International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Design Raindepths for 1° × 1° Grid Over the Godavari-Krishna Basins in India

B.D. Kulkarni[1], S. Nandargi and S.S. Mulye
Indian Institute of Tropical Meteorology, Pune - 411 008, INDIA
E-mail: [1]bdkul@tropmet.res.in

ABSTRACT: A paper is mostly emphasized with the developement of generalized areal design raindepths of Probable Maximum Precipitation (PMP) magnitudes over the two peninsular river basins in India viz. the Godavari and the Krishna basin for 1° × 1°. On the basis of severe rainstorms that experienced by the two basins during the period of about 100 years (1901–2000), highest average areal raindepths for different size areas and durations have been estimated. The transposition limits of these severe rainstorms have been identified for each of the homogeneous zone. Maximum design raindepths (Standard Project Storm) at 1° × 1° grid were then estimated in order to obtain generalized PMP raindepths. With this estimated PMP values generalized PMP charts for 500, 1000 and 5000 and 10,000 km^2 have been prepared. These grided PMP maps for different size areas and durations will be useful for estimating design storm raindepths of PMP magnitude for minor and medium sub-catchments in the Krishna and the Godavari basins whose areas are falling in the range of 500 to 10000 km^2. In this derivation of PMP we assume that the record rainstorms during the past 100 years or so are representative of the climate of extreme precipitation.

Keywords: Rainstorm, DAD Analysis, Transposition, Storm Maximization.

INTRODUCTION

Design rainfall information is generally expressed in terms of point rainfall intensity, which is the rainfall depth (mm) at a location per hour. However, for flood estimates of large catchments, an estimate of the average areal rainfall intensity across the catchment is required. Therefore, design storm studies are being conducted to study rainfall magnitude and its time distribution for use as main input for the hydraulic structures in whose case no risks can be taken. In India, large number of studies are available regarding rainfall analysis of different regions, basins, etc. (Rakhecha and Kennedy 1985, Dhar *et al.,* 1991, Kulkarni *et al.,* 2005). However, studies on rainfall variation within homogeneous zonal grids of different basins are lacking. Such microscale studies are essential for undertaking any projects in irrigation, water conservation and supply, hydropower generation, etc.

In view of the above, in the present study efforts have been made to give PMP design raindepths over 1° × 1° grid for the Krishna and the Godavari basins, the two major river systems of the peninsular India.

THE GODAVARI AND THE KRISHNA BASIN

The Godavari and the Krishna rivers constitute the important river systems of the northern Indian Peninsula. The two basins, viz. the Godavari and the Krisha, drain comparatively major part of the Western Ghat, which is the predominant source of water of these two rivers. After flowing eastwards from the origin, Godavari falls in to the Bay of Bengal about 97 km below Rajahmundry and the river Krishna near Masullipatnam in Andhra Pradesh. The important features of the two river basins are highlighted in the Table 1. Figure 1 shows the map of the Godavari and the Krishna basin.

RAINFALL CLIMATOLOGY OF THE TWO BASINS

The Godavari basin receives most of its rainfall during the four monsoon months of June–September. The onset of monsoon over the basin is around 10 June and it withdraws by about 1st week of October. As the basin falls directly in the path of the monsoon disturbances, basin receives comparatively good amount of rainfall. The average monsoon rainfall over the basin is of the order of 83.5 cm and annual rainfall is 107.5 cm.

[1]Conference speaker

Table 1: Major Features of the Godavari and the Krishna River Basins

Major Features	*Godavai Basin*	*Krishna Basin*
Origin of the river	Trimbakeshwar, Nasik at 1067 m a.s.l. in the Western Ghats	near Mahabaleshwar at 1360 m a.s.l. in the Western Ghats
Catchment area	3,12,812 km^2	2,58,948 km^2
% distribution of catchment area in adjoining peninsular states	Maharashtra 48.6% Madhya Pradesh 20.7% Karnataka 1.4% Orissa 5.5% Andhra Pradesh 23.8%	Maharashtra 26.8% Karnataka 43.8 Andhra Pradesh 29.4%
Major tributaries	the Manjra from southeast, the Penganga and the Wardha from the westnorth, the Wainganga from the north and the Indravati and Sabri from the east	the Koyna from Western Ghat, the Bhima from the northern parts of the Western Ghat, the Tungabhadra from the south of the Western Ghat. Tributaries like Dundi, Musi, Palleru and Muneru draining the north-eastern parts of the basin join the main river between Srisailam dam and Vijayawada but do not add much water.
Total length of the river	1465 km	1400 km

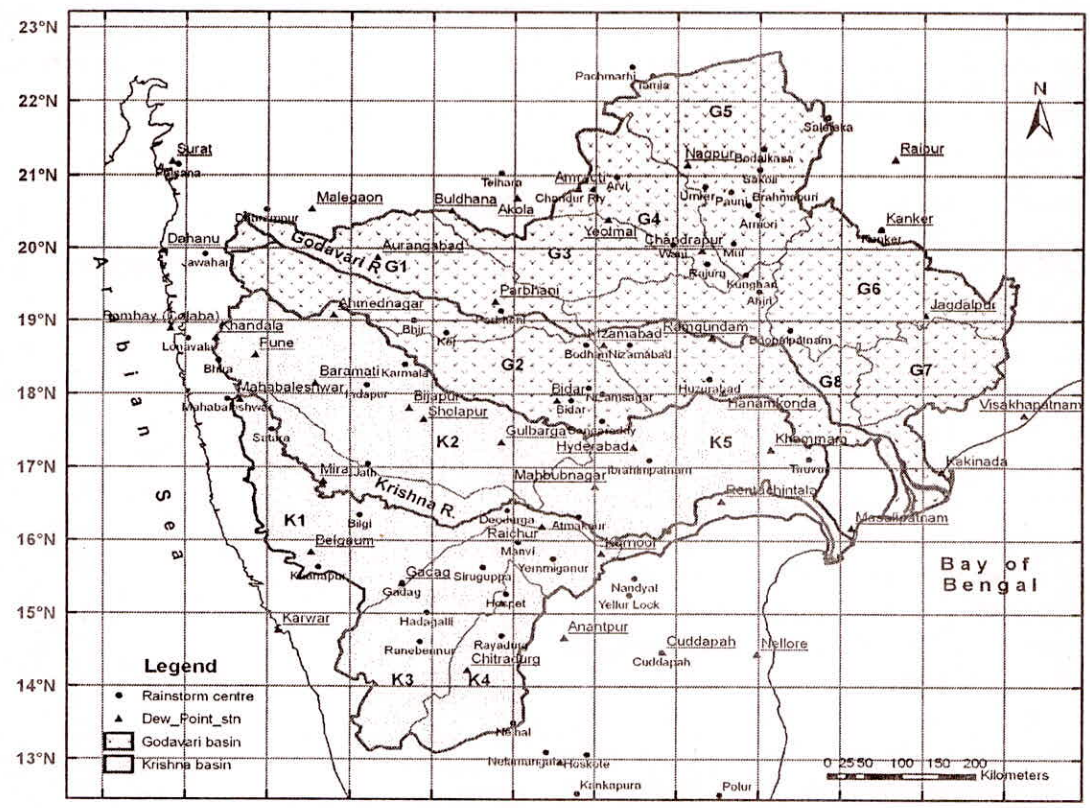

Fig. 1: Zonal map of the Krishna and the Godavari basin showing rainstorm centres and dew point temperature stations

The southwest monsoon normally advances over the Krishna basin and adjoining areas by around the first week of June and establishes firmly over the entire basin by the end of June. It withdraws from this region in the second week of October. The mean annual rainfall over the entire basin is of the order of about 90 cm and 74% of it (i.e. 70 cm) is contributed by the southwest monsoon season. About 25% of the annual rainfall is received during the month of July alone.

In the present study, an attempt has been made to prepare generalized maximum design raindepth charts of PMP magnitude for different standard areas and durations over 1° × 1° grid of the Godavari and the Krishna river basins for 1, 2 and 3 day durations on the basis of 100 year (1901–2000) daily rainfall data.

Data Used for Analysis

(a) *Daily Rainfall Data*—of all the available stations numbering around 600 stations in and around the Krishna and the Godavari basins have been procurred for the period (1901–2000) from the following sources:

1. National Data Centre (NDC), India Meteoroloical Department (IMD) Pune,
2. State rainguage authorites,
3. Drought Monitoring Cell, Govt. of Karanataka, Banglore,
4. Water Resources Division, Maharashtra state and
5. National Climate Data Centre (NCDC), NOAA, USA.

(b) *Dew Point Data*—The daily storm dew point temperature data were collected for 35 selected meteorological observatory stations in and around the basins (see Figure 1). The highest dew point temperature record based on long period data over the study region has been taken from the generalized maps of persisting dew point temperature included in the publication of Rakhecha, *et al.* (1990), Lal *et al.* (IMD, 2000).

METHODOLOGY

For the preparation of generalized design raindepth charts at 1° × 1° grid over the problem basin using moisture maximization and transposition techniques procedural steps are:

On scrutiny of daily rainfall data, severe rainstorms those occurred over the two basins were selected. DAD analysis was carried out at the place of occurrence of severe rainspell and envelope areal raindepths have been computed for different durations of 1, 2 and 3 day and areas of 100, 500, 1000 etc. km^2 for each of the sub-basins. On a base map of the basins, for computation of maximum design raindepth, a lat.-long. 1° × 1° grid systems was constructed. Envelope raindepths from DAD analysis of severe rain spells have been subjected to Moisture Maximization at their original locations using dew point temperature data. The isohyetal pattern of severe most rainstorm from the adjacent homogeneous grids were transposed to particular grid with the following adjustments: (i) Transpostion factor for new location. (ii) Barrier correction. Envelope grided maximum raindepths over a grid then multiplied by corresponding MMF yielded maximized grided average raindepths over that particular grid for different standard areas and durations.

ANALYSIS OF SEVERE RAINSTORMS

As mentioned above, on the basis of available daily rainfall data for the period 1901–2000, severe rainstorms have been selected for each sub-bains of the Goadavari and the Krishna basins. Considering the orography and rainfall climatology of the region, the entire Godavari and the Krishna basin have been divided into 8 and 5 homogeneous sub-basins respectively (see Figure 1). The details of which are as follows:

Main River basin	*Sub-basins*	
Godavari	• G1—Upper Godavari basin	G2—Manjra basin
	• G3—Penganga basin	G4—Wardha basin
	• G5—Wainganga basin	G6—Indravati basin
	• G7—Sabri basin	G8—Lower Godavari basin
Krishna	• K1—Upper Krishna basin	K2—Bhima basin
	• K3—Tungabhadra basin	K4—Vedavati basin
	• K5—Lower Krishna basin	

A rainstorm is defined as a spatial distribution of rainfall yielding average depths of precipitation, which equals or exceeds certain specified threshold value over a river basin in association with any meteorological phenomena. In the present study severe rainstorms are selected by fixing an appropriate threshold value which is about 10% of the seasonal normal rainfall of the basin or sub-basin.

Examination of daily rainfall data from 1901–2000 for raingauge stations in and around the Godavari and the Krishna basin showed that in the past, 47 severe rainstorms were experienced by these two basins. Figure 1 shows the location of heavy rain centres of these rainstorms. It is seen that most of the rainstorms occurred in the monsoon months of June to September as both the basins fall directly in the path of monsoon disturbances. It is also seen that the G4 and G5 sub-basin viz. Wardha and Wainganga sub-basins experienced comparatively higher number of severe rainstorms. In Krishna basin K1, K3 and K4 sub-basins experienced large number of severe rainstorms.

The quantitative analysis of all the rainstorms was made using standard technique given in the WMO manual of Depth-Area-Duration analysis (WMO, 1969). The DAD analysis has been carried out for 1, 2 and 3 day durations of all the rainstorms. However to keep the size of the paper concise, DAD data for 1 day duration only for 34 most severe rainstorms which occurred over different sub-basins of the Godavari and the Krishna basin are given in Table 2. On comparing these DAD raindepths it is seen that following severemost rainstorms occurred over different sub-basins which constituted maximum envelope DAD raindepths:

Godavari sub-basin	*Krishna sub-basin*
G1—27 Jun., 1914	K1—5 Aug., 1914
G2—15 Jul., 1965	K2—24 Jul., 1989
G4—12 Jul., 1994	K3—17 Nov., 1992
G5— 26 Jun., 1908, 31 Aug., 1947	K4—17 Aug., 1917
G6—23 Jul., 1967	K5—23 Jul., 1989
G8—3 Aug., 1953	

Table 2: 1 Day DAD Raindepths (cm) for the Godavari and the Krishna Basin for Standard Areas (km^2)

No.	Rainstorm	Centre	Sub-basin	*1 day DAD Raindepths of Severe Rainstorms for*							MAF	*Maximum DAD Raindepths on Applying MAF for*						
				Point	*500*	*1000*	*1500*	*2000*	*5000*	*10,000*		*Point*	*500*	*1000*	*1500*	*2000*	*5000*	*10,000*
1	27/06/1914	Parbhani	G1	40.1	38.5	36.7	35.3	34.0	28.6	24.2	**1.19**	47.7	45.8	43.7	42.0	40.5	34.0	28.8
2	24/07/1989	Bhir	G1	34.6	31.9	28.8	26.2	23.5	20.7	18.6	**1.36**	47.1	43.4	39.2	35.6	32.0	28.2	25.3
3	02/09/1992	Kej	G1	28.5	28.0	27.3	26.8	26.0	24.2	21.7	**1.18**	33.6	33.0	32.2	31.6	30.7	28.6	25.6
4	27/09/1908	Sangareddy	G2	30.7	30.1	28.9	28.1	27.5	25.0	23.0	**1.25**	38.4	37.6	36.1	35.1	34.4	31.3	28.8
5	15/07/1965	Nizamsagar	G2	50.6	44.5	39.4	35.7	32.6	24.5	20.2	**1.30**	65.8	57.9	51.2	46.4	42.4	31.9	26.3
6	31/07/1955	Bidar	G2	24.6	22.8	21.6	20.8	20.0	17.4	14.7	**1.25**	30.8	28.5	27.0	26.0	25.0	21.8	18.4
7	17/06/1927	Arvi	G4	29.1	28.2	27.5	26.8	26.2	22.1	17.8	**1.23**	35.8	34.7	33.8	33.0	32.2	27.2	21.9
8	02/07/1930	Wani	G4	36.0	33.5	31.5	29.5	27.8	22.1	18.8	**1.38**	49.7	46.2	43.5	40.7	38.4	30.5	25.9
9	13/08/1986	Rajura	G4	31.0	29.4	28.4	27.6	27.3	25.5	23.5	**1.28**	39.7	37.6	36.4	35.3	34.9	32.6	30.1
10	12/07/1994	Chandur Rly.	G4	46.8	44.5	43.5	42.0	40.5	37.0	32.0	**1.21**	56.6	53.8	52.6	50.8	49.0	44.8	38.7
11	26/06/1908	Sakoli	G5	38.0	37.0	36.4	35.8	35.2	31.9	28.2	**1.42**	54.0	52.5	51.7	50.8	50.0	45.3	40.0
12	04/08/1912	Armori	G5	27.7	36.9	26.3	25.9	25.4	23.3	21.0	**1.42**	39.3	52.4	37.3	36.8	36.1	33.1	29.8
13	16/06/1936	Umrer	G5	20.0	19.7	19.5	19.3	19.0	17.8	16.7	**1.30**	26.0	25.6	25.4	25.1	24.7	23.1	21.7
14	16/07/1936	Saleteka	G5	35.1	34.2	32.0	28.0	24.1	20.3	17.5	**1.30**	45.6	44.5	41.6	36.4	31.3	26.4	22.8
15	31/08/1947	Bodlkasa	G5	37.6	36.0	31.5	28.2	25.0	22.0	18.0	**1.40**	52.6	50.4	44.1	39.5	35.0	30.8	25.2
16	03/08/1953	Brahmapuri	G5	30.5	27.7	27.0	26.0	24.5	20.0	17.9	**1.28**	39.0	35.5	34.6	33.3	31.4	25.6	22.9
17	22/08/1990	Mul	G5	31.0	30.9	29.7	29.3	28.6	25.3	21.7	**1.28**	39.7	39.6	38.0	37.5	36.6	32.4	27.8
18	23/07/1967	Bhopalpatnam	G6	14.4	14.2	14.0	13.8	13.7	12.6	11.0	**1.23**	17.7	17.5	17.2	17.0	16.9	15.5	13.5
19	14/08/1953	Ahri	G8	32.0	31.0	30.6	30.0	29.5	26.8	23.8	**1.23**	39.4	38.1	37.6	36.9	36.3	33.0	29.3
20	09/08/1983	Huzurabad	G8	32.0	30.5	29.0	27.8	26.8	21.2	20.0	**1.23**	39.4	37.5	35.7	34.2	33.0	26.1	24.6
21	15/09/1964	Jath	K1	14.6	13.8	13.3	12.7	12.2	11.4	10.1	**1.17**	17.1	16.1	15.6	14.9	14.3	13.3	11.8
22	15/09/1931	Bilgi	K1	11.9	11.5	11.2	10.9	10.6	9.7	8.6	**1.17**	13.9	13.5	13.1	12.8	12.4	11.3	10.1
23	05/08/1914	Mahabaleshwar	K1	26.0	25.2	24.3	24.0	23.7	22.3	20.7	**1.32**	34.3	33.3	32.1	31.7	31.3	29.4	27.3
24	05/08/1915	Khanapur	K1	31.0	26.3	23.5	21.7	19.4	15.7	11.5	**1.32**	40.9	34.7	31.0	28.6	25.6	20.7	15.2
25	24/07/1989	Bhira	K2	71.3	52.5	47.0	42.0	38.5	35.2	32.0	**1.30**	92.7	68.3	61.1	54.6	50.1	45.8	41.6
26	11/07/1958	Lonavala	K2	31.0	28.0	25.0	23.6	21.7	17.0	12.0	**1.34**	41.5	37.5	33.5	31.6	29.1	22.8	16.1
27	07/11/1922	Indapur	K2	16.0	14.5	13.7	13.0	12.8	11.3	10.2	**1.26**	20.2	18.3	17.3	16.4	16.1	14.2	12.9
28	14/06/1942	Karmala	K2	18.0	16.5	15.7	15.3	15.0	14.0	13.3	**1.23**	22.1	20.3	19.3	18.8	18.5	17.2	16.4
29	31/10/1916	Yemmiiganur	K3	21.8	21.7	21.6	21.5	21.4	20.8	19.9	**1.13**	24.6	24.5	24.4	24.3	24.2	23.5	22.5
30	17/08/1905	Siruguppa	K3	19.6	16.7	15.3	14.8	14.3	12.4	10.8	**1.13**	22.1	18.9	17.3	16.7	16.2	14.0	12.2
31	17/11/1992	Ranebennur	K3	33.0	30.0	28.3	27.4	26.7	23.9	21.7	**1.30**	42.9	39.0	36.8	35.6	34.7	31.1	28.2
32	19/09/1960	Hospet	K4	13.1	12.5	12.1	11.7	11.3	9.7	7.9	**1.13**	14.8	14.1	13.7	13.2	12.8	11.0	8.9
33	17/08/1917	Rayadurg	K4	15.0	14.0	13.0	12.7	12.2	10.7	9.3	**1.13**	17.0	15.8	14.7	14.4	13.8	12.1	10.5
34	23/07/1989	Tiruvur	K5	38.0	34.7	32.3	31.5	30.2	26.8	23.1	**1.23**	46.7	42.7	39.7	38.7	37.1	33.0	28.4

RAINSTORM MAXIMIZATION

In the case of major hydraulic structures, virtually, cent per cent safety is required. These are, therefore, designed for Probable Maximum Flood (PMF). The maximization of design storm is required to provide optimum combination of moisture charge and dynamic efficiency (i.e. convergence and vertical motion) of the storm. The method which is commonly employed for maximization of observed rainstorms is based upon the following two assumputions (U.S.W.B., 1960):

1. Rainfall can be expressed as the product of available moisture and combined effect of storm efficiency and inflow wind, and
2. The most effective combination of storm efficiency and inflow wind has either already occurrd or has been closely approached in the major storms of record.

On the basis of above assumptions, in order to obtain Probable Maximum Precipitation (PMP), severe rainstorms over and near the basins were adjusted for optinum moisture charge using surface dew point temperature data. During rainstorm, the use of surface dew point temperature at number of station measured in the warm moist air given satisfactory estimates of moisture available in the atmosphere (Reitan, 1963). The corresponding value of maximum total moisture over these basins have been computed from the highest 24 hour persisting dew point temperature for the storm period (long period data).

In evaluating maximized design raindepth for the Krishna and the Godavari basins, the transposed grided raindepths were adjusted by the Moisture Maximization Factor (MMF) based on dew point temperature data of 35 stations inside the two basins (WMO, 1986). The MMF is a ratio between the maximum moisture observed over the catchment to the moisture observed during the actual rainstorm period.

$$\text{MMF of a severe rainstorm} = \frac{\text{the maximum moisture observed over the catchment on the basis of long period data during the period when the rainstorm occurred}}{\text{the moisture observed during the actual rainstorm period}}$$

These MMFs were then applied for all the severe rainstorms of different sub-basins in order to know maximum design raindepths for each rainstorm for different areas, viz. Point, 1000, 5000, 10000 km^2 areas. The genralized 1 day maxium raindepth-grided isohyetal maps for each of these areas were prepared for the Godavari and the Krishna basin and the same are shown in Figurs 2, 3 & 4 respectively.

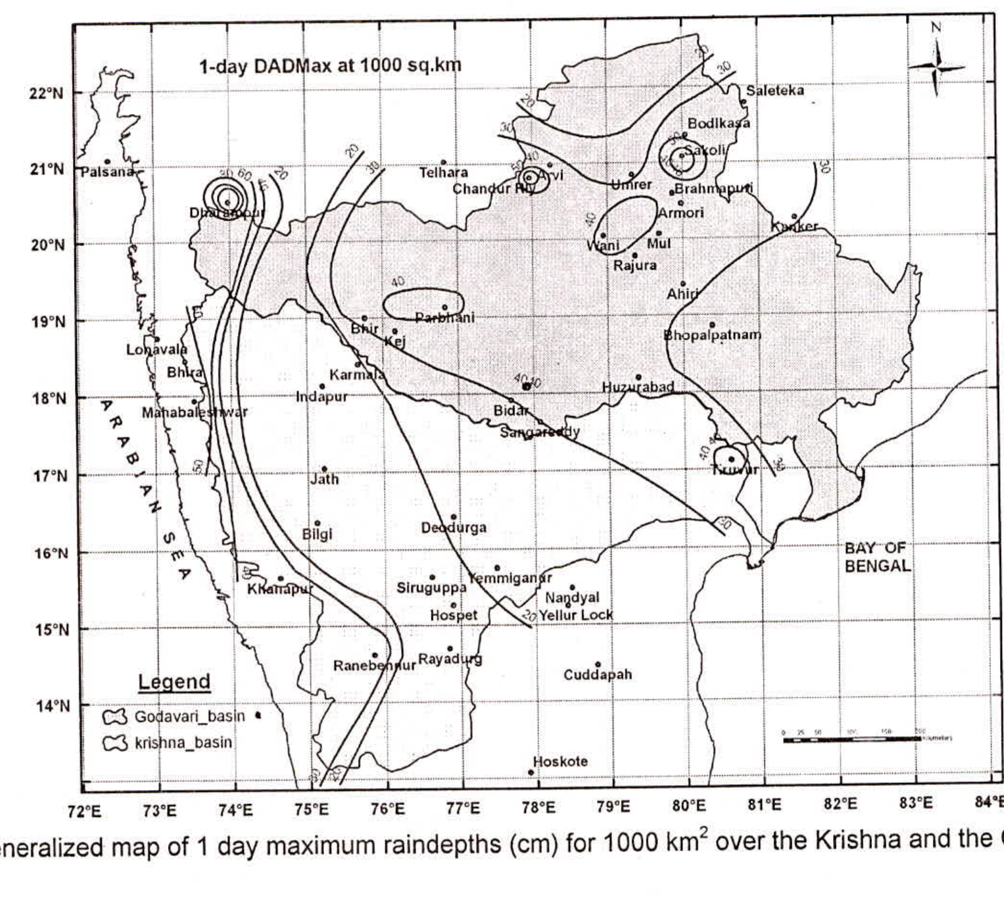

Fig. 2: Generalized map of 1 day maximum raindepths (cm) for 1000 km^2 over the Krishna and the Godavari basin

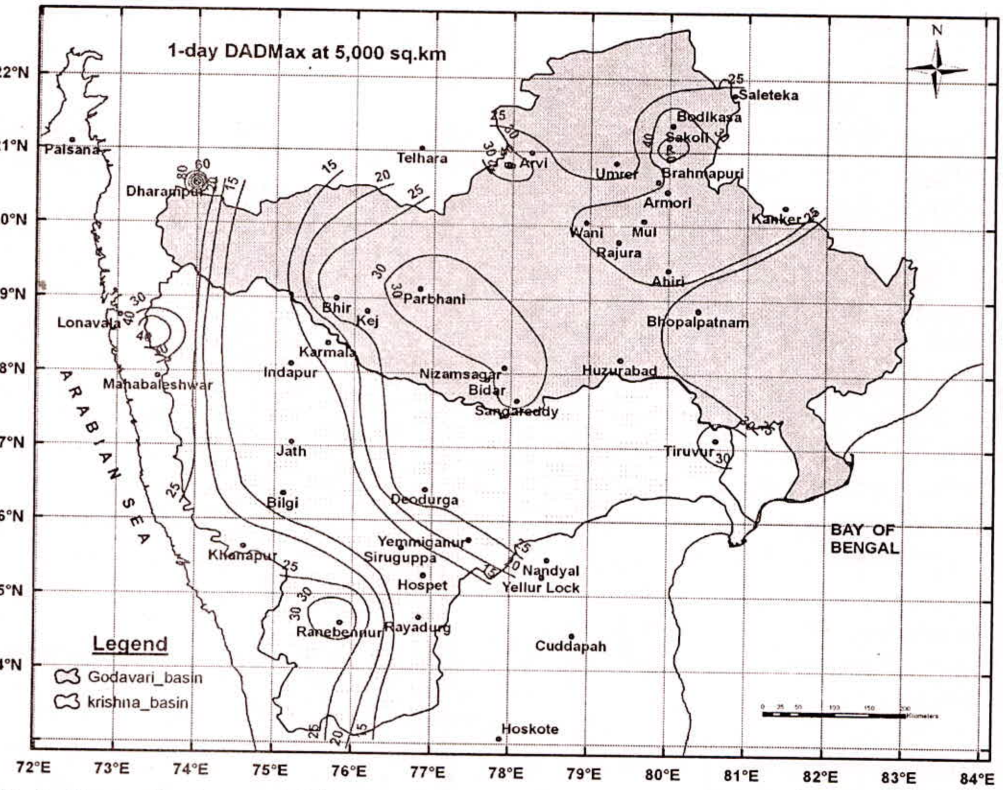

Fig. 3: Generalized map of 1 day maximum raindepths (cm) for 5000 km^2 over the Krishna and the Godavari basin

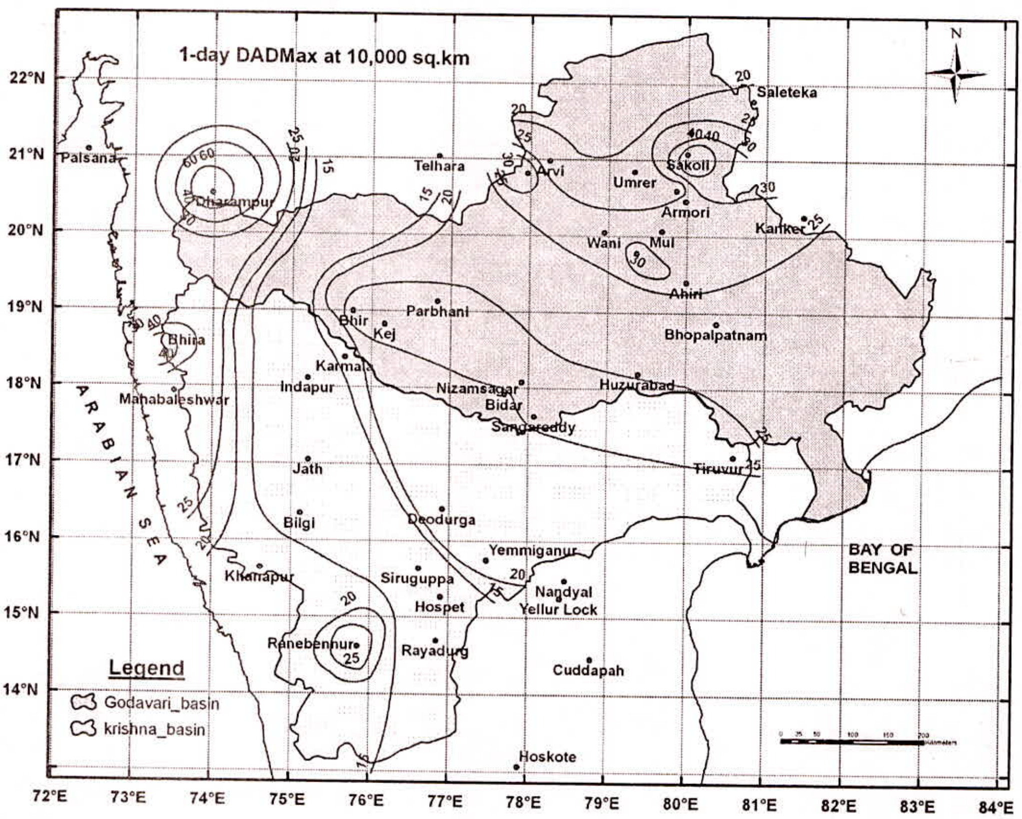

Fig. 4: Generalized map of 1 day maximum raindepths (cm) for 10000 km^2 over the Krishna and the Godavari basin

RESULTS AND DISCUSSION

The analysis shows that,

No severe rainstorms have occured in the grids between long. 81°–83°E and lat. 17°–20° N of the Godavari basin and between long.77°–80°E and lat. 16°–17.5°N of the Krishna basin. This may be due to the fact that these are the locations through which the monsoon disturbances enter the Indian land region and secondly, rainfall occurs to the southwest quadrant of the disturbances.

It is also seen that on the both side of the Western Ghat, DAD raindepths decrease and are in the range of 30–40 cm and over the Ghat region it ranges between 50 to 80 cms. In case of the Krishna basin towards the lee side of the Western Ghat, it even decreases upto 20 cms. The Wainganga sub-basin of the Godavari basin comprises maximum raindepth of the order of 50 cm for point area to 30 cm over 10,000 km^2 of area. Rest of the region receives on an average DAD raindepth of 30 cm.

The maximum raindepths obtained in this study are based upon more than 100 years of rainfall data and therefore can be used to estimate PMP raindepths within the grids given in the isohyetal maps. These grided maps of PMP for different size areas will be very useful for estimating design storm of PMP magnitude for catchments having area up to 10000 km^2.

ACKNOWLEDGEMENTS

Authors are highly grateful to Director, and Head of the Climatology and Hydrometeorology Division, IITM, Pune for their constant encouragement and support for carrying out this study. Thanks are also due to Additional Director General of Meteorology, Research (ADGMR), India Meteorological Department, for kindly permitting to use daily rainfall station data in this study.

REFERENCES

Dhar, O.N., Kulkarni, B.D. and Nandargi, S.S. (1991). Design storm estimation for Wainganga basin up to Dhapewada dam site a brief appraisal, J. of Applied Hydrology, Vol. IV, No. 1&2.

Kulkarni, B.D., Mandal, B.N., Mulye, S.S. and Deshpande, N.R. (2005). Estimation of Design storm for the Manjra Catchment J. of Applied Hydrology, Vol. XVII, No. 2&3, pp. 52–59.

Lal, B., Mehra, H.C. and Guha, K.B. (2000). Generalized maps of 1 day point maximum persisting dew point temperature, IMD Publ.

Rakhecha, P.R. and Kennedy, M.R. (1985). A generalized technique for estimation of probable maximum precipitation in India, J. of Hydrology, Vol. 78.

Rakhecha, P.R., Deshpande, N.R. and Nandargi, S.S. (1990). Maximum persisting dew points during the southwest monsoon season over India, Mausam, Vol. 41, No. 1, pp. 140–142.

Reitan, C.H. (1963). Surface dew point and water vapor aloft, J. of Applied Meteorology, Vol. 2.

U.S. Weather Bureau (1960). Tech. Paper No. 38.

World Meteorological Organisation (1969). Estimation of maximum floods. Tech. Note 98, WMO, No. 233 TP. 126.

World Meteorological Organisation (1986). Manual for estimation of probable maximum precipitation, Operational hydrology Report No. 1, Second Edition, W.M.O. No. 332.