551.311.2 : 551.578.1 (543)

A pilot study on determining the range of moisture adjustment factors for rainstorms of Madhya Pradesh Region

R. C. SHENOY, T. G. CHANGRANEY and P. K. RAMAN

Central Water and Power Commission, New Delhi

(*Received 6 February 1967*)

ABSTRACT. In this paper, procedural steps involved in determining moisture adjustment factors for transposition and maximisation of rainstorms have been discussed. Moisture maximisation factors for **13** major storms of Madhya Pradesh region have been determined on the basis of data of representative storm dew points and corresponding highest recorded dew points with respect to three standard isobaric levels of 200, 300 and 500 mb. From the results of the study it is concluded that for obtaining the estimates of maximum probable storm for Madhya Pradesh region, the moisture adjustment factors range from 1·25 to 1·67 with an average of 1·46.

1. Introduction

In the design of major hydraulic structures, such as dams, the hydraulic engineer is often confronted with the problem of knowing the physical upper limit to the magnitudes of floods in the area of interest. This maximum probable flood is again interdependent on the maximum probable storm or probable maximum precipitation. An approach to this problem has been discussed in this study with particular emphasis on determining the range of moisture adjustment factors in respect of some severe rainstorms of Madhya Pradesh region.

1.2. *Moisture charge and storm efficiency*

The dynamical aspects of rain-producing processes in the atmosphere are not known with requisite precision to compute probable maximum storm on a purely theoretical basis and arrive at reliable results. Every attempt so far made in this direction involves hypothesizing as to how storm precipitation would have given higher value over an area under atmospheric conditions assumed to be in a state of saturation with respect to moisture. When the air mass is saturated and assumed to have pseduo adiabatic temperature lapse rate, moisture content of a column of air or moisture charge will depend on dew point temperatures over sea level or reduced to reference standard isobaric level, say 1000 mb. During marked convergent flow of air in a storm, a large horizontal inflow of water vapour and upward motion of air is maintained into the area of heavy precipitation. In estimating convergence of winds, speed and direction of both inflow and outflow at various levels over the storm area are considered. Other factor which requires examination is the height to which surface moisture can be carried aloft by vertical motion in a tropical maritime air mass. This depends upon (*i*) the rate at which moist air is transported into the area of precipitation, (*ii*) the thermal stability of the air column and (*iii*) the magnitude of convergence over the storm area. All these factors contribute to the storm producing mechanism and are collectively termed as 'Storm efficiency'.

1.3. *Probable Maximum Precipitation (PMP)*

Precipitation can be expressed as the product of available moisture and combined effect of storm efficiency and inflow winds. Probable Maximum Precipitation (PMP) or Probable Maximum Storm (PMS) represents the critical precipitation depth or physical upper limit to storm rainfall over a basin. This critical precipitation depth is estimated by analysing the recorded major storms in the region in which the basin is located and suitably increasing the highest storm rainfall depth so as to represent the most favourable combination of dynamic efficiency, inflow winds and maximum moisture charge for realising the maximum precipitation in a given area and time. In this study it is assumed that a most effective combination of storm efficiency and inflow wind has either occurred or has been closely approached in major storm on record.

Bruce (*see* Ref.) has justified this assumption on the basis of following three reasons —

(1) Little is known of the structure of the storm and factors controlling their efficiency.

(2) Major observed storms have undoubtedly produced heavy precipitation because of their high efficiency rather than high moisture charge.

TABLE 1

Madhya Pradesh Storms

Storm Centre	Storm period	Repre-sentative per-sisting D.P. (°C)	Max. D.P. (°C)	Precipitable water 200 mb (a)	(b)	(c)	300 mb (a)	(b)	(c)	500 mb (a)	(b)	(c)
22°55′N, 81°00′E	18–22 Sep 1926	22·66	25·86	2·64	3·40	1·29	2·60	3·30	1·27	2·35	2·96	1·26
Shergarh	9–12 Aug 1941	23·90	27·00	2·90	3·80	1·31	2·88	3·75	1·30	2·60	3·25	1·25
21°30′N, 81°52′E	11–13 Jul 1942	22·00	28·00	2·50	4·10	1·64	2·48	4·05	1·63	2·30	3·52	1·53
23°42′N, 78°05′E	27–29 Jun 1945	22·00	27·50	2·50	3·95	1·58	2·48	3·90	1·57	2·30	3·40	1·48
Bandal Kasa	29–31 Aug 1947	24·20	28·00	2·97	4·10	1·38	2·93	4·05	1·38	2·65	3·52	1·33
Dhantari	15–17 Aug 1948	22·50	29·50	2·60	4·70	1·81	2·58	4·60	1·78	2·40	3·88	1·62
Sindhewahi	12–14 Aug 1949	23·00	28·00	2·70	4·10	1·52	2·68	4·07	1·52	2·45	3·52	1·44
20°15′N, 80°23′E	30 Jul–1 Aug 1951	24·00	30·00	2·90	4·90	1·69	2·87	4·80	1·67	2·60	4·05	1·56
Rudri	4–5 Sep 1952	23·00	29·40	2·70	4·63	1·71	2·68	4·50	1·68	2·45	3·82	1·56
23°15′N, 80°05′E	24–26 Aug 1952	23·00	29·00	2·70	4·50	1·67	2·68	4·40	1·64	2·45	3·75	1·53
19°05′N, 80°03′E	13–15 Aug 1953	23·50	30·50	2·80	5·10	1·82	2·78	5·00	1·80	2·52	4·22	1·67
22°50′N, 77°15′E	29–31 Aug 1955	23·00	27·00	2·70	3·80	1·41	2·68	3·75	1·40	2·45	3·25	1·33
24°10′N, 81°57′E	13–15 Jul 1958	24·00	30·00	2·90	4·90	1·69	2·88	4·80	1·67	2·60	4·05	1·56

Note : (a) Precipitable water corresponding to the representative and persisting dew point, (b) Precipitable water corresponding to the maximum dew point, (c) Moisture adjustment factor

(3) It is generally suspected that maximum efficiency of a storm is realised when the moisture content is not maximum.

Fletcher (1951) has concluded that when major rain-producing storms are considered the magnitude of rainfall depths varies directly with the water vapour content of the airmass from which the rain falls.

Therefore, for obtaining estimates of PMS of Madhya Pradesh region, major storms of this region have been studied and maximised for moisture charge only.

2. Meteorological situations causing heavy rain spells in Madhya Pradesh Region

2.1. Synoptic weather situations which contribute to the storm efficiency in the region during southwest monsoon season are generally low pressure systems or depressions originating from the Bay of Bengal and moving across Madhya Pradesh in a westerly or northwesterly direction causing rainfall in south or southwestern sector of depression. There have also been instances, when low pressure systems over Madhya Pradesh have intensified due to incursion of moisture from the Arabian Sea current of southwest monsoon. This region also receives heavy and widespread rain in association with the strengthening of seasonal trough or when the axis of the monsoon trough passes either through or just above this region. Hence it can be reasonably assumed that in any river catchment of this region rainstorm can occur with same dynamic efficiency but not necessarily with same moisture charge which in turn will be proportional to the highest recorded surface dew points temperatures.

In view of the above, Depth-Area-Duration (DAD)/Storm Transposition method of storm analysis may be considered applicable for this region.

2.2. India Meteorological Department have analysed all major rainstorms of Madhya Pradesh region by DAD method (Raman and Dhar 1966) and have given weighted average storm rainfall depths for all the storms that have been studied in this paper.

3. Data used

3.1. All the observatory stations in and around the Madhya Pradesh region for which dew point temperature data for all synoptic hours of observations are available, have been considered and compiled for 20 years, *i.e.*, 1945—1964. From this data maximum dew points recorded at each of the stations for each fortnight of the monsoon period during the above period were picked up.

The storms that have been selected for the study are given in Table 1. Dew point temperatures recorded at each synoptic hour of observation for which the data were available were compiled for each day of the storm, as well as for a day prior to and after the day of heavy rainstorm.

4. Evaluation of maximum probable precipitation

4.1. The highest observed dew points reduced to 1000-mb level for the first half and second of the months in respect of the observatory stations over Madhya Pradesh and adjoining areas were evaluated for the period June to October on the basis of available observational data for the period 1945—1964. The results are shown in Table 3. The values were also plotted on charts and isopleths drawn to facilitate picking out of values for desired locations.

4.2. The storms selected for study are shown in Table 1. Dew point temperature values for the storm day as well as for the previous and subsequent days were examined and representative value of dew point appropriate to the storm was selected. These values are also shown in Table 1.

4.3. The method of evaluation of maximum probable precipitation is illustrated with reference to the storm of 15-17 August 1948 (Table 1) which occurred in association with a monsoon depression. The representative dew point over the storm area was estimated as 22·5°C. The maximum dew point for the area in question during the second half of August was estimated as 29·5°C. For a saturated atmosphere with saturated adiabatic lapse-rate and temperature values of 22·5° and 29·5°C at 1000-mb level, the precipitable water vapour contents in atmospheric columns extending up to 500, 300 and 200-mb levels are given below:

Layer (mb)	Precipitable water (inches)		Adjustment factor
	T_0=22·5°C (a)	T_0=29·5°C (b)	(b)/(a)
1000-500	2·40	3·88	1·62
1000-300	2·58	4·60	1·78
1000-200	2·60	4·70	1·81

The last column gives the adjustment factors for obtaining maximum probable precipitation from the observed precipitation.

Adjusted storm rainfall DDA values for this storm are given in Table 2. Similar procedure was followed in respect of the other storms.

TABLE 2

Standard area (sq. miles)	D.D.A. values	Adjusted storm rainfall depths for 15-17 August 1948 storm, maximised upto different standard isobaric levels		
		500 mb	300 mb	200 mb
Central rainfall	20·17	32·68	35·90	36·51
500	18·50	29·97	32·93	33·48
1000	17·20	28·35	30·62	31·13
5000	12·30	19·93	12·89	22·26
10,000	10·30	16·69	18·33	18·64
20,000	7·90	12·80	14·06	14·30

5. Adjustment for transposition and maximisation of storm

The principle of storm transposition requires careful examination of meteorological homogenity as well as climatology and orography of the problem basin with respect to the region in which the storm in question has actually occurred. These factors also affect the upper limits of the maximum precipitable water over the area with respect to the precipitable water actually available during the major storm.

The storms that occur with centres on the windward side of the Vindhya Mahadeo and Pachmarhi hills should not be superimposed on the leeward side of these hills. In other areas storms will have to be suitably adjusted for transposing it to the problem area keeping in view the climatological variation and the moisture charge over the two areas.

TABLE 3

Maximum dew point temperatures in °C (reduced to 1000-mb level) recorded in each fortnight of monsoon season at observatory stations in and around Madhya Pradesh Region

Station	June		July		August		September		October	
	I	II	I	II	I	II	I	II	I	II
Gwalior	27·8	30·8	30·8	28·6	28·2	28·1	29·2	27·6	25·9	28·1
Guna	29·0	27·9	31·1	29·5	32·1	29·5	28·7	28·1	27·0	25·0
Nowgong	31·2	29·4	28·7	30·6	28·4	28·6	27·6	27·0	25·4	23·5
Neemuch	32·0	29·8	28·4	28·0	26·8	27·5	29·0	26·5	25·0	25·0
Indore	32·1	32·1	25·3	30·0	25·1	24·4	30·0	27·0	23·1	22·4
Sagar	30·0	27·8	26·2	26·0	26·5	25·6	26·2	25·9	23·8	25·0
Khandwa	27·6	26·6	29·4	27·1	26·2	30·0	33·1	28·8	26·0	23·8
Hoshangabad	33·3	32·8	32·2	32·2	29·4	28·3	27·0	27·5	29·7	28·9
Seoni	29·9	33·2	31·2	29·0	29·8	25·8	32·3	29·8	28·1	23·3
Pachmarhi	28·5	26·3	31·3	25·3	26·8	26·8	26·8	26·3	24·6	26·9
Satna	29·5	29·0	30·5	32·8	27·1	27·0	26·6	26·3	25·4	23·8
Jabalpur	31·1	26·2	26·7	26·5	28·9	26·4	25·7	25·6	25·2	24·2
Pendra Road	29·6	28·7	25·8	29·0	27·0	28·3	25·0	25·6	23·9	24·0
Raipur	33·7	27·1	33·8	27·5	29·5	32·3	30·7	33·0	28·4	24·7
Kanker	28·3	29·4	27·7	28·9	27·4	28·3	27·0	28·3	29·0	25·1
Jagdalpur	25·6	27·2	24·0	26·7	27·6	28·6	24·5	27·1	24·3	24·8
Ambikapur	24·7	24·7	28·0	28·2	27·0	28·7	28·7	28·6	26·2	23·9
Champa	29·0	28·3	27·9	27·3	27·3	28·9	30·4	26·2	28·1	26·8
Chindwara	26·3	27·8	27·8	26·2	26·0	24·4	25·0	24·2	21·4	24·3
Mandla	32·2	30·6	31·7	26·1	26·1	26·9	25·6	25·0	27·0	24·3
Raigarh	28·3	28·9	27·8	27·2	28·3	29·4	27·1	27·2	28·1	27·2
Ratlam	31·4	28·3	28·3	26·7	27·0	25·6	30·8	30·8	31·4	30·7
Sheopur Kalan	31·2	30·0	32·9	31·1	31·1	31·1	32·1	32·7	33·2	28·2
Umaria	32·9	28·9	31·8	29·4	29·3	29·4	28·2	28·8	27·2	29·0
Betul	28·0	26·1	25·0	26·4	24·4	24·0	26·0	28·0	23·3	23·3
Bairagarh	25·7	25·0	25·7	26·4	28·1	25·6	27·3	24·6	24·4	23·6
Rajgarh	26·1	29·4	29·0	26·9	28·7	26·1	25·6	25·0	26·6	27·7
Bamrauli	28·0	29·3	28·5	30·6	28·5	29·3	28·1	29·2	26·2	29·8
Fatehpuri	27·2	33·1	29·8	29·8	29·8	29·8	28·2	28·5	27·0	25·4
Orai	31·8	31·8	31·7	31·1	31·1	32·8	30·4	28·3	26·4	25·4
Brijnagar	26·2	26·8	27·3	28·5	27·3	27·8	26·1	25·6	29·4	20·4
Banda	31·8	32·3	32·2	30·0	32·2	29·4	31·4	31·1	29·4	27·8
Hanomkonda	32·0	26·7	26·1	26·1	25·6	30·6	31·7	30·6	29·2	24·8
Titlagarn	29·2	31·2	28·9	30·6	30·6	30·0	27·2	29·4	26·7	25·8
Gondia	30·6	31·7	28·5	27·4	26·7	26·1	33·3	33·3	32·1	32·7
Yeotmal	29·6	30·8	28·0	25·6	27·2	25·0	26·5	26·5	24·8	26·5
Sambalpur	34·4	33·0	32·8	34·0	30·6	31·7	31·0	31·0	30·2	28·7
Daltonganj	34·0	34·0	30·2	28·9	29·1	31·1	29·0	31·0	28·7	28·0
Gaya	32·2	27·8	30·6	27·6	28·1	30·6	33·3	27·1	25·3	25·6
Varanasi	34·0	31·7	34·0	31·1	33·3	31·7	32·8	30·9	33·3	26·8
Akola	31·1	32·1	32·0	30·0	30·4	28·7	29·0	26·8	33·7	28·7
Amarvati	33·9	29·0	27·2	30·0	28·3	27·8	28·3	30·5	25·5	23·7
Nagpur	31·7	28·8	27·2	28·0	26·1	28·3	27·8	28·3	28·7	29·4
Jhansi	36·0	37·1	36·0	30·0	28·0	29·0	33·1	31·5	27·7	24·9
Kotah	36·0	33·0	31·0	30·6	33·0	31·0	33·2	32·0	32·0	28·7
Dohad	30·1	32·8	33·9	30·6	27·0	31·0	28·0	28·1	35·6	28·3
Chanda	35·6	33·0	33·9	29·0	32·0	30·0	28·2	30·5	31·0	28·7
Jalgaon	29·4	29·0	31·0	27·0	28·7	28·0	29·8	26·7	29·2	30·8
Ramnagundam	31·5	31·1	28·1	29·0	29·4	33·9	29·0	28·7	29·6	30·8

I and II refer to first and second fortnight

6. Current practice regarding moisture maximisation

The current practice of computing precipitable water in the column of air between 1000—200 mb has been examined since it is considered that moisture maximisation factors obtained are generally excessive. This aspect has been examined with reference to upper air flow patterns and the influx of moisture to the Madhya Pradesh region. Precipitable water content in respect of all radiosonde stations in India has been computed (Ananthakrishnan *et al.* 1965) and it is observed that, over this region, moisture charge above 500-mb atmospheric level is not appreciable. Further, convergence layer does not generally extend above the mid-tropospheric level of 500 mb (Venkataraman and Rao 1965). As the depth of convergent inflow layer increases there must be some increase in the compensating divergent flow above it. In the present study moisture adjustment factors with all the three levels, *viz.*, 200, 300 and 500 mb have been computed. But it has been shown that we will be justified in adopting the adjustment factor for atmospheric layer upto 500 mb.

The moisture adjustment factors with respect to all the 13 storms have been given in Table 1.

7. Moisture adjustment for transposition of storm

Keeping in view the climatic, synoptic and orographic limitations for transposition of storms, it was felt that the storm of 15-17 August 1949 can be transposed to the following locations —

(*a*) *Seonath* river catchment before its confluence with *Mahanadi*

(*b*) *Mahanadi* sub-basin before its confluence with *Seonath* river.

There is only one dew-point station in each of the sub-basin (*vide* Fig. 1) — Raipur in Seonath sub-basin and Kanker in Mahanadi sub-basin. The maximum dew points recorded at these places in the second half of August (Table 3) are 32·3°C and 28·3°C, while the maximum dew point for the actual storm location is 29·5°C. The transposition adjustment factors for the two basins are derived as follows —

Layer (mb)	Precipitable water (inches)			Adjustment factor	
	DP= 29·5°C (a)	DP= 32·3°C (b)	DP= 28·3°C (c)	Seonath basin b/a	Mahanadi basin c/a
1000-500	3·88	4·80	3·65	1·24	0·94
1000-300	4·60	5·70	4·15	1·24	0·90
1000-200	4·70	5·87	4·18	1·25	0·89

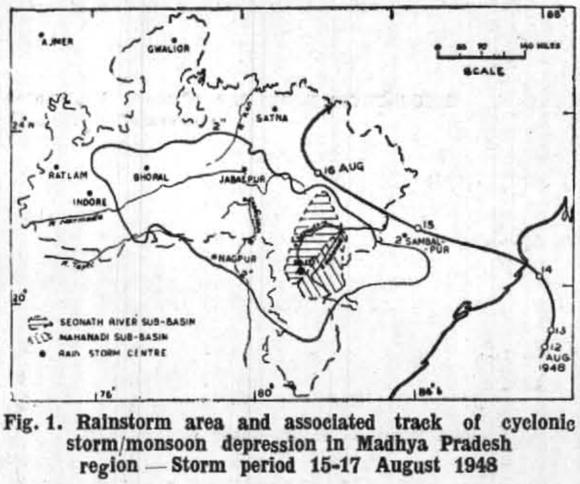

Fig. 1. Rainstorm area and associated track of cyclonic storm/monsoon depression in Madhya Pradesh region — Storm period 15-17 August 1948

The combined adjustment factor for obtaining the maximum probable precipitation of the transposed storm at the new locations from the observed precipitation at the actual location is obtained by multiplying the adjustment factors given in 4·3 and above. The appropriate values are given below.

Layer (mb)	Seonath basin	Mahanadi basin
1000–500	1·62×1·24=2·00	1·62×0·94=1·52
1000–300	1·78×1·78=2·21	1·78×0·90=1·60
1000–200	1·81×1·25=2·26	1·81×0·84=1·61

8. Conclusions

From the results given in Table 1, it is seen that adjustment factor for moisture charge for Madhya Pradesh region on the basis of the study of 13 storms varies as follows —

Level (mb)	Range	Average
200	1·29–1·82	1·56
300	1·27–1·80	1·54
500	1·25–1·67	1·46

We recommend adoption of maximisation factor with respect to 500-mb level, *i..e.*, 1·25 to 1·67 with an average of 1·46 on the basis of this pilot study. These may be revised when detailed studies are undertaken with better network of dew point temperature stations.

9. Acknowledgements

This study was undertaken at the instance of the Sub-Committee set up by Inter-Directorate Committee of the Central Water and Power Commission on streamlining procedural steps for estimation of maximum probable floods for spillway designs.

The authors are very grateful to Shri D. B. Anand, Chairman, Central Water and Power Commission for taking keen interest in this study and for permission for sending the same for publication.

We are thankful to India Meteorological Department for the supply of necessary dew point temperature data.

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