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The rainstorm which caused the Morvi dam disaster in August 1979

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ABSTRACT On 11 August 1979, the Machhu-2 earth dam, situated about 6 km upstream of the town of Morvi in the Saurashtra region of India, collapsed under the onrush of an unprecedented volume of water. An 8-10 m high flood wave rolled down Machhu valley, entirely submerging Morvi and nearby villages. This flash flood caused the deaths of thousands of people and totally destroyed urban and rural property downstream of the dam. The heavy rainfall of August 1979 over and around the Machhu basin has been analysed by both depth-area-duration and depth-duration methods. Important aspects of heavy rainfall distribution such as: analysis of past severe rainstorms, maximum point rainfall of different return periods, and probable maximum precipitation, were also studied. This study has shown that this event was not the most severe rainstorm in this region. Possibly, the antecedent conditions of the Machhu basin played a significant role in generating the flood volume which caused the earth flanks of the dam to give way.

L'orage qui a provoqué la catastrophe du barrage Morvi août 1979
RESUME Le 11 août 1979 le barrage en terre Machhu-2, situé a environs 6 km à l'amont de la ville de Morvi dans la région de Saurashtra aux Indes a été détruit sous la poussée d'un volume d'eau sans précédent. Une vague de crue de 8 à 10 m de haut a dévalé la vallée de Machhu submergeant entièrement Morvi et les villages voisins. Cette crue brutale a causé la mort de milliers de riverains et a complètement detruit toutes les propriétés urbaines et rurales à l'aval du barrage. La très forte averse de août 1979 sur le bassin de Machhu et à la périphérie a été analysée à la fois par la méthode hauteur-superficie-durée et par la méthode, hauteur de précipitations-durée. Des caractères importants de la distribution des très fortes averses ont été également étudiés, tels que: l'analyse des orages sévères dans le passé, la hauteur de précipitation maximale ponctuelle pour différentes périodes de retour et la hauteur de précipitation maximale probable. Cette étude a montré que cet évènement n'était pas l'averse la plus sévère observée dans la région. Il est possible que les conditions sur le bassin, ayant précédé cet orage aient

joué un rôle significatif dans la formation de la crue qui a emporté la digue en terre du barrage.

INTRODUCTION

The Machhu basin located in the Saurashtra region (Fig. 1) experienced incessant rains during the first 12 days of August 1979. During this period, rainfall over Saurashtra region was more than 7 times the normal for this period. Rainfall was, however, exceptionally heavy between 10 and 12 August, which caused huge inflows of water into the two dams, viz., Machhu-1 and Machhu-2 (see Figs. 1 and 2), located on the Machhu River at a distance of about 30 km from each other. According to press reports, the Machhu-2 earth dam was designed to pass a peak flood of 5.7×10^3 m^3 s^{-1}, while on 11 August 1979 it was reported that a peak flood exceeding 1.4×10^4 m^3 s^{-1} was generated, which resulted in the over topping of the earth flanks of the dam on the afternoon of 11 August 1979 between 1430 and 1500 h IST (Fig. 3).

The worst affected area was Morvi town and neighbouring villages some 6 km downstream of the dam, where a flood wave of 8-10 m in height rolled down from the damaged Machhu-2 dam, submerging everything in its path. It is estimated that this flash flood caused the loss of thousands of lives, irreparable damage to livestock and property in the Morvi town which till then had been known as the "Paris of the East".

This study examines the heavy rain spell of August 1979 over Machhu basin (up to Machhu-2 dam) and compares it with similar rain

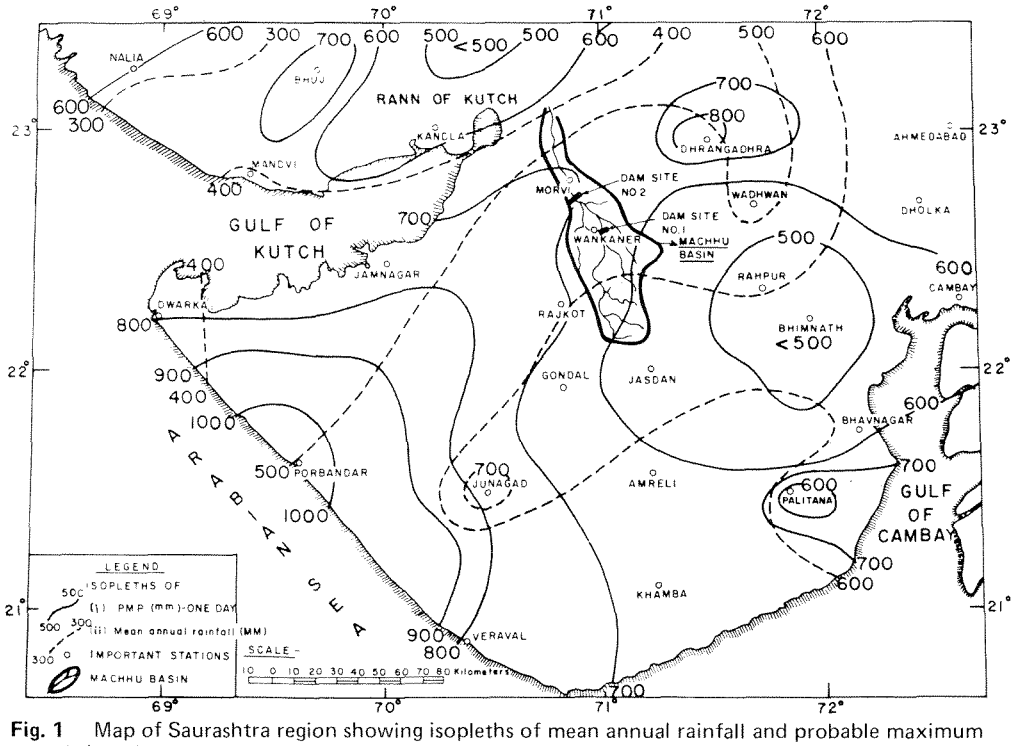

Fig. 1 Map of Saurashtra region showing isopleths of mean annual rainfall and probable maximum rainfall (PMP).

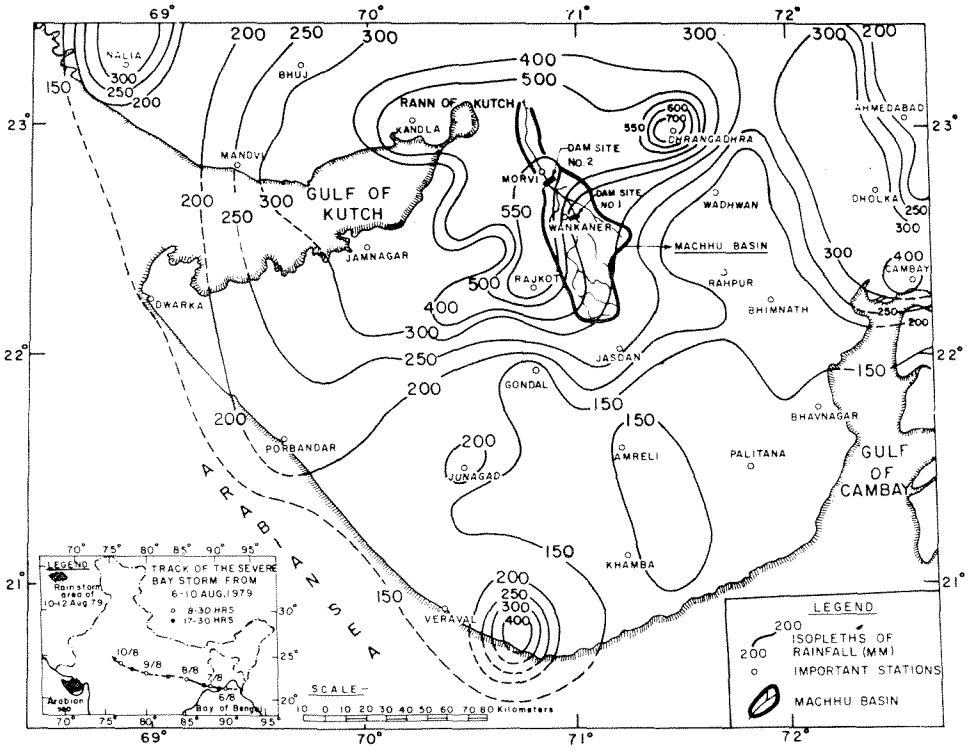

Fig. 2 Isohyetal map of the 10-12 August 1979 rainstorm over Machhu basin.

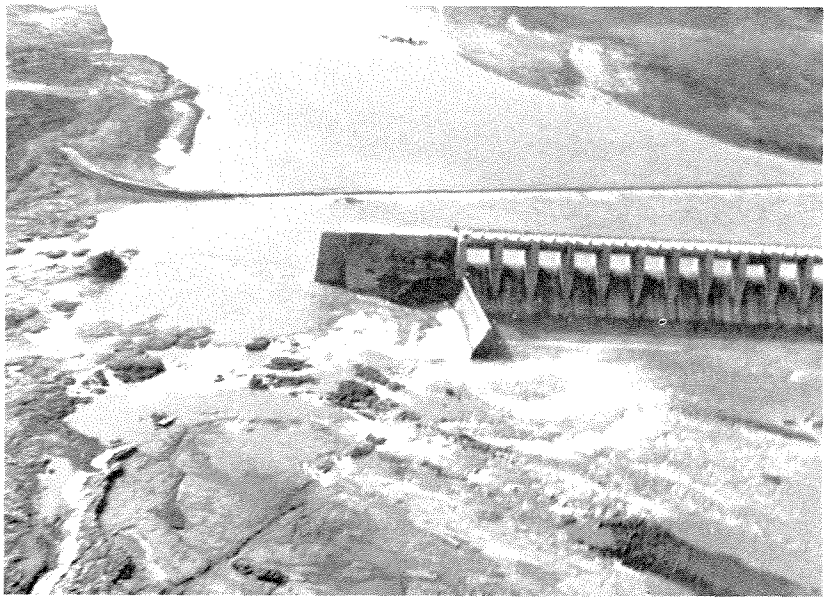

Fig. 3 Aerial photograph of the collapsed Machhu-2 dam. The earthen flank to the right of the masonry dam was washed away on 11 August 1979 and even 3 days after the disaster the water continues to rush through the breached portion. (Photo by courtesy of the Information Department of the Government of Gujarat at Rajkot.)

spells of the past 80 years in order to establish whether the August 1979 rain spell was unprecendented.

DATA USED

Past rainfall data for this region from 1891 to 1970, available in the archives of the Meteorological Office at Poona, were used in this study. Daily rainfall data for the period 1-12 August 1979 for all the available rainfall stations in and around Machhu basin were obtained through the courtesy of the Directorate of Agriculture, Government of Gujarat. Rainfall data for the meteorological observatories were obtained from the State Meteorological Centre at Ahmedabad.

Before analysing the rainstorm of August 1979 some aspects of heavy rainfall distribution in and around Machhu basin have been investigated to establish the incidence of heavy rainfall in this region.

RAINFALL CHARACTERISTICS OF MACHHU BASIN

The Machhu River, whose total length is about 140 km, rises in the hills of northern Saurashtra and flows into the Rann of Kutch. Its total catchment area up to Machhu-2 dam is of the order of 1900 km^2. Two important towns, Wankaner and Morvi (Fig. 1) are located on its banks besides numerous other big and small villages. Beyond Morvi, the Machhu flows through a flat treeless area and the river finally loses itself in the Rann of Kutch. The normal monthly and annual rainfall of the entire basin up to Machhu-2 dam have been worked out by the isohyetal method (Fig. 1) on the basis of 1950 normals of rainfall (India Meteorological Department, 1962). Table 1 gives the mean monthly and annual rainfall of the entire basin up to Machhu-2 dam; mean annual rainfall for the basin is of the order of 569 mm, of which the southwest monsoon period (June-September) contributes about 533 mm. About 94% of the annual rainfall therefore occurs during the southwest monsoon season.

Table 1 Mean monthly and annual rainfall for the entire Machhu basin up to Machhu-2 dam (see Figs. 1 and 2)

Months	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Rainfall (mm)	1.3	2.1	2.3	1.8	9.2	84.9	249.0	123.0	75.8	13.8	4.7	1.3	569.2
% of annual	0.2	0.4	0.4	0.3	1.6	14.9	43.7	21.6	13.3	2.4	0.8	0.2	100.0

INCIDENCE OF HEAVY RAINFALL IN AND AROUND MACHHU BASIN

Maximum observed 1, 2 and 3-day rainfall

For long-period stations in and around Machhu basin, the maximum observed 1, 2 and 3-day rainfalls have been extracted from the daily rainfall records for the period 1891-1960 and are presented in

Table 2. Table 2 shows that one station in this region, Palitana, experienced a fall greater than 500 mm in a single day. At Morvi

Table 2 Maximum and extreme (PMP) rainfall values of stations in and around Machhu basin

Stations	Mean annual rainfall (mm)	Highest observed rainfall 1891-1960 (mm)			50-year rainfall (mm)	100-year rainfall (mm)	PMP (mm)
		1-day	2-day	3-day			
Bhavnagar	620	307	330	463	258	290	593
Bhuj	340	468	501	507	269	307	729
Dhrangadhra	508	441	512	692	332	378	838
Gondal	624	320	512	539	274	308	641
Jasdan	617	278	461	541	253	283	568
Junagad	844	368	679	768	375	422	869
Mandvi	407	311	509	552	283	320	679
Morvi	534	449	533	569	287	324	703
Palitana	616	508	645	673	326	370	834
Porbandar	500	492	625	660	415	474	1063
Rahpur	351	184	332	352	197	221	449
Rajkot	594	398	475	520	309	348	723
Veraval	526	302	447	529	336	379	794
Wadhwan	487	308	445	607	234	264	574
Wankaner	561	308	386	452	275	309	647

and Wankaner stations the highest 1-day rainfalls of 449 mm and 308 mm respectively were recorded on 23 July 1894. The 2-day highest rainfall for stations in the region varied from 330 to 680 mm and the 3-day highest rainfall from 350 to 770 mm. It is also observed that stations in this region have recorded their mean annual rainfall in a single day. As an example Bhuj recorded 468 mm in 1 day in July 1959 which is 128 mm more than the mean annual rainfall for this station. Dwarka, a coastal station, recorded 350 mm in 1 day in November 1951 which is almost equal to its mean annual rainfall (Rao, 1959).

Point rainfall of 50 and 100-year return periods and probable maximum rainfall (PMP)

Maximum 1-day point rainfall for 50 and 100-year return periods for each of the long-period stations in and around Machhu basin have been determined using the Gumbel (1954) procedure as adopted by Chow (1964); these values of rainfall are also given in Table 2. The magnitudes of 50-year 1-day rainfall vary from 200 to 415 mm and the 100-year from 220 to 475 mm.

Using Hershfield's (1961, 1965) statistical technique, which is one of the recognized WMO (1970, 1973) techniques for determination of PMP, Dhar & Kamte (1971) prepared a generalized PMP chart for 1-day duration for this region, using those stations which have 60-70 years of rainfall data. The PMP pattern of this region along with the mean annual rainfall isopleths are shown in Fig. 1. The estimates of PMP for some selected stations in and near Machhu basin, obtained from the generalized chart, are given in Table 2. One-day point PMP estimates in this region range from about 450 to 1060 mm.

ANALYSIS OF PAST SEVERE RAINSTORMS

The data for severe rainstorms for the period 1891-1970 over and near Machhu basin were examined and it was observed that this region experienced the following three severe rainstorms during this period: (a) 21-23 July 1894, (b) 25-27 July 1927, and (c) 12-14 July 1950. It was observed that these three rainstorms had their centres outside but close to Machhu basin. All three were analysed by the depth-area-duration (DAD) method and maximum rain depths up to an area of about 13 000 km^2 are given in Table 3. This table indicates that the rainstorm of July 1927 was the most severe for 2 and 3-day durations while the July 1894 rainstorm ranked second in order of severity. The July 1927 rainstorm, with its centre near

Table 3 Depth-area-duration (DAD) statistics of past severe rainstorms over and near Machhu basin

Area (km^2)	July 1894			July 1927			July 1950		
	1-day (mm)	2-day (mm)	3-day (mm)	1-day (mm)	2-day (mm)	3-day (mm)	1-day (mm)	2-day (mm)	3-day (mm)
Point	450	533	543	457	749	841	399	511	538
259	446	527	530	452	718	825	390	510	536
518	436	521	526	437	708	816	376	504	532
777	428	519	522	420	698	806	360	498	530
1295	417	513	516	392	678	794	338	487	522
*1900	403	507	509	374	665	782	319	474	516
2590	393	500	502	365	650	770	304	460	507
5180	363	477	478	336	604	743	274	420	472
12950	303	420	423	281	534	682	229	361	409

*Machhu basin up to Machhu-2 dam has an area of the order of 1900 km^2.

Dakor (22°45'N, 73°09'E) in north Gujarat, was analysed and it was found that this rainstorm gave areal rain depths which have not so far been exceeded in this country (Dhar *et al.*, 1980). This very rainstorm moved westwards 2 days later and was centred close to the Machhu basin. The maximum rain depths at its new location are given in Table 3.

RAIN SPELL OF AUGUST 1979 OVER AND NEAR MACHHU BASIN

Meteorological situations responsible

Study of meteorological situations during the first two weeks of August 1979 has revealed that widespread rainfall in and around Machhu basin was mainly caused by the following synoptic situations:

(a) During the first week of August, two low pressure systems moved westnorthwest in quick succession along the monsoon trough, which was then lying south of its normal position. Also, from 5 to 8 August, a cyclonic circulation extending to the middle troposphere developed over Gujarat region. In association with these, the monsoon was fairly active over Machhu basin during the period 1-8 August causing widespread rainfall.

(b) There was another intense rainspell in and near Machhu basin

in the second week of August 1979. This was caused by the movement of a low pressure area which developed in the northeast Bay of Bengal on 5 August. It intensified into a severe cyclonic storm and crossed the coast on the midnight of 7 August. Continuing to move westnorthwest it weakened into a low pressure area over Gujarat and adjoining southeast Rajasthan on 11 August, and subsequently merged with the seasonal monsoon trough by about 14 August. The track of this disturbance up to depression stage is shown in the inset of Fig. 2. Under its influence, the monsoon was strong to vigorous in and around Machhu basin.

It is seen that during the rainspell, Rajkot, a station located close to Machhu basin, recorded rainfall of 354 mm on 11 August 1979 with return period about 100 years. Maximum 1-day rainfalls at Morvi and Wankaner stations were found to have return periods of the order of 25 years.

Average daily rain depths at Machhu basin during 1-12 August 1979

As mentioned earlier, stations within Machhu basin experienced light to heavy rainfall from 1 to 12 August. During this period, rainfall was particularly heavy from 10 to 12 August. The average basin rainfall was calculated by the isohyetal method up to Machhu-2 dam, for each day of the rain spell; these data are given in Table 4.

Table 4 Average daily rain depths over the Machhu basin up to Machhu-2 dam during 1-12 August 1979

Date (August, 1979)	Entire basin rain depths up to Machhu-2 dam (mm)	Percentage of mean August basin rainfall (%)	Percentage of mean annual basin rainfall (%)
1	39	32	7
2	57	46	10
3	39	32	7
4	72	59	13
5	33	27	6
6	24	20	4
7	40	33	7
8	22	18	4
9	22	18	4
10	75	61	13
11	237	193	42
12	135	110	24

Table 4 shows that the peak period of heavy rainfall over Machhu basin (up to Machhu-2 dam) was from 10 to 12 August. It is also seen that this basin received maximum rainfall of 237 mm on 11 August, which is nearly twice the mean rainfall for August. The total 3-day rainfall experienced by the basin from 10 to 12 August was 447 mm, nearly 4 times the amount the basin normally receives in the entire month of August. Table 4 suggests that the antecedent conditions of Machhu basin, at the time of intense rainfall of 10-12 August, were quite favourable for causing maximum runoff, as the basin was almost saturated from the light to moderate rain of the previous 10 days.

Depth-area-duration (DAD) analysis of 10-12 August 1979 rainfall over Machhu basin

Depth-area-duration analysis of the 10-12 August 1979 heavy rainfall was also carried out and DAD rain depths obtained for areas up to 13 000 km^2 are given in Table 5 and the 3-day isohyetal pattern of the rainstorm is shown in Fig. 2. This figures shows that the rainstorm had its heavy rain centre quite close to Rajkot which is about 20 km west of Machhu basin (Fig. 2). Had this centre of heavy rain occurred over the basin itself, perhaps the magnitude of the flood generated would have been greater and the disaster caused by the dam failure would have been even worse.

Table 5 Depth-area-duration (DAD) statistics of the 10-12 August 1979 rainstorm over Machhu basin

Area (km^2)	1-day 11 Aug. 1979 (mm)	2-day 11-12 Aug. 1979 (mm)	3-day 10-12 Aug. 1979 (mm)
Point	352	554	704
259	350	552	660
1295	336	535	624
1900	330	525	612
2590	326	518	600
12950	266	425	504

The DAD analysis of the 10-12 August rainstorm (see Table 5) has revealed that Machhu basin up to Machhu-2 dam could have experienced 1-day, 2-day and 3-day rain depths of the order of 330, 525 and 612 mm respectively had the rainstorm centred over the basin in a critical pattern.

COMPARISON OF DEPTH-DURATION (DD) VALUES OF SEVERE RAINSTORMS OVER MACHHU BASIN

The average rain depths actually experienced by Machhu basin (up to Machhu-2 dam) during the severe rainstorms of 1894, 1927, 1950 and 1979 were also worked out for durations of 1 to 3 days and these data are given in Table 6. This table shows that Machhu basin experienced the highest rain depth for 3-day duration during the August 1979 rainstorm. This is perhaps due to the fact that the

Table 6 Depth-duration (DD) rain depths for 3-day duration experienced by Machhu basin (up to Machhu-2 dam) during severe rainstorms

Duration	21-23 July 1894 (mm)	25-27 July 1927 (mm)	12-14 July 1950 (mm)	10-12 August 1979 (mm)
1-day	280	229	229	237
2-day	399	302	351	372
3-day	400	387	377	447

centre of the August 1979 rainstorm was close to the basin.

TIME DISTRIBUTION OF AUGUST 1979 RAINSTORM

There are no recording raingauge stations located within the basin and as such the actual time distribution of the heavy rainfall of 10-12 August 1979 could not be assessed accurately. However, recording raingauges at Bhavnagar, Porbandar and Veraval stations, which lie in the vicinity of the rainstorm area, functioned satisfactorily during the storm period. Hourly rainfall data of these stations were, therefore, used to determine the time distribution of the August 1979 rainfall. Figure 4 shows the time distribution curves of these stations for 2-day rainfall, as rainfall of 2 days more or less represents 48-h rainfall (US Weather Bureau, 1961, 1964). By way of comparison, the time distribution of Ahmedabad station (Changraney & Jain, 1978), located east of Machhu basin, has also been shown in Fig. 4. This figure shows that the Porbander curve almost envelopes all other curves of this region and hence the time distribution curve of this station has been used to work out short duration rainfall of the basin. The maximum DD rain depths for the August 1979 rainfall (Table 6) for different durations are given in Table 7.

Table 7 Maximum basin rain depths for short durations for the 10-12 August 1979 rainstorm

Hours	1	3	6	12	18	24	36	48	72
Rainfall (mm)	141	167	208	268	312	342	364	372	447

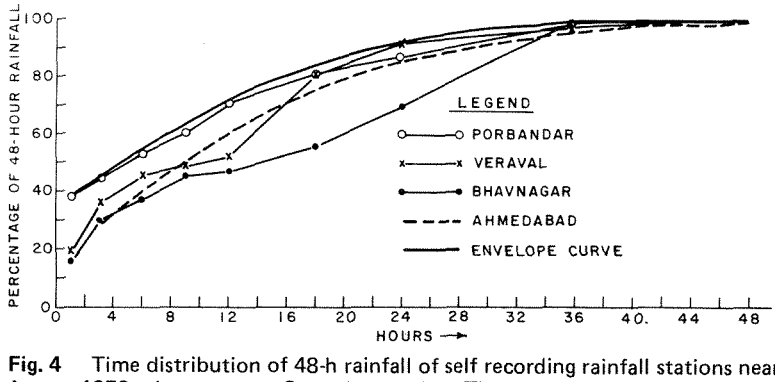

Fig. 4 Time distribution of 48-h rainfall of self recording rainfall stations near the August 1979 rainstorm over Saurashtra region. The curve for Ahmedabad is from Changraney & Jain (1978).

SUMMARY AND CONCLUSIONS

Examination of rainfall data of past 80 years of stations in and around Machhu basin revealed:

(a) there have been instances when stations in this region received their respective mean annual rainfall just in a single day;

(b) maximum 1-day rainfall at these stations varied from 180 to 510 mm and 2-day from 330 to 680 mm; and

(c) PMP of 1-day duration worked out to be of the order of 450-1060 mm.

During the period 10-12 August 1979, Machhu basin up to Machhu-2 dam received about 4 times the normal basin rainfall for August. Depth-duration analysis of past rainstorms over this basin has revealed that the July 1894 rainstorm gave maximum rain depths for durations of 1 and 2 days while the 10-12 August 1979 rainstorm gave maximum rain depths for 3-day duration. Depth-area-duration analysis of the past severe rainstorms of this region has shown that, by and large, the 1927 rainstorm was the most severe and the rain depths measured in this storm were much higher than the rainstorm of 10-12 August 1979. Apparently, the large volume of water generated during the rainstorm of August 1979 was mainly due to the favourable antecedent basin conditions of moderate to heavy rainfall during the 10 days before the dam failure.

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