Mausam, (1993), 44, 4, 373-380

551.515 : 551.577

Spatial distribution of severe rainstorms over India and their associated areal raindepths

O. N. DHAR and SHOBHA NANDARGI

Indian Institute of Tropical Meteorology, Pune

(*Received 3 December 1992, Modified 27 April 1093*)

सार–भारत में 1880 से 1990 के दौरान घटित 97 भीषण वर्षा झंझावातों के आंकड़ों को भारत के बृहत-माप वाले मानचित्रा पर अंकित करके उनके क्षेत्रीय बंटन का अध्ययन किया गया है। ज्ञात हुआ है कि कुछ वर्षा-झंझावातों को छोड़कर अधिकांश वर्षा-झंझावात कुछ विशेष क्षेत्रों में ही घटित होते है। इन क्षेत्रों को रेखांकित किया गया है तथा उनकी सीमाएं उन क्षेत्रों की स्थल सीमाओं से मिलती है। इन वर्षा-झंझावातों के डी ए डी आंकड़ों के आधार खींची गई वर्षा की सममान रेखाओं के नमूने यह दर्शाते हैं कि प्रत्येक वर्षा-झंझावात के क्षेत्रक में भारी वर्षा के क्षेत्र अथवा प्रकोष्ठ हैं। अभिकल्प झंझावात के आकलन के लिये झंझावातों को एक क्षेत्र से दूसरे क्षेत्र पर पक्षांतरित करने के लिये सावधानी की आवश्यकता है।

ABSTRACT. Spatial distribution of 97 severe rainstorms of India which occurred during the period 1880 to 1990 was examined by plotting this data over large-scale base maps of the country. It was found that excepting a few rainstorms, most of these rainstorms have preferred zones of occurrence. These zones have been demarcated and their boundaries are found to correspond with the orographic boundaries of the region where these zones occur. Also, the isohyetal patterns drawn on the basis of DAD data of these rainstorms for different size areas and durations have shown that within each of the rainstorm zones, there are areas or cells of heavy rainfall which need to be taken care of while transposing rainstorms from one area to another for obtaining design storm estimates.

Key words — Servere rainstorms, Rainstorm transposition, Design storm estimation, Recurving storm tracks, Meteorologically homogeneous areas, Spillway design flood.

1. Introduction

In 1954 Central Board of Irrigation and Power (CBIP) passed a comprehensive resolution on rainfall analysis for the development of water resources of this country. Emphasis in the resolution was specially laid on the analysis of major rainstorms of the country with a veiw to obtain their Depth-Area-Duration (DAD) data for different parts of the country. In 1957, after the Mahboobnagar Railway Bridge disaster in Andhra Pradesh, a high level Committee of Engineers was set up by the Ministry of Railways to investigate and review the methods of estimation of maximum floods especially from small and medium catchments. This committee also strongly recommended countrywide analysis of major rainstorms to be undertaken at an early date. As a sequel to these recommendations, India Meteorological Department (IMD) was requested by the Central Water Commission (CWC) to take up early the analysis of major rainstorms as IMD had the required data as well as the technical knowhow to undertake this work.

In early 1960, a Storm Analysis Unit (SAU) was set up in IMD at New Delhi. This unit had to be wound up after about 2 years of its existence as a measure of economy caused by Chinese attack on India in October 1962. During the course of 2 years, SAU analysed nearly 150 to 200 major and medium rainstorms of different durations in Bihar and Madhya Pradesh. After the closure of SAU, storm analysis work was being mostly carried out for those projects where water and power projects were being planned or executed. This work was mainly being done in the Hydrometeorological Divisions of IMD, Indian Institute of Tropical Meteorology (IITM) and Central Water Commission (CWC).

In the present paper, after giving a brief resume of the progress made so far in the analysis of rainstorms in this country, an attempt has been made to study the distribution of DAD rainfall magnitudes in the country with a view to know the areas of the country where application of storm transposition technique should be carried out with caution.

2. Work done in India on rainstorm analysis

Satakopan (1950) was one of the earliest meteorologists of this country who carried out storm analysis using DAD technique. He analysed major rainstorms of south Bihar and Gangetic West Bengal for the development of water resources of Damodar Valley where a chain of dams were being planned. Parthasarathy (1959) using rainfall data of the country up to 1955, selected 5 severe rainstorms in different parts of the country and analysed them and prepared their DAD curves. Raman and Dhar (1966) after analysing nearly 200 rainstorms of Madhya Pradesh and Bihar found that August 1917 and September 1926 rainstorms were the

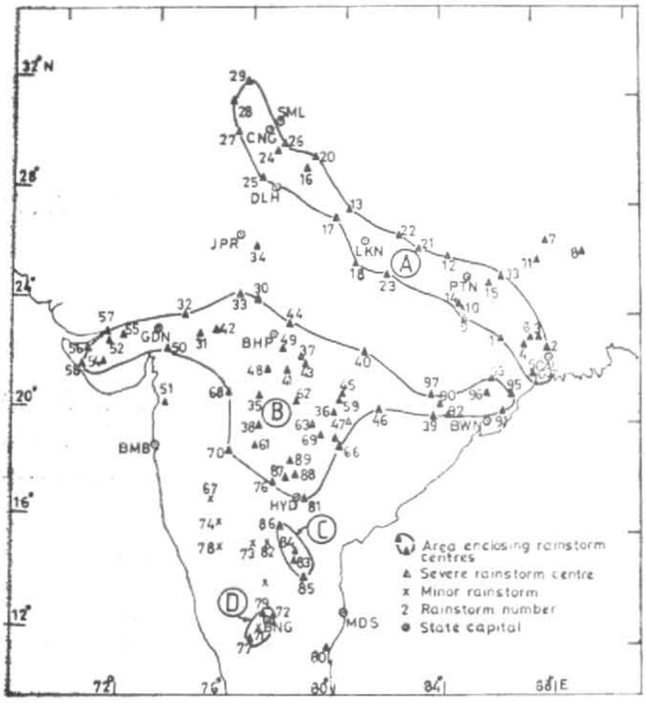

Fig. 1. Zones of severe rainstorm activity over India for 3-day duration

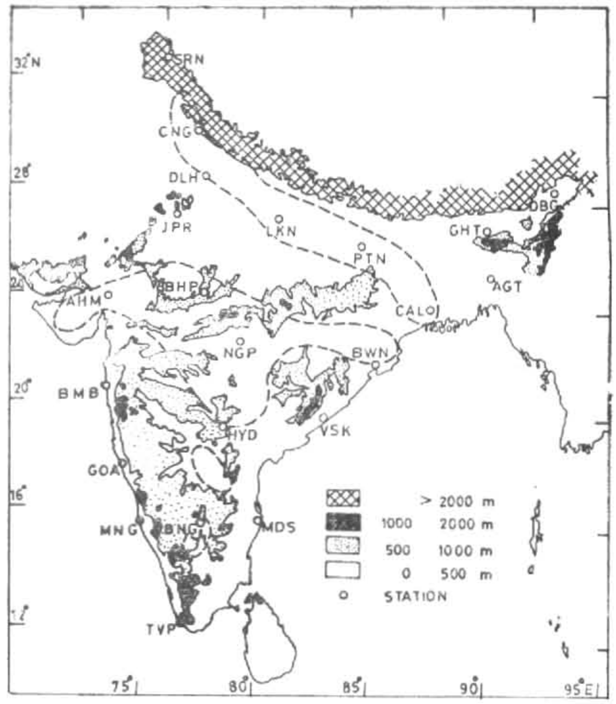

Fig. 2. Orographic features and rainstorm zones over India

severe most rainstorms of these two States on considerations of DAD analysis. For the first time, Dhar and Bhattacharya (1975) presented at a National Symposium on Hydrology at Roorkee University a comprehensive DAD data of all the major rainstorms of north India. In the mean time rainstorm analysis of Peninsular India which Ratnam and Sarker (1966) had just started was completed and its results were presented at a seminar at Bangalore (Dhar *et al.* 1982). In recent years rainstorm of Andhra Pradesh and Maharashtra were also analysed and their results were published [Dhar *et al.* 1989, 1990 (a & b)].

Severe rainstorm DAD data of this country obtained from various storm studies was compared with similar data of tropical USA and Australia. This comparison (Dhar *et al.* 1985) showed that except for a few minor areas in the range of 100 to 1000 sq miles, the areal raindepths obtained from the severemost Indian rainstorms (*viz.*, rainstorms of July 1941, July 1927 and September 1880) exceeded those of USA and Australia.

During 1989-1990, CBIP, New Delhi conducted 4 workshops, at Bhubaneshwar (May 1989), Srinagar (July 1989), Narmadasagar Dam site (September 1989) and Nagarjunsagar Dam site (February 1990), on the topic of unusual storm events and their relevance to dam safety. A large number of papers on storm analysis were contributed to these workshops whose proceedings were pre-printed in 4 volumes by CBIP.

In recent papers [Dhar and Nandargi 1993 (a&b)] it has been shown that using the severe rainstorm data of the period 1880 to 1990, severe rainstorms occurred in certain preferred zones or areas. They have also worked out envelope DAD raindepths for these zones in order to know the distribution of average areal raindepth magnitudes of these severe rainstorms.

From the foregoing it is seen that from early fifties there has been considerable progress in the study of rainstorms. However, the present study aims at studying spatial distribution of their areal raindepths which was not attempted so far in this country.

3. Selection of severe rainstorms and criteria used

Normally, in this country severe rainstorms are associated with meteorological systems like active low pressure areas, depressions and cyclonic storms. Generally these systems originate from the neighbouring seas of the Bay of Bengal and the Arabian Sea and after crossing the respective coasts these move inland. Their life-span is, on an average 3 to 6 days over land. Associated with these disturbances heavy to very heavy rainfall occurs over a very wide area of the country through which these disturbances travel. It has been observed that generally duration of a rainstorm over a given area or region associated with these disturbances, is of the order of about 2 to 3 days.

In order to select severe rainstorms experienced by this country during the last 110 years or so the following broad criteria was adopted :

(*i*) A severe rainstorm should have a closed isohyetal pattern for different durations,

(*ii*) The areal extent of the severe rainstorm for each duration may be of the order of 50,000 sq km or more, (*iii*) The central value of the rainfall of the isohyetal pattern may be ⩾ 20 cm for 1-day, ⩾25 cm for 2-day and ⩾ 30 cm for 3-day durations and so on.

4. Rainstorm zones

Using the criteria mentioned in section 3 for the selection of severe rainstorms, it was found that during the last 110 years (1880 to 1990) about 97 severe rainstorms of 2 to 3 day durations affected the country. Their distribution over the different States of the country is given in Table 1.

TABLE 1

Monthwise distribution of severe rainstorms over different States of the Indian region (1880-1990)

S. No.	State	Pre-monsoon	Monsoon				Post-monsoon		Total
		May	Jun	Jul	Aug	Sep	Oct	Nov	
1	Orissa	—	3	2	2	1	—	—	8
2	West Bengal	—	2	1	1	2	2	—	8
3	Bihar	—	1	1	1	3	1	—	7
4	Uttar Pradesh	—	—	1	2	4	1	—	8
5	Punjab & Haryana	—	—	—	1	4	1	—	6
6	Rajasthan	—	1	4	—	—	—	—	5
7	Madhya Pradesh	—	3	3	8	1	—	—	15
8	Gujarat	—	2	6	1	—	—	—	9
9	Maharashtra	—	4	2	5	1	—	—	12
10	Karnataka	1	—	1	1	5	—	1	9
11	Tamil Nadu	1	—	—	—	—	—	—	1
12	Andhra Pradesh	1	—	2	1	3	2	—	9
	Total	3	16	23	23	24	7	1	97

A detailed list of these 97 rainspells has been given by Dhar and Nandargi [1993 (a)] in their recent paper on severe rainstorm zones of India. The break up of meteorological disturbances which caused these 97 severe rainstorms was found to be as follows :

(*i*) Severe cyclonic storms	14
(*ii*) Cyclonic storms	19
(*iii*) Depressions	40
(*iv*) Low pressure areas and other weather disturbances	24
Total	97

It has been shown by Dhar and Nandargi [1993 (a)] that if the centres of these 97 severe rainstorms are plotted on a base map of the country, it is seen that these rainstorms have four preferred zones or areas of occurrence. These zones have been designated as zones A, B, C and D. Details about these zones as to their area, length, breadth etc are given by Dhar and Nandargi [1993 (a)] and hence are not repeated here, however, these four zones (*viz.*, A, B, C and D) are shown in Fig. 1. In zone A, 29 rainstorm centres are located while in zone B there are about 56. Areawise zones A and B are the largest zones, while zones C and D, which happen to be located in southern half of the Indian Peninsula are the two smallest zones encompassing hardly 4 and 3 rainstorm centres respectively within them. The larger two zones, A and B, have further been sub-divided into 4 homogeneous sub-zones to facilitate transposition of rainstorms. For each sub-zones of A and B and zones C and D envelope DAD raindepths have been worked out [Dhar and Nandargi 1993 (b)].

5. Rainstorm zones and orography

If the outlines of zones B, C and D are superimposed on a map showing orographic features of the country of the same scale, it is observed that zone B very much tallies with the orographic boundaries of the central parts of the country and northern half of the peninsula. It is seen from Fig. 2 that zone B lies to the south of the Mahadev-Maikal and Vindhya-Satpura hill ranges of the central India. To the west of this zone are the Western Ghats and to its east are the Eastern Ghats. Zone B thus appears to be formed due to this configuration of mountain ranges of central India and northern half of the Indian Peninsula. Zone C is hemmed in the upper section of the Krishna basin just to the east of the Western Ghats and zone D is located over the high lands of Mysore Plateau and its neighbourhood. It thus appears that so far rainstorm zones B, C and D are concerned, they broadly appear to be formed due to configuration of orographic boundaries of mountain ranges of the central and Peninsular India.

As already mentioned, zone A has been formed by about 29 rain centres of severe rainstorms. Excepting a few of the rainstorms, most of the rainstorms of this zone are associated with the cyclonic disturbances from the Bay of Bengal. The rainstorms associated with these disturbances were caused by recurving storm tracks after their landfall and travel over land in the interior of the country. Perhaps, orographic barrier of the Himalayas was to a large extent responsible for making these systems to shed most of their moisture well before these disturbances could actually strike the Himalayan ranges. It, therefore, appears that on this account heavy rain centres associated with these rainstorms are found to be located about 150 to 300 km south of the Himalayan foothills and the orientation of zone A is parallel to the Himalayan range from Punjab in the west to Bihar in the east. Fig. 3 shows recurving storms tracks of the majority of cyclonic disturbances whose heavy rain centres constitute zone A.

From the above it thus appears that mountain ranges of the Indian sub-continent play an important role in determining and fixing the rainstorm zones.

6. Rainstorm transposition

Dhar and Nandargi [1993 (a & b)] have argued that since rainstorms in this country have been occurring, by and large, in four zones only, as such transposition of these rainstorms can only be undertaken within these

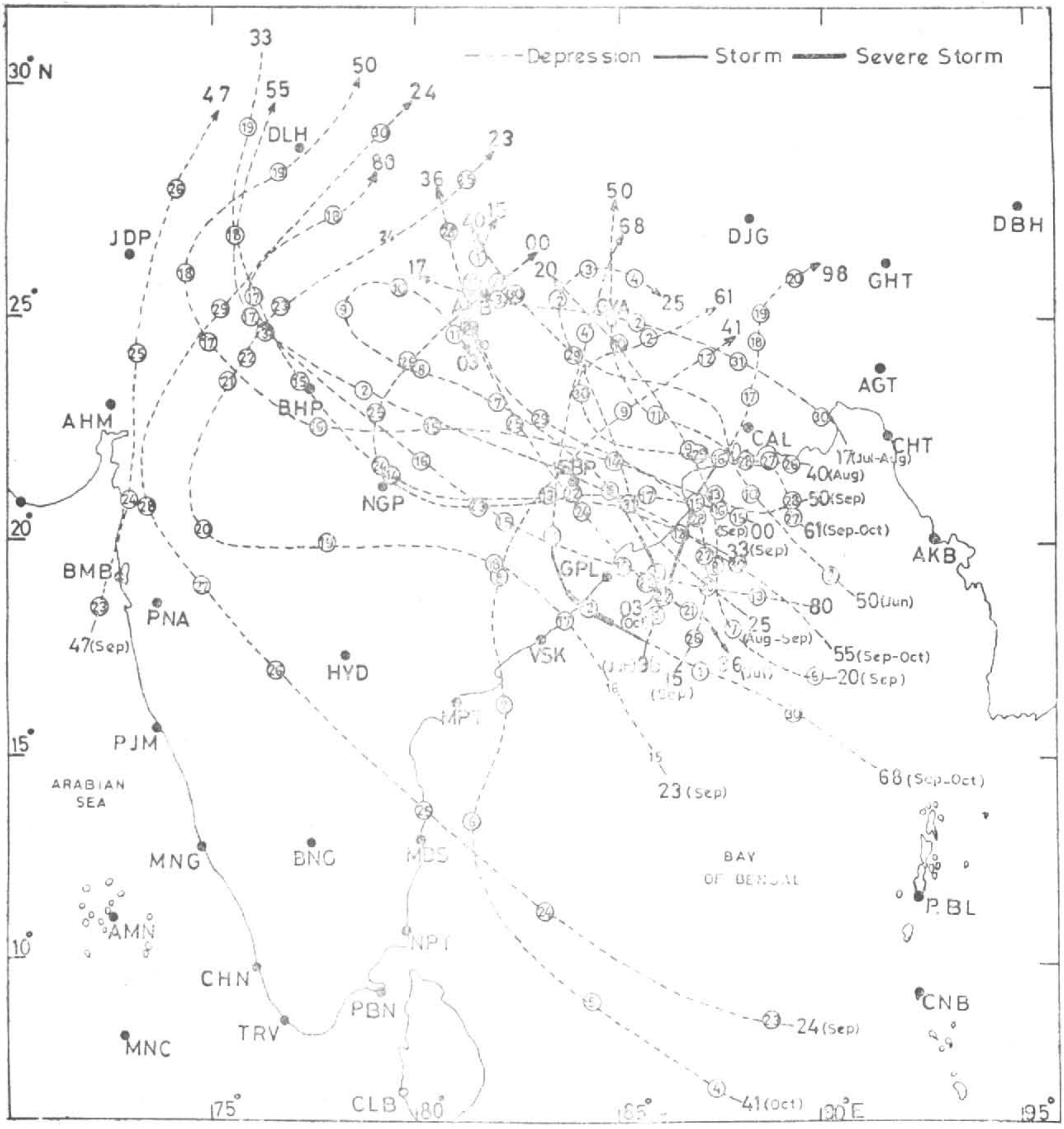

Fig. 3. Storm tracks of recurving disturbances towards Himalayas of zone A over north India

zones by rainstorms which have occurred in the respective zones. In this connection it may be mentioned that Rakhecha and Kennedy (1985) has suggested that the entire Indian area may be considered as one homogeneous aiea for transposition of rainstorms, excepting some extreme areas in the north and the south vide Fig. 2 of their paper. The present study has shown that this may not be correct as by and large rainstorms occur only in certain preferred zones of the country and, therefore, transposition can only be undertaken within the zones by rainstorms of the respective zones. Inter zonal transposition may not be a correct procedure taking into consideration the orography of the country.

7. Spatial distribution of rainstorm depths

On the basis of depth-area-duration (DAD) data of each of 97 severe rainstorms, maximum average raindepths over different standard areas, *e.g.*, 100, 500, ..., 50,000 sq km and for 1, 2 and 3-day durations were worked out [Dhar and Nandargi 1993 (b)]. Envelope raindepths for each of the rainstorm zones of A, B, C and D on the basis of DAD data of rainstorms within these zones for the durations of 1, 2 and 3 days are given in Table. 2.

In this study areal raindepths for different standard areas like 500, 1000, ..., etc sq km and

TABLE 2

Envelope raindepths (cm) for different zones over Indian region

Duration	Zone	Point	Area in hundreds of sq km						Rainstorms contributing to envelope raindepths
			5	10	50	100	200	500	
1-day	A	82.3 (a)	80.0 (a)	77.5 (a)	62.8 (a)	51.5 (a)	40.5 (a)	26.3 (a)	(a) 18 Sep 1880 (b) 22 Jun 1983
	B	73.8 (b)	68.0 (b)	65.0 (b)	48.0 (b)	44.0 (c)	36.8 (c)	24.0 (d)	(c) 30 Jul 1927 (d) 28 Jul 1927 (e) 23 May 1952
	C	38.9 (e)	37.2 (e)	35.9 (e)	29.3 (e)	25.7 (e)	21.2 (e)	14.3 (f)	(f) 29 Sep 1964
2-day	A	104.1 (g)	100.0 (g)	99.1 (g)	86.8 (g)	76.8 (g)	63.0 (g)	41.4 (g)	(g) 17-18 Sep 1880 (h) 27-28 Jul 1927
	B	99.8 (h)	95.0 (i)	92.0 (i)	78.0 (i)	66.0 (i)	50.0 (i)	40.5 (h)	(i) 21-22 Jun 1983 (j) 23-24 May 1952
	C	45.0 (j)	42.2 (j)	40.8 (j)	33.8 (j)	30.7 (j)	26.4 (j)	22.8 (k)	(k) 21-22 Sep 1949 (l) 23-24 May 1957
	D	30.0 (l)	29.5 (l)	29.5 (l)	27.0 (l)	25.0 (l)	18.9 (l)	12.9 (m)	(m) 11-12 Nov 1903
3-day	A*	83.6 (n)	79.7 (o)	78.0 (o)	68.2 (o)	62.0 (o)	54.1 (o)	41.5 (o)	(n) 3-5 Oct 1955 (o) 24-26 Sep 1988
	B	129.0 (p)	121.0 (q)	117.0 (q)	98.0 (q)	85.0 (q)	71.3 (p)	55.2 (p)	(p) 26-28 Jul 1927 (q) 20-22 Jun 1983
	C	62.1 (r)	56.1 (r)	51.4 (r)	38.1 (s)	34.9 (s)	31.3 (s)	26.2 (t)	(r) 28-30 Sep 1964 (s) 23-25 May 1952
	D	34.8 (u)	34.5 (u)	34.1 (u)	31.8 (u)	29.0 (u)	24.3 (u)	—	(t) 20-22 Sep 1949 (u) 22-24 May 1957

NOTES : 1. Zone D does not exist for one-day duration [Dhar and Nandargi, 1993 (a)].

2. * These raindepths are of rainstorms having 3-day duration but these are less than 2-day raindepths, therefore, using Chow (1953) extended duration principle, for design purpose 2-day raindepths may be used.

different durations like 1, 2 and 3 days were plotted at the respective rain centres of each of the 97 rainstorms on a base map of the country. These maps were then subjected to isohyetal analysis to locate the areas of the country which are subjected to very heavy rainfall. Figs. 4–6, as specimen samples, show the spatial rainfall distribution of rainstorms for 1000 sq km for 1, 2 and 3-day durations. It has been found from this analysis that the isohyetal patterns broadly remain the same for these durations but magnitudes of areal rainfall differ. In the isohyetal map of say 1000 sq km of 1-day duration, it is seen that magnitudes of rainstorm isohyetals are far less when compared to rainstorm isohyetals of 1000 sq km of 2 and 3-day durations. This is because as area increases, raindepths decrease exponentially, whereas with the increase in durations, raindepths increase because these are cumulative raindepths for that duration.

Examination of Figs. 4 – 6 show that the isohyetal pattern of these maps broadly correspond with the location of rainstorm zones in these maps. However, in the isohyetal pattern of zone B the raindepths obtained from July 1941 rainstorm have been included as it fits in the isohyetal pattern of this zone. The large-area rainstorm zones of A and B (of Fig. 1) are quite distinctly seen in the isohyetal patterns of Figs. 4 – 6. Rainstorm zones of C and D (Fig. 1) have merged in Figs. 4 – 6 into one single isohyetal pattern in the southern half of the peninsula.

In the Figs. 4 – 6 the isohyetal pattern corresponding to zone A shows that there are 4 heavy rain cells or areas within this pattern. The first cell is over the Gangetic West Bengal, second one over south Bihar, third one, the severe most of all, over northwest Uttar Pradesh and the fourth one over Punjab. In the isohyetal

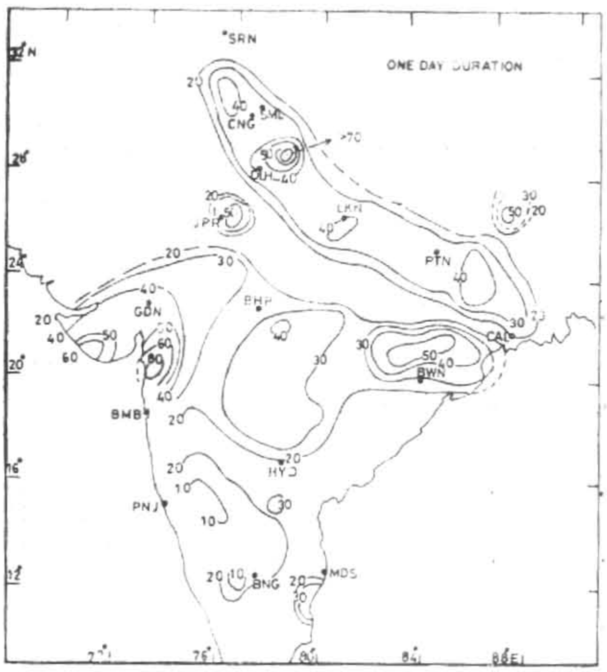

Fig. 4. Areal raindepths of severe rainstorms for 1-day duration and 1000 sq km

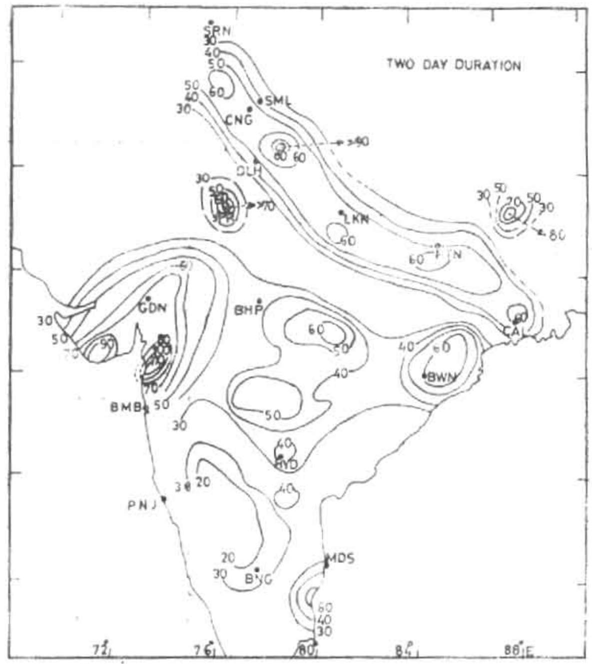

Fig. 4. Areal raindepths of severe rainstorms for 2-day duration and 1000 sq km

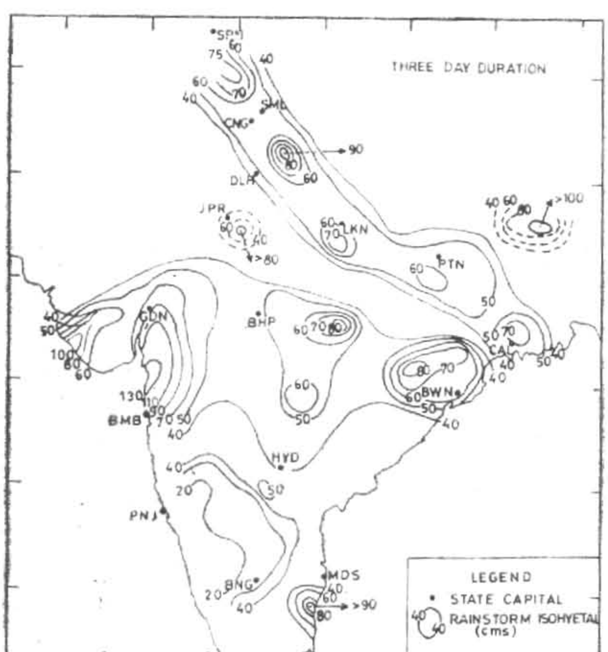

Fig. 6. Areal raindepths of severe rainstorms for 3-day duration and 1000 sq km

pattern corresponding to zone B, there are also 4 heavy rain cells. The first one is located over Orissa, second one over central Madhya Pradesh and adjoining Andhra Pradesh, third one over south Gujarat and the fourth one over Saurashtra peninsula.

The isohyetal pattern over southern half of the peninsula (vide Figs. 4-6) extending from about Sholapur in Maharashtra to about Bangalore in Karnataka to the east of the Western Ghats, is caused by the severe rainstorms of the C and D zones of Fig. 1. This area covers broadly the semi-arid area of Rayalaseema and the neighbouring districts.

Outside these isohyetal patterns of Figs. 4-6 it is seen that there are three small isohyetal patterns caused by severe rainstorms which did not fall in any of the rainstorm zones of Fig. 1. These isohyetal patterns are located in north Bengal (close to Kurseong), near Jaipur in Rajasthan and near Cuddalore along the Tamil Nadu coast. These are isolated cases of rainstorms which did not form part of any of the four rainstorm zones of Fig. 1.

Broadly speaking, isohyetal patterns of severe rainstorms have shown that in each rainstorm pattern, there are areas or cells where heavy to very heavy areal raindepths have occurred in the past associated with severe rainstorm activity. Considering this, transposition of rainstorms for obtaining design storm estimates from or to these cells or areas from their neighbourhood has to be done rather carefully.

In the rainstorm zone A, it has particularly been noticed that very heavy areal raindepths have occurred over areas which are far away from the moisture source. As an example; the occurrence of the heavy rainfall over northwest Uttar Pradesh and Punjab in September 1880 and October 1955 rainstorms respectively. In such cases, the moisture depletion technique due to distance travelled by disturbances over land from the sea, may not be a true guide in modifying or adjusting design storm estimates for basins in the interior of the country (WMO 1986).

It is also clear from this study that excepting coastal areas, southern half of the Indian Peninsula is not subjected to very heavy areal raindepths due to severe rainstorms as is the case in northern and central India.

8. Summary and conclusions

From the foregoing the following broad conclusions can be drawn :

(*i*) Examination of daily rainfall data of the period 1880 to 1990 has shown that there are about 97 severe rainstorms which affected different parts of the country during May to November months.

(*ii*) It has been found that excepting a few severe rainstorms, rest of the rainstorms have preferred zones of occurrence in the country. These zones have been demarcated and are located in northern India, central and Peninsular India as shown in Fig. 1. The boundaries of these zones have been found to be broadly tallying with the orographic boundaries of mountain ranges in the respective regions of the country.

(*iii*) Distribution of areal rainfall for different areas and durations associated with these severe rainstorms has shown that the isohyetal patterns of rainfall broadly follow the zonal pattern. Within these isohyetal patterns it is seen that there are cells of heavy rainfall over some areas. Transposition of rainstorms to or from these areas have to be undertaken with caution for the estimation of design storm studies of river basins within these rainstorm zones. Areal isohyetal patterns of rainstorms (*vide* Figs. 4-6) have identified the areas where caution is required in the rainstorm transposition

Acknowledgement

Authors are grateful to Prof. R. N. Keshavamurty, Director, Indian Institute of Tropical Meteorology, Pune for giving all the facilities to the authors for carrying out this study.

References

Central Board of Irrigation and Power (CBIP), 1989 & 1990, Technical papers of Regional Workshop on Unusual storm events and their relevance to dam safety held at Bhubaneswar (May 1989), Srinagar (July 1989), Narmadasagar Dam site (September 1989) and Nagarjunsagar Dam site (February 1990), CBIP Publ. No. 234. July 1993.

Chow, V.T., 1953, Frequency analysis of hydrologic data with special application to rainfall intensities, Univ. Illinois, Eng. Exp. Stn., Bull. 414.

Dhar, O.N. and Bhattacharya, B.K., 1975, A study of depth-area-duration statistics of the severe most rainstorms over different meteorological divisions of north Indian plains, Proc. National Symp. on Hydrology, Roorkee Univ. Roorkee.

Dhar, O.N., Kulkarni, A.K. and Rakhecha, P.R., 1982, A study of maximum point and areal rainfall over the central parts of the Indian Peninsula, Proc. National Workshop on Hospet and its environs –2001 AD, held at Bangalore.

Dhar, O.N., Rakhecha, P.R., Kulkarni, A.K. and Mandal, B.N., 1985, Raindepths associated with most severe rainstorms of India. Proc. 6th conference on Hydromet. held at Indianapolis, USA, Amer. Met. Soc. publication.

Dhar, O.N., Nandargi, S.S. and Kulkarni, A.K., 1989, Analysis of severe rainstorms of Andhra Pradesh, AHI's journal of Applied Hydrology, 2, 1.

Dhar, O.N., Nandargi, S.S. and Kulkarni, B.D., 1990 (a), Analysis of severe rainstorms of the peninsular States for design storm estimation. Proc. CBI & P's Regional Workshop on unusual storm events and their relevance to dam safety held at Nagarjunsagar Dam site.

Dhar, O.N., Kulkarni, B.D. and Nandargi, S.S., 1990 (b), Hydrometeorological studies of Maharashtra rainfall—A brief appraisal, Proc. Third National Symp. on Hydrology held at CWPRS, Pune.

Dhar, O.N. and Nandargi, Shobha, 1993 (a), "The zones of severe rainstorm activity over India", *Intern. J. Climatol.*, **13**, 3.

Dhar, O.N and Nandargi, Shobha, 1993 (b), "Envelope DAD raindepths for different homogeneous rainstorm zones of the Indian region", *Theo. Appl. Climatol.*, **47**. 2.

Parthasarathy, K., 1959, Comparison of depth-area-duration values of the biggest recorded storms in different parts of India, Proc. symp. on Meteorological and Hydrological aspects of floods and droughts in India, IMD publication.

Rakhecha, P.R. and Kennedy, M.R., 1985, "A generalized technique for the estimation of probable maximum precipitation in India", *J. Hydrol.*, **78**.

Raman, P.K. and Dhar, O.N., 1966, "A study of major rainstorms of Bihar and Madhya Pradesh for evaluation of design storm", *Indian J. Met. Geophys.*, **17**, Spl. No.

Ratnam, V. and Sarker, R.P., 1966, "A rainfall study in association with storms, and depressions", *Indian J. Met. Geophys.*, **17**, Spl. No.

Satakopan, V., 1950, Time-depth-area curves of maximum precipitation for the Damodar area," *Indian J. Met. Geophys.*, **1**, 3.

World Meteorological Organisation (WMO), 1986, Manual for the estimation of probable maximum precipitation, Operational Hydrology Rep. No. 1, WMO No. 332.