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# Efficiency of the severe recorded rainstorms over north India

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ABSTRACT. 38 severe rainstorms that have been experienced over north India during the last 70 to 80 years were analysed by DAD method and for each rainstorm $P/M$ ratios were worked out for different size of areas. Comparison of these ratios has shown that the most efficient rainstorm that has occurred during the last 80 years over north India was the rainstorm of October 1955 over the Punjab plains for one-day duration and upto 10,000 sq. miles (25,900 sq. km).

## 1. Introduction

In this study an attempt has been made to study the storm efficiency of the severe recorded rainstorms which have occurred during the last 80 years (1891-1970) over different meteorological divisions of north India (Fig. 1). Major rainstorms numbering about 38 were selected for this study from a thorough scrutiny of the daily rainfall data of the different meteorological divisions in north India, roughly north of Lat. 20°N. The efficiency of these rainstorms was worked out on the day of maximum rainfall for the standard areas of 2590, 12950, 25900 sq. km (1000, 5000 and 10,000 sq. miles). On the basis of this study, envelope rainstorm efficiency values have been determined for each of the meteorological divisions in north India. These envelope efficiency values can be used to estimate the maximum probable precipitation (hereafter referred to as PMP) for small size areas of these meteorological divisions.

## 2. Rainstorm efficiency

Over a plain area, besides the maximum moisture content in the inflowing winds, rainfall in an intense rainstorm mainly results from an optimum combination of the following factors :

(*a*) Convergence, (*b*) vertical velocities, and
(*c*) condensation into cloud particles.

These factors collectively are termed as rainstorm efficiency (Miller 1969). At present there are no satisfactory methods of assigning maximum values individually or collectively to various factors that constitute the storm efficiency. On the other hand, maximum moisture content over an area can be estimated from a study of appropriate climatological data of the region (WMO 1969 and Miller 1969). However, in recent years an indirect approach has been found to estimate efficiency of rainstorms. This approach is based upon the observed rates of rainfall in a rainstorm over a non-orographic region. In recent years, US Weather Bureau have used this approach in some of their *Hydrometeorological Reports* (1961, 1963 and 1966) and *Technical Papers* (1963). WMO (1969) has recommended this approach for obtaining maximum rainfall for small size basins. Wiesner (1970) has used this method to work out the efficiencies of the severe rainstorms in USA.

According to this technique, efficiency ($E$) of a rainstorm is defined as the ratio of the observed rainfall ($P$) in a rainstorm over a given area to the precipitable water ($M$) present in the moist air over the storm area during a given duration. In other words, efficiency ($E$) of a rainstorm is given by :

$$E = P/M \qquad (1)$$

$P/M$ ratio is thus an index of the efficiency of storm processes which convert water vapour available to a given storm in a given duration into precipitation over a given region which is free from orography.

## 3. Estimation of PMP with the help of enveloping value of rainstorm efficiency

Enveloping value of rainstorm efficiency for a plain region can be used for obtaining PMP estimates for point areas or small size basins in those regions.

U.S. Weather Bureau (1961) have given the following relationship for obtaining PMP by using the envelope value of storm efficiency :

$$(\text{PMP})_{\text{non-orographic}} = (P/M)_{\text{env}} \times (\text{Moisture})_{\text{max}} \qquad (2)$$

In Eq. (2) $(P/M)_{\text{env}}$ is the envelope value of the storm efficiency values of severe rainstorms over a given region obtained by analysing all the major recorded rainstorms in that region. $(\text{Moisture})_{\text{max}}$ is the envelope of all the observed values of moisture over that region over a long period of years.

**TABLE 1**

**Efficiency values of the severe rainstorms over North India**

| Rainstorm period | Date of max. rainfall | Area in sq. km (sq. miles) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2590 (1000) | | | | 12,950 (5000) | | | | 25,900 (10,000) | | | |
| | | DAD (inch) | $P$ (inch/hr) | $M$ (inch) | $P/M$ (%) | DAD (inch) | $P$ (inch/hr) | $M$ (inch) | $P/M$ (%) | DAD (inch) | $P$ (inch/hr) | $M$ (inch) | $P/M$ (%) |
| **Punjab and Haryana** | | | | | | | | | | | | | |
| 3–5 Oct 1955 | 5 Oct | 17·0 | 0·71 | 2·4 | *29·0* | 13·0 | 0·54 | 2·4 | *22·2* | 10·2 | 0·43 | 2·4 | *17·4* |
| 24–26 Sep 1954 | 25 Sep | 4·5 | 0·19 | 2·8 | 6·8 | 3·9 | 0·16 | 2·8 | 5·8 | 3·5 | 0·15 | 2·8 | 5·3 |
| 2–5 Sep 1950 | 4 Sep | 7·6 | 0·32 | 3·3 | 9·6 | 5·1 | 0·21 | 3·3 | 6·5 | 4·2 | 0·18 | 3·3 | 5·3 |
| **Uttar Pradesh** | | | | | | | | | | | | | |
| 5–7 Sep 1938 | 6 Sep | 9·0 | 0·38 | 3·2 | 11·7 | 7·5 | 0·31 | 3·2 | 9·7 | 6·0 | 0·25 | 3·2 | 7·8 |
| 9–11 Aug 1938 | 10 Aug | 15·5 | 0·65 | 3·2 | *20·5* | 10·0 | 0·44 | 3·2 | 13·2 | 7·5 | 0·30 | 3·2 | 9·7 |
| 27–30 Sep 1924 | 28 Sep | 11·8 | 0·49 | 2·4 | 20·1 | 9·5 | 0·40 | 2·4 | *16·2* | 8·0 | 0·33 | 2·4 | *13·6* |
| 20–23 Sep 1922 | 21 Sep | 7·7 | 0·32 | 2·9 | 10·9 | 5·7 | 0·24 | 2·9 | 8·1 | 4·6 | 0·19 | 2·9 | 6·5 |
| 31–3 Aug 1915 | 1 Aug | 11·6 | 0·48 | 3·0 | 15·9 | 6·5 | 0·27 | 3·0 | 8·9 | — | — | — | — |
| **Bihar** | | | | | | | | | | | | | |
| 1–3 Oct 1961 | 2 Oct | 13·4 | 0·56 | 2·7 | *20·8* | 10·2 | 0·43 | 2·7 | *15·8* | 8·0 | 0·33 | 2·7 | *12·4* |
| 27–29 Aug 1940 | 28 Aug | 9·1 | 0·38 | 3·3 | 11·6 | 7·1 | 0·30 | 3·3 | 9·1 | 5·9 | 0·25 | 3·3 | 7·5 |
| 31·2 Aug 1917 | 1 Aug | 13·3 | 0·55 | 3·3 | 17·1 | 10·2 | 0·43 | 3·3 | 13·1 | 8·2 | 0·34 | 3·3 | 10·6 |
| 17–19 Jun 1898 | 18 Jun | 15·0 | 0·63 | 3·2 | 19·5 | 10·7 | 0·45 | 3·2 | 13·9 | 8·2 | 0·34 | 3·2 | 10·7 |
| **West Bengal** | | | | | | | | | | | | | |
| 4–6 Oct 1968 | 5 Oct | 15·5 | 0·65 | 2·1 | *28·0* | 8·3 | 0·35 | 2·1 | *15·0* | 5·0 | 0·21 | 2·1 | 9·0 |
| 11–13 Jun 1950 | 12 Jun | 15·9 | 0·66 | 2·5 | 25·0 | 9·5 | 0·40 | 2·5 | *15·0* | 6·3 | 0·26 | 2·5 | 10·0 |
| 17–19 Jun 1898 | 18 Jun | 15·0 | 0·63 | 3·1 | 20·4 | 10·9 | 0·45 | 3·1 | 14·8 | 8·0 | 0·33 | 3·1 | *10·9* |
| **Orissa** | | | | | | | | | | | | | |
| 13–15 Jun 1936 | 14 Jun | 12·4 | 0·52 | 3·1 | 16·9 | 9·5 | 0·40 | 3·1 | 13·0 | 7·9 | 0·33 | 3·1 | 10·8 |
| 28–30 Jul 1927 | 29 Jul | 18·8 | 0·78 | 2·9 | *26·7* | 13·1 | 0·55 | 2·9 | *18·6* | 9·9 | 0·41 | 2·9 | 14·4 |
| 16–18 Aug 1926 | 17 Aug | 11·5 | 0·48 | 3·1 | 15·7 | 9·3 | 0·39 | 3·1 | 12·7 | 7·6 | 0·32 | 3·1 | 10·4 |
| 28–30 Jun 1925 | 29 Jun | 12·3 | 0·51 | 2·7 | 19·1 | 10·2 | 0·43 | 2·7 | 15·9 | 9·4 | 0·39 | 2·7 | *11·6* |
| 15–17 Jun 1918 | 16 Jun | 12·3 | 0·51 | 2·8 | 18·6 | 9·8 | 0·41 | 2·8 | 14·8 | 8·0 | 0·33 | 2·8 | 12·1 |
| **Madhya Pradesh** | | | | | | | | | | | | | |
| 27–29 Jul 1965 | 28 Jul | 13·8 | 0·58 | 3·0 | 19·5 | 6·3 | 0·26 | 3·0 | 8·9 | 3·2 | 0·13 | 3·0 | 4·5 |
| 2–4 Jul 1930 | 3 Jul | 14·1 | 0·59 | 3·0 | 19·5 | 11·8 | 0·49 | 3·0 | 16·3 | 9·2 | 0·38 | 3·0 | 12·7 |
| 18–22 Sep 1926 | 21 Sep | 14·1 | 0·59 | 2·5 | *23·3* | 10·4 | 0·43 | 2·5 | *17·2* | 8·8 | 0·37 | 2·5 | *14·6* |
| 1–3 Aug 1919 | 2 Aug | 15·3 | 0·64 | 3·1 | 20·5 | 10·6 | 0·44 | 3·1 | 14·2 | 8·3 | 0·35 | 3·1 | 11·1 |
| 19–21 Jul 1894 | 20 Jul | 12·4 | 0·52 | 2·8 | 18·5 | 9·3 | 0·39 | 2·8 | 13·9 | 7·4 | 0·31 | 2·8 | 11·0 |

**TABLE 1** (*contd*)

| Rainstorm period | Date of max. rainfall | Area in sq. km (sq. miles) 2590 (1000) DAD (inch) | *P* (inch/hr) | *M* (inch) | *P*/*M* (%) | 12,950 (5000) DAD (inch) | *P* (inch/hr) | *M* (inch) | *P*/*M* (%) | 25,900 (10,000) DAD (inch) | *P* (inch/hr) | *M* (inch) | *P*/*M* (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gujarat** | | | | | | | | | | | | | |
| 5–7 Sep 1970 | 6 Sep | 9·8 | 0·41 | 2·7 | 15·1 | 8·8 | 0·37 | 2·7 | 13·6 | 8·0 | 0·33 | 2·7 | 12·3 |
| 17–19 Sep 1950 | 18 Sep | 14·2 | 0·59 | 2·7 | 22·3 | 11·5 | 0·48 | 2·7 | 18·1 | 9·5 | 0·40 | 2·7 | 14·9 |
| 22–24 Aug 1944 | 23 Aug | 12·1 | 0·50 | 2·9 | 17·6 | 9·8 | 0·41 | 2·9 | 14·3 | 8·0 | 0·33 | 2·9 | 11·7 |
| 28–30 Jul 1943 | 29 Jul | 10·9 | 0·45 | 2·9 | 15·7 | 8·6 | 0·36 | 2·9 | 12·3 | 7·4 | 0·31 | 2·9 | 10·6 |
| 4–6 Aug 1942 | 5 Aug | 14·0 | 0·58 | 2·8 | 20·1 | 11·2 | 0·47 | 2·8 | 16·5 | 9·4 | 0·39 | 2·8 | 13·9 |
| 11–13 Aug 1941 | 12 Aug | 11·1 | 0·46 | 2·9 | 16·0 | 9·4 | 0·39 | 2·9 | 13·5 | 8·4 | 0·35 | 2·9 | 12·1 |
| 24–26 Jun 1933 | 25 Jun | 12·2 | 0·51 | 2·8 | 18·3 | 9·0 | 0·38 | 2·8 | 13·5 | 6·8 | 0·28 | 2·8 | 10·2 |
| 25–28 Jul 1927 | 28 Jul | 16·8 | 0·70 | 2·5 | *28·0* | 12·5 | 0·52 | 2·5 | *20·8* | 10·4 | 0·43 | 2·5 | *17·2* |
| **Rajasthan** | | | | | | | | | | | | | |
| 28–30 Jun 1945 | 29 Jun | 13·6 | 0·57 | 3·1 | 18·4 | 10·5 | 0·44 | 3·1 | 14·2 | 8·3 | 0·35 | 3·1 | *11·2* |
| 29–1 Jul 1937 | 30 Jun | 13·0 | 0·54 | 3·2 | 17·0 | 9·7 | 0·40 | 3·2 | 12·7 | 7·7 | 0·32 | 3·2 | 10·1 |
| 26–28 Jul 1913 | 27 Jul | 14·2 | 0·59 | 2·9 | *20·6* | 10·0 | 0·42 | 2·9 | *14·5* | 7·5 | 0·31 | 2·9 | 10·9 |
| 1–3 Jul 1906 | 2 Jul | 11·8 | 0·49 | 3·1 | 15·8 | 8·9 | 0·37 | 3·1 | 11·9 | 7·8 | 0·33 | 3·1 | 10·5 |
| 30–2 Jul 1896 | 1 Jul | 10·8 | 0·45 | 3·0 | 14·9 | 7·6 | 0·32 | 3·0 | 10·5 | 5·5 | 0·23 | 3·0 | 7·6 |

Note : Figures in italics are the highest storm efficiency values for that region for different areas

Generally estimation of maximum moisture over a region is based upon 12 or 24-hr persisting dew point temperatures of record over that region (US Weather Bureau 1960). Moisture in a column of air is expressed in terms of depth of precipitable water (*M*) and values of *M* for different dew point temperatures are available in tables of precipitable water or the nomogram of precipitable water (US Weather Bureau 1951, 1947). Therefore, if the envelope efficiency value for a region is available, the estimation of PMP does not present any serious difficulty as envelope moisture values can be obtained from the generalised 1000-mb maximum dew point charts of the region. Recently US Weather Bureau (1963) have used this procedure to obtain point PMP values for different regions in Alaska.

In India, Pramanik and Hariharan (1951) have worked out maximum dew point temperatures for some representative stations on the basis of the dew point temperature data then available. Dhar and Mhaisker (1968) have worked out the maximum 24-hr persisting dew point temperatures for 10-yr period for stations in southern half of the Indian peninsula in order to study the range of maximization factors over that region. A similar study has been made for the Madhya Pradesh

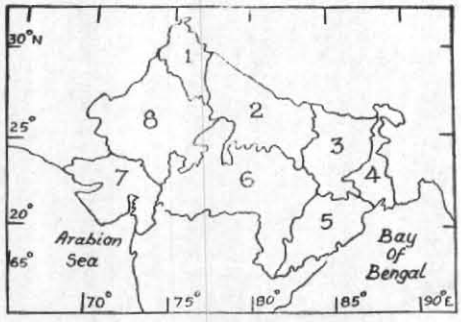


**Fig. 1. Meteorological divisions**

1. Punjab & Haryana, 2. Uttar Pradesh, 3. Bihar, 4. West Bengal, 5. Orissa, 6. Madhya Pradesh, 7. Gujarat and 8. Rajasthan.

region by Shenoy *et al.* (1970). Using the *M* value corresponding to the maximum persisting dew point temperature of the area with the envelope efficiency value of the region will yield PMP estimate for the small size area. With this in view an attempt has been made in this study to obtain envelope efficiency estimates for the various meteorological divisions in north India.

#### 4. *P*/*M* values for the severe rainstorms over north India

Table 1 gives a list of observed severe rainstorms over different meteorological divisions in north

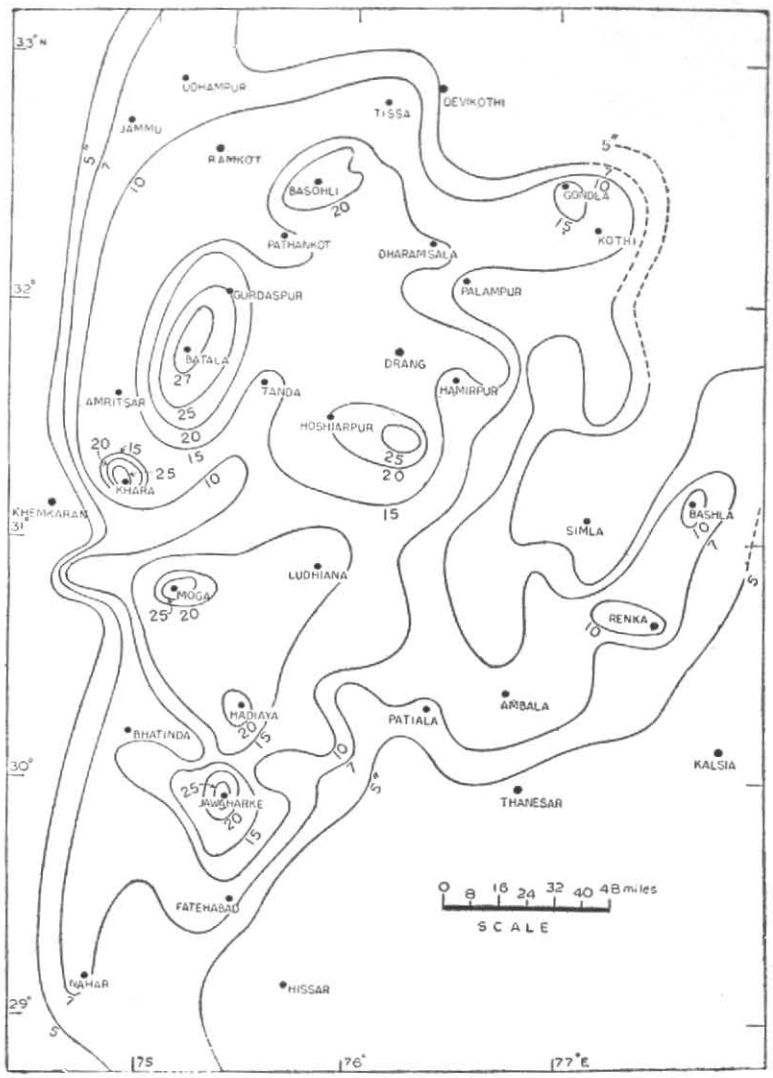


**Fig. 2**

Total isohyetal map of Punjab rainstorm of 3-5 October 1955
(Rainfall isopleths in inches)

India. It is seen that for each meteorological division a few observed severe rainstorms have been picked out from a thorough scrutiny of available storm rainfall data. Rain spells associated with these rainstorms were then analysed by depth-area-duration (DAD) method. Maximum rain depths were then picked out from the DAD curves of each of these rainstorms for the three standard areas mentioned earlier on the day of maximum rainfall. Moisture available to these rainstorms on the day of maximum rainfall was also determined with the help of observed maximum 24-hr persisting storm dew point temperatures for a number of stations in the upwind path of the moisture bearing winds to the storm areas. For each of the rainstorms mentioned in Table 1 at least 5 to 10 dew point stations were selected to obtain a fairly representative value of $M$ over the storm area (from 1000 to 200 mb) on the day of maximum rainfall. The $P/M$ ratios were then worked out for each of the standard areas for each rainstorm. The $P/M$ values (in italics) in Table 1 show the envelope values of the storm efficiency for the diffierent size of areas in each meteorological division.

It is evident that of all the major rainstorms experienced over north India so far, the most efficient rainstorm was that of 3-5 October 1955 over the Punjab plains. The storm efficiency values obtained for this storm are the highest for all the three standard areas (*vide* Table 1). The

efficiency of this rainstorm was of the order of 22 per cent for an area of 12,950 sq. km (5000 sq. miles). In the tropical storm of 3-7 September 1950 (hurricane *EASY*) in USA which gave the greatest depths of rain for areas from 10 to 5000 sq. miles (Myer 1967), the storm efficiency was just 21 per cent for 5000 sq. miles (Wiesner 1970). Next to the Punjab rainstorm of October 1955, the other important rainstorms over north India in the order of their storm efficiencies (over 12,950 sq. km) are as follows :

(*a*) Gujarat rainstorm of July 1927 ($E$= 20.8 )

(*b*) Orissa rainstorm of July 1927 ($E$=18.6%)

(*c*) Madhya Pradesh rainstorm of September 1926 ($E$ = 17.2%)

(*d*) Uttar Pradesh storm of September 1924 ($E$ = 16.2%)

(*e*) Bihar storm of October 1961 ($E$ = 15.8%)

(*f*) West Bengal rainstorms of June 1950 and October 1968 ($E$ = 15.0 % for each)

(*g*) Rajasthan rainstorm of July 1913 ($E$ = 14.5%)

(NOTE : $E$ = Storm efficiency in % on the day of max. rainfall).

A brief description of the October 1955 rainstorm over Punjab plains appears appropriate as it gave the highest values of storm efficiency for one-day duration upto 10,000 sq. miles over the whole of north India.

### 5. October 1955 Punjab rainstorm

This rainstorm caused unprecedented rain depths in most of the river basins of the Punjab and west U.P. as a result of which severe floods occurred in all the Punjab and west U.P. rivers during the second week of October 1955. A record average depth of 25.4 cm (10 inches) of rain was received over the Beas basin (upto Pong) during this rain spell (Dhar and Narayanan 1965). Other rivers of this region, *Chenab*, *Ravi*, *Sutlej* and *Yamuna* also recorded maximum rain depths in their respective catchment areas in Punjab-Kumaon hills causing severe flooding all over Punjab and west U.P. plains.

The October 1955 heavy rain spell over Punjab occurred in association with a Bay cyclonic storm which was centred 160 km (100 miles) southeast of Puri at 0830 IST of 30 September. It crossed the Orissa coast near Chandbali on the same night. It was centred near about Jhalwar in Rajasthan on the morning of 3 October where it remained practically stationary till 4th evening and got strengthened as a result of fresh feed of monsoon air from the Arabian Sea. Under the influence of a westerly wave moving eastwards across the Kashmir-Himalayas, it moved northwards over the Punjab plains on 5 October, giving exceptionally heavy falls of rain over the Punjab plains. This disturbance finally got filled up over the Punjab hills by about 6 October. The total isohyetal map of this rainstorm for the period 3 to 5 October, is shown in Fig. 2. The depth-area-duration (DAD) values of rainfall for different durations of this storm are given in Table 2. It is seen that an average rain depth of 6.3 inches was obtained over an area of 30,000 sq. miles (77,700 sq. km) in one-day duration.

**TABLE 2**

**Depth-area-duration values of rain depths of 3 to 5 October 1955 of Punjab rainstorm for different durations**

| Area in sq. miles (sq. km ) | Depth-area-duration values of | | |
|---|---|---|---|
| | One-day (inch) | 2-day (inch) | 3-day (inch) |
| 1000(2590) | 17·0 | 23·6 | 24·6 |
| 2000(5180) | 15·9 | 21·8 | 22·9 |
| 3000(7770) | 14·7 | 20·8 | 21·9 |
| 4000(10,360) | 13·7 | 19·8 | 21·0 |
| 6000(15,540) | 12·3 | 18·4 | 19·3 |
| 8000(20,720) | 11·3 | 17·0 | 18·5 |
| 10,000(25,900) | 10·2 | 16·0 | 17·7 |
| 15,000(38,850) | 8·5 | 14·0 | 16·2 |
| 20,000(51,800) | 7·7 | 12·6 | 15·0 |
| 25,000(64,750) | 7·0 | 11·6 | 13·8 |
| 30,000(77,700) | 6·3 | 10·9 | 12·7 |

Areas in sq. km are given in brackets

### 6. Summary

Severe rainstorms which have been experienced over the different meteorological divisions in north India during the last 70 to 80 years were analysed by DAD method on the day of maximum rainfall. Moisture available to these storms was also worked out with the help of 24-hr persisting dew point data of observatory stations in and near the storm area. Storm efficiency of these rainstorms was then worked out by calculating $P/M$ ratios of each of these storms for different size of areas upto 10,000 sq. miles (125,900 sq. km). The results of this analysis are shown in Table 1. Envelope $P/M$ ratios for each meteorological division have been indicated in Table 1, the highest values shown in italics. The envelope $P/M$ ratios obtained in this study can be used in

obtaining PMP values for non-orographic small size basins in these divisions by using equation (2). A comparison of $P/M$ ratios of these rainstorms has shown that upto 10,000 sq. miles (25,900 sq. km) October 1955 rainstorm over the Punjab plains was the most efficient rainstorm over north India during the last 80 years. An isohyetal analysis of this storm has shown that rain depths of the order of 6.3, 10.9 and 12.7 inches were obtained over a plain area of 77,700 sq. km (30,000 sq. miles) in 1, 2 and 3-day durations respectively.

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