfall during 1961-1980. These stations are well spread across whole of the Indian region i.e. they are located in almost all the meteorological subdivisions of the India. The magnitudes of the EPRE recorded at some selected stations, the dates of the occurrence of these events and the data lengths of the stations are shown in Table 1. The locations of the stations (with abbreviated names) which recorded very high rainfall events are depicted in Figure 1 and the meteorological sub-divisions of India are shown in Figure 2. Just one or two stations from each sub-division are tabulated for brevity. The bold digits in the Table 1 indicate that the rainfall was the highest for all the months (all time record) while others are for the specific months. In case, any station has registered the EPRE for more than one month, only a case with the maximum rainfall is taken into account. Some of the major cities, hill stations and islands which have reported their highest 24-hour rainfall during 1961-1980 are listed below.

C*ities* : New Delhi, Mumbai, Chennai, Kolkata, Bangalore, Hyderabad, Panjim, Ahmedabad, Bhopal, Ranchi, Raipur, Dehradun, Thiruvanthapuram, Jaipur, Jammu, Pune, Nagpur, Kochi, Kanpur, Agra, Gaya, Madurai, Aligarh, Indore, Ludhiana.

Hill stations : Cherrapunji, Dalhousie, Darjeeling, Kalimpong, Kodaikanal, Mount Abu, Mussoorie, Mahabaleshwar, Panchmarhi**,** Shimla, Udhagamandalam (Ooty).

Islands : Amini Divi, Minicoy, Port Blair

It is evident from the Table 1 that the EPRE have occurred in all the seasons encompassing the entire region. A few significant cases of EPRE at stations in different locations are highlighted below.

- The highest 24-hour rainfall of India was reported on September 13, 1974 (98.55/cm) at Cherrapunji (Sohra), a hill station located in the NE India.
- Colaba observatory in Mumbai recorded 58 cm rainfall on July 5, 1974.
- Chennai (SE peninsula) received rainfall of 45 cm on November 25, 1976 as its highest ever recorded rainfall on a single day.
- Thiruvanathapuram (southwest peninsula) recorded 40 cm rainfall on October 18, 1964, as its all time record in 140 years.
- Mahabaleshwar (northwest peninsula) reported 44 cm during 1961-1980 as its record highest for all the months.
- Mount Abu (northwest India) reported 56 cm rainfall on September 19, 1973.
- Motihari (northeast India) recorded 46 cm rainfall as its highest in 93 years.
- Dehra Dun (north India) recorded 49 cm rainfall on July 25, 1966 as the highest rainfall for 100 years.
- The annual mean rainfall of Phalodi, (northwest India) is about 26 cm, but on July 12, 1964, it reported 23 cm rainfall in just 24 hours.

It is observed that out of 165 stations, 128 (77.6 %) reported their EPRE during the bi-decadal period 1961-1980. Further, 85 stations have recorded the rainfall ≥ 20 cm/day.

4.1.2. Period : 1981-2000

High rainfall instances reported at some stations during 1981-2000 are shown in Tables 2. Bold digits indicate the rainfall ≥ 40 cm/day. Some notable instances are described below.

- Cherrapunji recorded 156 cm rainfall on June 16, 1995 crossing its previous all time highest of 98.55 cm reported on September 13, 1974 (Table 1). It had also set a record for the northern hemisphere overtaking the earlier record held by Paishih (Taiwan) of 125 cm reported on September 10-11, 1963 (Randall et al., 2007). However, this Cherrapunji record was exceeded after ten years, as Isla Mujere (Mexico) got 163 cm rainfall on October 21-22, 2005 (http://wmo.asu.edu)**.** Still, it remains as a record for the Indian sub-continent.

- Bhira, a station on the windward side of the western ghats (northwest peninsula) got 71 cm rainfall on July 24, 1989 as its all time highest during the period data availability from 1932. The rainfall was associated with the passage of a depression moving towards northwest India.

- Beed in Marathwada, subdivision, reported its all time highest rainfall (32 cm) on July 24, 1989 under the influence of the same depression mentioned above.

- Santacruz (Mumbai) received 40 cm rainfall on June 10, 1991 exceeding its previous highest rainfall of 38 cm reported on July 5, 1974.

- Jodhpur (NW India) recorded 29 cm rainfall on August 5, 1996. It is noteworthy that its annual mean rainfall is about 36 cm.

- Rainfall of 49 cm on July 7, 1991 at Silchar (NE region) has crossed its previous all time highest (29 cm) recorded in 1893.

- Koida (SE peninsula) recorded 67 cm rainfall on June 17, 1996.

4.1.3. Period: 2001 – 2009

EPRE for this period from 2001 to July 2009 are depicted in Table 3. A few typical cases are highlighted below.

- Amini Divi recorded 117 cm rainfall on May 6, 2004 and created a record for the north Indian ocean. It was associated with a passage of a tropical cyclone. It is worthwhile to mention that this station recorded 184 cm rainfall during just three days viz. May 5-7, 2004 !

- Mumbai (Santacruz) experienced exceptionally heavy rainfall of 94 cm on July 27, 2005 (Table 3). Some other nearby stations also reported very high rainfall (e.g. Vihar lake : 105 cm) and the city was hit miserably due to unprecedented deluge. It was mainly due to the cloud burst and intense thunderstorm activity embedded in the monsoon circulation (Vaidya and Kulkarni, 2007). The peculiarity of this event was that the activity was highly localized to the northern part of the city as Colaba, just 25 km south of Santacruz reported only 7 cm rainfall on the same day.

- Ratnagiri, a coastal station about 230 km south of Mumbai recorded 64 cm rainfall on May 31, 2006 surpassing its previous all time highest (31 cm) recorded on June 30, 1953.

- Mahabaleshwar reported its all time highest 46 cm on 3 August 2004. However, it was also exceeded on 11 August 2008 with 49 cm rainfall.

- Veraval (Saurashtra and Kutch) reported 50 cm rainfall on 16 July 2009 surpassing its highest (36 cm) recorded in the previous decade i.e. on July 26, 1996 (Table 2).

4.2. Rainfall events exceeding 50 cm/day

Sixty nine stations which reported the rainfall ≥ 50 cm/day have been identified over the region for the period: 1875- 1990 (Dhar and Nandargi, 1998). Out of them, 45 cases have occurred up to 1960 (86 years) and 24 during 1961-90 (30 years). Afterwards, following stations (as per the data of the study) have joined this elite '**R50**' club.

Amini Divi, Koida, Malda, Kaleswaram, Motihari, Songadh, Ratnagiri, Poladpur (west coast), Vihar lake, Santacruz (and the stations around Mumbai which recorded very heavy rainfall on July 27, 2005), Veraval and Mangrol (Saurashtra and Kutch) recorded on 16 July 2009.

4.3. Surpassing of all India records

Mawsynram, a station (northeast India) recorded 98.96 cm rainfall on July 10, 1952. It was the record as the highest 24-hour rainfall over the India (Thapaliyal and Kulshrestha, 1992). During last 15 years, three stations viz. Cherrapunji, Amini Divi and Vihar lake have crossed this record. It is further noticed that five of the top seven rain events have occurred after 1970 (Table 4), indicating the rise in the intensity of EPRE in the recent times.

4.4. High rainfall spells on different time scales

The cases of extreme rain events for 24 hours are described above. There are some instances of very high rainfall reported from 1995 on different time scales. They are described below.

4.4.1. Short duration record rainfall

On June 16, 1995, Cherrapunji recorded 42 cm rainfall in just **one hour** exceeding the world record of 30.5 cm held earlier jointly by Holt, MO and Kilauea sugar plantation (Randall et al, 2007). During June 15-16, 1995, same station reported 249 cm rainfall (Pai and Guhathakurta, 2007), crossing **48-hour** world record of 247 cm of Aurere, La Reunion, occurred during January 8-10, 1958 (http://wmo.asu.edu).

4.4.2. Record rainfall over desert area

Extreme northwest region of India is a part of the Thar desert. It received record rainfall of 55 cm during August 16-25, 2006 i.e. just in 10 days **(**Jayanthi et al, 2006). More than 100 persons lost their lives, many animals died and lot of destruction was reported to the agriculture sector due to the floods.

4.4.3. Un-seasonal heavy rainfall instances

Chennai reported 21 cm rainfall during the last week of February 2000. Getting more than 20 cm rainfall in the last week of February is an event of the century for the city (Asokan and Nair, 2000). However, it was a blessing to the city dwellers as these un-seasonal rains relieved them from acute scarcity of the water caused by deficient rainfall during the NE monsoon season.

4.4.4. Excess rainfall on the seasonal and annual scale over a semi-arid location

Pune city situated on the leeward side of the western ghats, falls under the semi-arid or the rain-shadow zone with the mean annual rainfall about 72 cm as against about 250 cm on the windward side. During 2004-2007, it recorded more than 80 cm rainfall consecutively in four summer monsoons. It was significantly high as compared to the seasonal normal- 55 cm. In 2005 and 2006, the city reported 116 cm (134 cm) and 110 cm (127 cm) rainfall in the summer monsoon (calendar year) respectively crossing its earlier annual record 124 cm which was established in 1892.

4.4.5. Rainiest station in the world

Annual mean rainfall of Mawsynram is 1151 cm considering the data of past 66 years i.e. for the period : 1940-2005 (Pai and Guhathakurta, 2007). It is more than other two most rainy stations in the world viz. Waialeale, Hawaii, USA (1144 cm) and Cherrapunji (1115 cm).

5. Discussion of results

5.1. Rise in the number and intensity of ERPE in recent decades

The results presented in section 3 bring out that out 165 stations, the majority (77.6 %) have registered their EPRE during 1961-1980. Thereafter, several stations have reported the rainfall events surpassing the intensity of their previous highest rainfall. Some records were established on different time scales varying from hourly to the annual scales with the most of them noticed from 1995. Table 5 shows 20 stations where the previous EPRE have been exceeded after 1980. Many stations have experienced an alarming rise (40-370 %) in their intensity. These stations are located in north, northeast, northwest, central India and along the coastal zones.

5.2 Possible cause of rise in EPRE and their intensity in recent decades

It is a well established fact that the global average surface temperature has increased during last 150 years and eleven years of the recent time (1995-2006) were among the warmest years. The global land surface has warmed at the rate of 0.07° C per decade during the past century (Jones and Moberg, 2003). From the late 1950s, the rise is noticed in the lowest 8 km of the atmosphere. The details are available in the third assessment report (Houghton et al., 2001) of the Intergovernmental Panel on Climate Change (IPCC).

The studies over the Indian region indicate that all India mean annual surface temperature has increased by 0.05^{o} C per decade for the period 1901-2003 and the rise is steeper during last three decades i.e. at the rate of 0.22° C per decade (Kothawale and Rupa Kumar, 2005). Similarly, the tropospheric temperatures have also increased for last 3 decades with the rise of 0.3° C per decade from 1971 at 850 hPa level (Kothawale and Rupa Kumar, 2002). The sea surface temperature (SST) of the oceanic region around India has also gone up by 0.6^{o} C in 100 years and by about 0.15 ^{o} C per decade from 1971 (Kothawale et al., 2008).

The rise in SST causes more evaporation and the increase in the surface air temperature leads to deeper convection. Besides, the warming of upper levels enhances the moisture holding capacity of the atmosphere. As such, under this scenario, the weather systems like the thunderstorms, the depressions and the cyclonic storms etc. would have more potential for intense precipitation as compared to the cooler environment. Therefore, it is conjectured that the accelerated warming during last three decades and the warmest period of recent 11 years, could be the major cause for the increase in the extreme rainfall spells during past four decades with the sharp rise their intensity after the mid 1990s.

Although, the climate models have certain uncertainties and the atmospheric processes are not well understood, it may be mentioned that some model projections show that current rise in incidence of hot summers is likely to continue in the northern hemisphere (e.g. Jones et al., 2008). During next two decades, warming about 0.1^{o}-0.2^{o} C per decade is expected to take place due to green house gases emissions (Houghton et.al., 2001). The extremes in the temperature (Rupa Kumar et al., 2006; Soloman et al., 2007) and the intensity of heavy rainfall events (May, 2004) may increase in the future over the Indian region. In the light of these studies, under climate change scenario, it is quite likely that the steep rise in the instances of EPRE may continue in coming decades.

6. Conclusions

A study of 165 stations across the Indian region with a long data series, shows that majority of them have reported their highest 24-hour rainfall during 1961-1980 with an alarming rise in their intensity thereafter. Record rainfall events on different time scales (hourly to annual) have also taken place in the recent decades. The instances of EPRE have mainly affected the regions on NW, NE, central India, the coastal zones and the hill stations. These events may be associated with the global and the regional warming signaling the effect of the climate change over the region. Therefore, if the trend of the global warming continues, the EPRE also may continue to occur in the future. They would pose serious problems in some parts due to their adverse impact on the socio-economic issues like the damage to life and the property. Such spells, especially at the hill stations would result in the environmental degradation due to soil erosion, river silting, landslides etc. In view of these points, it is imperative that proper care need be exercised in near future for the work of town planning, disasters management and the environmental protection for the sustainable development of the human beings over the Indian region.

Acknowledgements

Authors are grateful to Prof. B.N. Goswami, Director, IITM, for the support to carry out this study. Thanks are due to Dr. S.G. Narkhedkar, Dr. D.R. Kothawale for useful suggestions and Dr. A.A. Munot for a critically reviewing of the manuscript and offering valuable comments.

References

Ajaymohan RS and Rao SA. (2008). Indian ocean dipole modulates the number of extreme rainfall events over India in a warming environment, *Jr. Met. Soc. Japan,* **86**: 245-252.

Asokan R, Nair EKNK (2000). Unusual heavy rainfall over Chennai during the last week of February 2000, *Vayu Mandal*, Indian Met. Society **30**: 56-63.

Dhar ON, Nandargi S. (1998). Rainfall magnitudes that have not been exceed in India, *Weather,* **53** : 145-151.

Francis PA., Gadgil S. (2006). Intense rainfall events over the west coast of India, *Met. & Atmosp. Phys.,* **94** : 27-45.

Goswami BN, Venugopal VD, Sengupta D, Madhusudan MS, Xavier PK. (2006). Increasing trend of extreme rain events over India in a warming environment, S*cience,* **314** : 1442-1445.

Guhathakurta P, Rajeevan M. (2006). Trends in the rainfall pattern over India, *Int. Jr.Climato.***28:** 1453-1469, DOI: 10.1002/joc.1640.

Houghton JT. *et al*., Eds. (2001). Climate Change 2001 : The Scientific Basis, Cambridge Univ. Press, Third Assessment Report, IPCC, 881.

Jayanthi N, Rajeevan, M, Srivastava AK, Devi S, Roy Bhowmik SK, Hatwar HR., (2006). Monsoon 2006 -A Report, *IMD Met Monograph* **4:** 103.

Jones GS, Scott PA, Christidis N. (2008). Human contribution to rapidly increasing frequency of very warm Northern Hemisphere summers, *Jr. of Geophysical Res.,* **113 :** D02109, doi:10.1029/2007JD008914.

Jones PD, Moberg A.(2003). Hemispheric and large-scale surface air temperature variations : An extensive revision and update to 2001, *Jr. of Climate*,**16:** 206- 223.

Kothawale DR, Rupa Kumar K. (2002). Tropospheric temperature variation over India and links with the Indian summer monsoon : 1971-2000, *Mausam* **53**: 289- 308.

Kothawale DR, Rupa Kumar K. (2005). On the recent changes in surface Temperature, *Geophysical Res. Lett.,* **32 :** 2005.L18714, doi:10.1029/2005GL023528.

Kothawale DR, Munot AA, H.P. Borgaonkar HP. (2008). Temperature variability over Indian ocean and its relationship with Indian summer monsoon rainfall, *Theor. & App. Climato.,* **92**: 31-45.

May W. (2004), Simulation of the variability and extremes of daily rainfall during the Indian summer monsoon for present and future times in a global time-slice Experiment, *Climate Dynamics* **22 :** 183-204, DOI 10.1007/s00382-003-0373-x.

Pai DS, Guhathakurta P. (2007). Cherrapunji & Mawsynram : Wettest Places on the Earth, *Bull. Indian Met. Soc, Pune,* XII, 15 -16.

Pant GB, Rupa Kumar K. (1997). *Climates of south Asia*, Eds. J. Wiley and Sons, Chichester, 320P.

Rajeevan, M., Bhate, J., Kale, J. D. and Lal, B. (2006), High resolution daily gridded rainfall data for the Indian region: analysis of break and active monsoon spells, *Current Science*, **91**, 296–306.

Randall SC, Lawrimore J, Edwards R, Landsea C. 2007. Extreme weather records - Compilation, Adjudication, and Publication, *Bull. Amer. Met. Soc.* **88** : 853-860.

Rupa Kumar K., Sahai AK, Krishna Kumar K, Patwardhan SK, Mishra PK, Revadekar JV, Kamala K, Pant GB. (2006), High resolution climate change scenarios for India for the 21st century, *Current Science,* **90** : 334-345.

Sen Roy S., Balling RC (Jr.). 2004. Trends in extreme daily precipitation indices in India, *Int. Jr. Climato.,* **24:** 457-466.

Sinha Ray KC, De US. 2003. Climate change in India as evidenced from instrumental records, *WMO Bulletin.,* **52 :** 53 -59.

Soloman et. al. 2007. Eds., Climate Change (2007): The Physical Science Basis. Cambridge Univ. Press, Cambridge, Fourth Assessment Report, IPCC.

Thapliyal V, Kulshreshtha SM. (1992), Which is the rainiest place in the world? *Mausam* **43:** 331-332.

Vaidya SS, Kulkarni JR.(2007). Simulation of heavy precipitation over Santacruz, Mumbai on 26 July2005, using mesoscale model, *Met. & Atmos. Phys.,* **98**: doi: 10.1007/800703-006-0233-4.

Table 1 : Extreme point rainfall events at the stations during 1961-1980.

Station	Met. Subdivision	Data length (years)	Rainfall (cm)	Date of spell
Ahmedabad	Gujarat	85	25	Aug. 30, 76
Ajmer	E. Rajasthan	100	**29**	July 16, 79
Aligarh	W. U. Pradesh	117	22	Sept. 26, 64
Amini Divi[i]	Lakshadweep	85	**25**	Nov. 21, 77
Bahraich	E. U. Pradesh	85	**38**	Aug. 20, 69
Bhuj	Sau. & Kutch	99	24	Aug. 12, 79
Chapra	Bihar	60	**24**	Oct. 05, 77
Chennai[c]	Tamilnadu	100	**45**	Nov. 25, 76
Cherrapunji[h]	Assam& Megh.	74	**99**	Sept. 13, 74
Colaba [c]	Konkan & Goa	100	**58**	July 05, 74
Dalhousie[h]	Himachal Pra.	113	**41**	Sept. 09, 66
Dehra Dun	Uttarakhand	100	**49**	July 25, 66
Dumka	Jharkhand	94	**30**	Sept. 27,78
Gulbarga	N. Int. Karna.	89	28	Sept. 23, 67
Hoshangabad	W. M. Pradesh	100	**30**	July 28, 65
Jalpaiguri	S.H. W. Bengal	95	26	May 14, 75
Jammu	Jammu& Kash.	59	30	July 31, 61
Kolkata	Gang. W. Bengal	100	**37**	Sept. 28, 78
Ludhiana	Punjab	100	25	July 30, 80
Machilipatnam[c]	Coastal Andhra	100	46	Nov. 06,68
Mahabaleshwar[h]	Madhya Maha.	100	**44**	July 07, 77
Malda	S.H. W. Bengal.	63	**24**	Oct. 01, 71
Mangalore[c]	Coast. Karnataka	100	27	June 22, 75
Motihari	Bihar	93	**46**	July 23, 77
Mount Abu[h]	East Rajasthan	98	**56**	Sept 19, 73
Nagpur	Vidarbha	100	22	Aug. 04, 79
Palayamkottai	Tamilnadu	111	**29**	Jan. 09, 63
Panjim[c]	Konkan & Goa	80	23	May 22, 61
Passighat	Arunachal Prad.	54	41	June 19, 74
Phalodi	West Rajasthan	91	**23**	July 12, 64
Port Blair[i]	Andaman & Nic.	100	**37**	Dec. 31, 76
Raipur	Chattisgarh	100	23	July 02, 70
Sagar	W. Madhya Prad.	99	**38**	July 13, 73
Sambalpur	Orissa	99	22	Sept. 02, 61
Sandheads[i]	Gang. W. Bengal	70	**37**	July 14, 72
Silchar	Assam & Megha.	93	23	June 20, 72
Tiruvanathapuram[c]	Kerala	140	**40**	Oct. 18, 64
Udhagmandalam[h]	Tamilnadu	67	**33**	Nov. 05,78

Notes : (1) Bold digit indicates the highest rainfall for all the months.
(2) Superscripts [h, i] and [c] indicate a hill station, an island and a coastal station resp.

Table 2 : High rainfall events during 1981-2000

Station	Met. Subdivision	Rainfall (cm)	Date of occurrence
Ahwa	Gujarat	**46**	Aug. 01, 1997
Amraoti	Vidarbha	28	July 23, 1986
Amini Divi	Lakshwadweep	31	June 12, 1992
Bahraich	E. Uttar Pradesh	**56**	Sept. 07, 1984
Beed	Marathwada	35	July 24, 1989
Bhira	Konkan & Goa	**71**	July 24, 1989
Bhubaneswar	Orissa	**43**	Oct. 30, 1999
Chapra	Bihar	37	Aug. 16, 1995
Chennai	Tamilnadu	29	Feb. 17, 1984
Cherrapunji	Assam & Megha.	**156**	June 16, 1995
Hoshangabad	W. Madhya Pra.	32	Aug. 20, 1983
Jalpaiguri	SH W. Bengal	**47**	July 10, 1999
Jodhpur	W. Rajasthan	29	Aug. 05, 1996
Kakinada	Coastal Andhra Pr.	**40**	Sept. 29, 1997
Karwar	Coastal Karnataka	**47**	June 12, 1999
Koida	Telengana	**67**	June 17, 1996
Malda	SH W. Bengal	**57**	Sept. 28, 1995
Passighat	Arunachal Pradesh	**48**	Aug. 22, 1988
Sambalpur	Orissa	**58**	Aug. 19, 1982
Santacruz	Konkan & Goa	**40**	June 10, 1991
Silchar	Assam & Megh.	**49**	July 07, 1991
Veraval	Saurashtra & Kutch	36	July 26, 1996

Note : Bold digits indicate the rainfall ≥ 40 cm/day

Table 3 : High rainfall events during 2001-2009

Station	Sub-division	Rainfall (cm)	Date of occurrence
Ambala	Haryana C. & Delhi	34	Aug. 03, 2004
Amini Divi	Lakshawadweep	**117**	May 06, 2004
Hoshangabad	W. Madhya Pradesh	38	Aug. 14, 2006
Kaleswaram	Telengana	**63**	Aug. 04, 2006
Mahabaleshwar	M. Maharashtra	**49**	Aug. 11, 2008
Motihari	Bihar	**52**	July 25, 2005
Ramanathapuram	Tamilnadu	35	Dec. 11, 2005
Ratnagiri	Konkan & Goa	**64**	May 31, 2006
Sagar	W. Madhya Pradesh	**48**	April 07, 2005
Santacruz (Mumbai)	Konkan & Goa	**94**	July, 27, 2005
Songadh	Gujarat	**55**	June 29, 2005
Veraval	Saurashtra & Kutch	**50**	July 16,2009
Vihar lake (Mumbai)	Konkan & Goa	**105**	July, 27, 2005

Note : Bold digits indicate the rainfall ≥ 40 cm/day

Table 4 : Top point rainfall events over the region

No.	Station	Rainfall (cm)	Date of occurrence
1	Cherrapunji	156.3	June 16, 1995
2	Amini Divi	116.8	May 06, 2004
3	Vihar lake (Mumbai)	104.9	July 27, 2005
4	Mawsynram	98.96	July 10, 1952
5	Dharampur	98.7	July 02, 1941
6	Cherrapunji	98.55	Sept. 13, 1974
7	Santacruz	94.4	July 27, 2005

Table 5 : Comparison of magnitudes of EPRE before and after 1980 (cm)

No.	Station	EPRE up to 1980 (Date of occurrence)	Instances of crossing the previous EPRE after 1980 (Date)
1	Ambala	23 (Aug. 10, 1896)	34 (Aug. 03, 2004)
2	Amini Divi	25 (Nov. 21, 77)	117 (May 06, 2004)
3	Bahraich	39 (Aug. 20, 1969)	56 (Sept. 07, 1984)
4	Beed	17 (Aug. 10, 1970)	35 (July 24, 1989)
5	Bhira	43 (June 29, 1967)	71(July 24, 1984)
6	Bhubaneswar	28 (July 30, 1969)	43 (Oct. 30, 1999)
7	Chapra	31 (Sept. 15, 1921)	37(Aug. 16, 1995)
8	Cherrapunji	99 (Sept. 13, 74)	156 (June 16, 1995)
9	Hoshangabad	30 (July 29, 1965)	38 (Aug. 14, 2006)
10	Jaipur	19 (Aug. 16, 1959)	22 (July 19,1981)
11	Jalpaiguri	39 (July 8, 1892)	47 (July 10, 1999)
12	Malda	24 (Oct. 1, 1971)	57 (Sept. 28, 1995)
13	Malegaon	16 (July 26, 1896)	29 (Oct. 11, 2001)
14	Motihari	46 (July 23,1977)	52 (July 25, 2005)
15	Ratnagiri	31 (June 30,1953)	64 (May 31, 2006)
16	Sagar	38 (July 13, 1973)	48 (April 07, 2005)
17	Sambalpur	40 (July 20, 1889)	58 (Aug. 19, 1982)
18	Sandheads	37 (July 14, 1972)	51(June 12,1981)
19	Santacruz	38 (July 05, 1974)	94 (July 27,2005)
20	Silchar	29 (May 30, 1893)	47 (July 07, 1991)

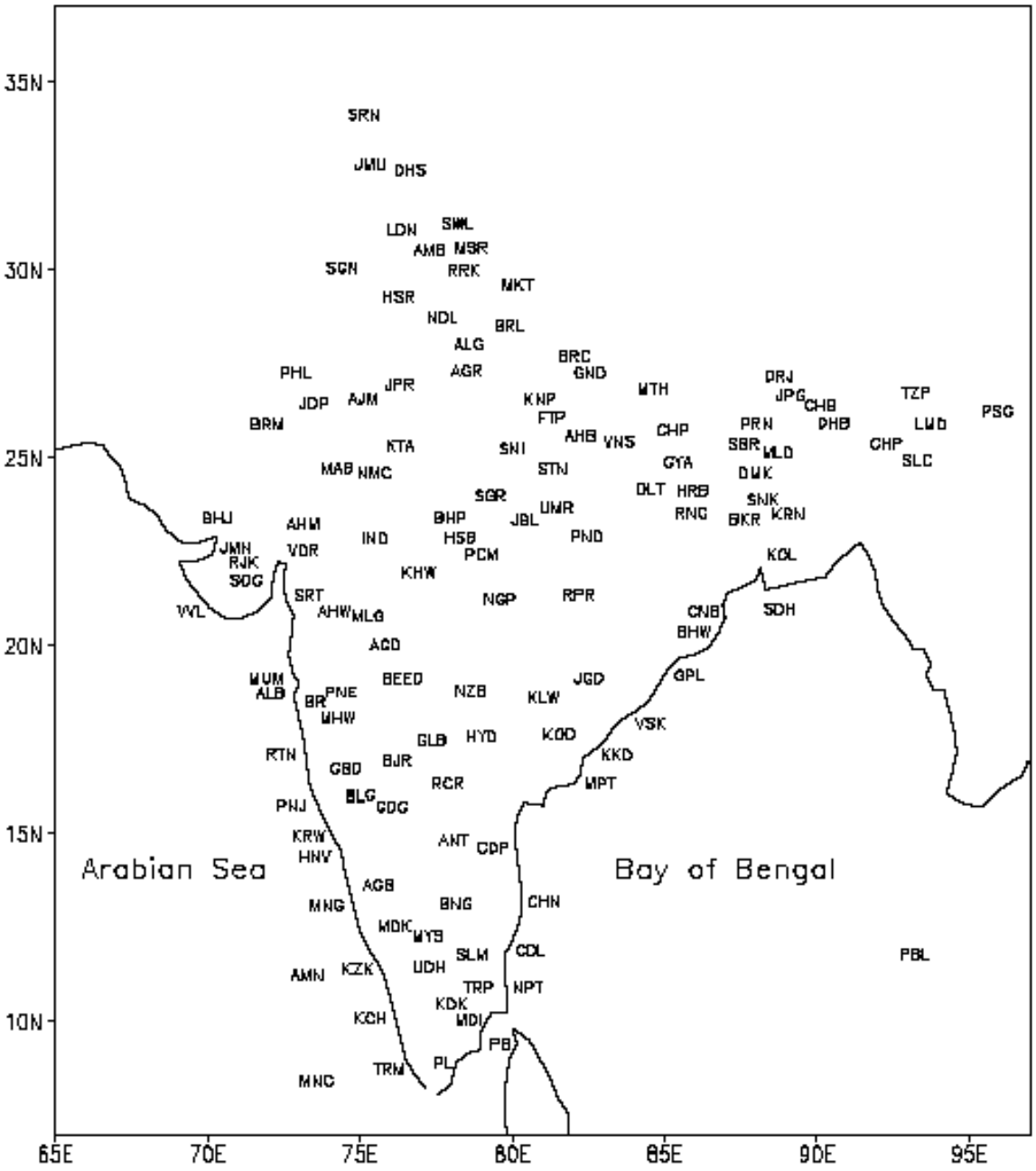


Fig 1 : The stations which received extreme rainfall after 1960.

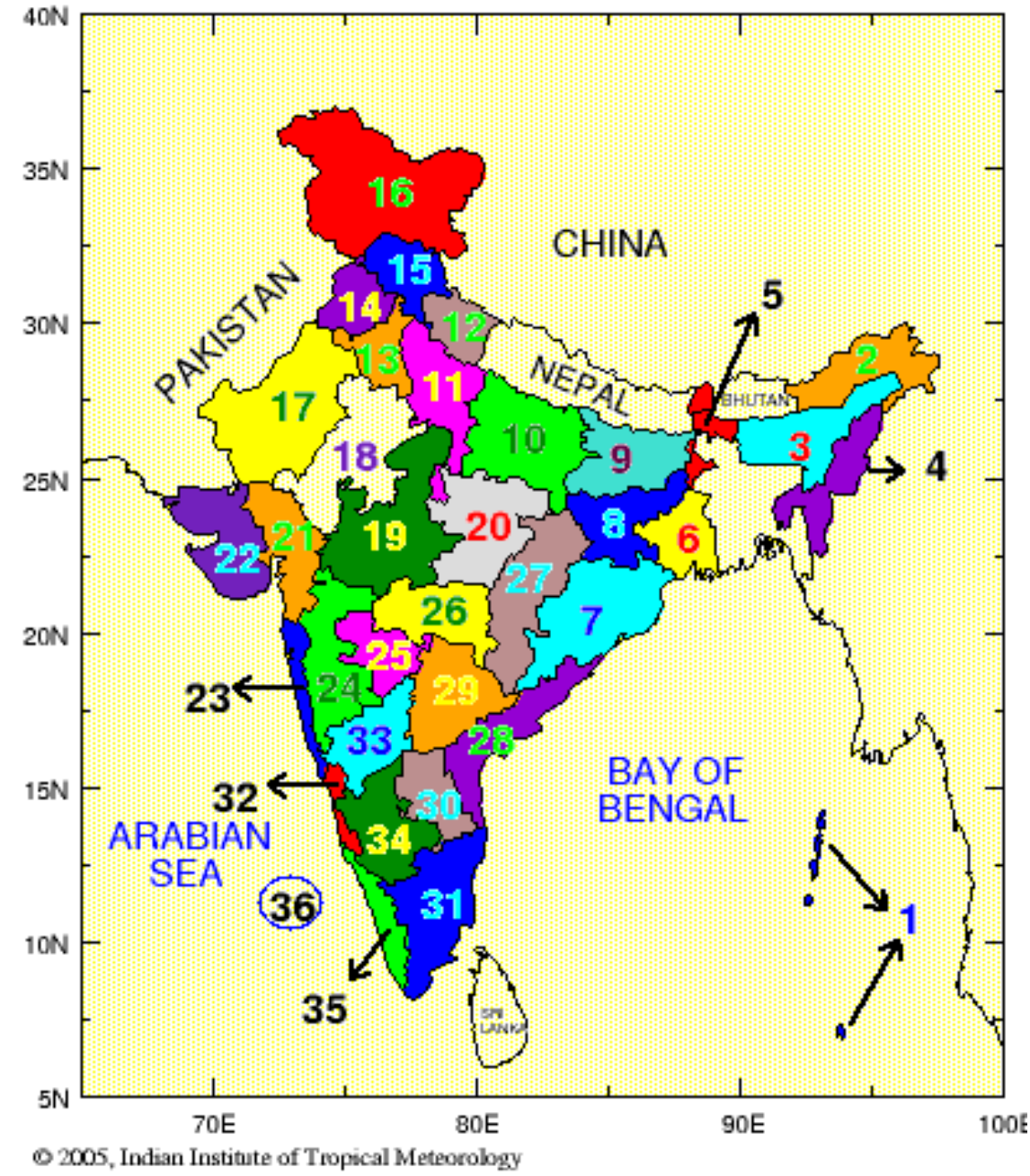


Fig. 2 : Subdivisions of Indian region