Indian J. Met. Geophys. (1971), **22**, 203-212

551·577·3 : 551·515 (282·253)

A study of major rainstorms of Tapi basin for evaluation of design storm

S. D. S. ABBI and B. C. JAIN

Meteorological Office, New Delhi

(*Received 5 December 1970*)

ABSTRACT. 40 major rainstorms of various durations ranging from 1-day to 4-day which occurred over Tapi basin during the period 1891-1968 have been studied by Isohyetal Method. Depth-Duration Curves have been drawn for obtaining the envelope curve. The synoptic situations associated with these major rainstorms have also been discussed.

The hea.iest rainstorm has been maximised for moisture charge for obtaining "Design Storm". The design storm has also been evaluated by the statistical method for the sake of comparison. Other climatological data like rainfall, temperature and relative humidity in respect of selected stations in the basin have also been included.

1. Introduction

Tapi is one of the two large rivers in India which flow from east to west and empty their discharge into the Arabian Sea. It is a flood menacing river and there is a great need for proper harnessing of its water potential. A multi-purpose dam is already under construction at Ukai over this river for the purpose of power generation, irrigation and flood control measures. In order to operate this dam to maximum advantage both for power generation/irrigation and flood control, it is necessary to estimate the frequency and magnitude of rainstorms and their contribution to the reservoir.

The river *Tapi* originates from Multai in the Gavilgadh hill ranges of Satpura mountains in Madhya Pradesh and has a vast catchment area of about 64,000 sq. km (25,000 sq. miles). The length of the river is about 720 km and passes through Madhya Pradesh, Maharashtra and Gujarat, almost parallel to river *Narmada*. The river basin according to its topographical features can be divided into 4 sections (Rao 1970). The first section of 240 km is covered with dense forests in the Betul, Amraoti and Nimar districts and emerges into a narrow plain which starts widening near Burhanpur. The second section stretching upto 290 km is fertile plains of East and West Khandesh districts of Maharashtra. Here, the river *Tapi* is joined by several large tributaries like *Purna*, *Waghur*, *Girna*, *Bori*, *Panjhra*, *Buray*, etc. The third section consisting of about 80 km is again hilly covered with forests and the river becomes deep. In the fourth and the last section of 110 km, the river passes through the flat and fertile plains of Gujarat and widens out. Of the total catchment area of 64,000 sq. km about 28,200 sq. km lies in Madhya Pradesh, 33,000 sq. km in Maharashtra and the remaining 2,800 sq. km in Gujarat region.

The geographical location and the east-west orientation of the Tapi basin play an important role in experiencing floods particularly during southwest monsoon season. In a detailed study conducted earlier (Abbi *et al.* 1970) it was found that in the months of July and August Bay depressions/storms which move in a westerly direction through Narmada basin with Tapi basin falling in their southwestern sector, cause very heavy rainfall in the Tapi basin. Simultaneously the coastal area of Tapi basin also receive heavy rainfall due to the accentuation of monsoon trough along Maharashtra-Gujarat coast. The basin, thus receive heavy rainfall in its entire catchment area and is, therefore, prone to floods. Consequently, with a purpose to facilitate Engineers to estimate the "Design Flood" the present study has been attempted. Other climatological data like rainfall, maximum and minimum temperatures and relative humidity in respect of selected stations in the basin have also been included in this paper.

2. Raingauge network and rainfall features of the basin

In Tapi basin, there are 62 raingauge stations for which rainfall data for long period are available. Of these, 7 are India Meteorological Department Observatory stations and the remaining are the

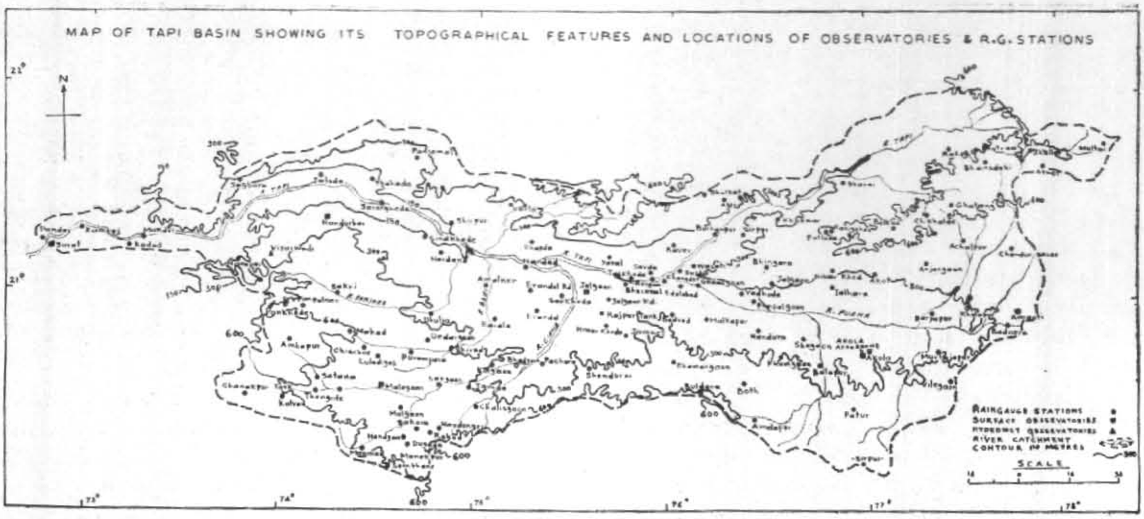

Fig. 1

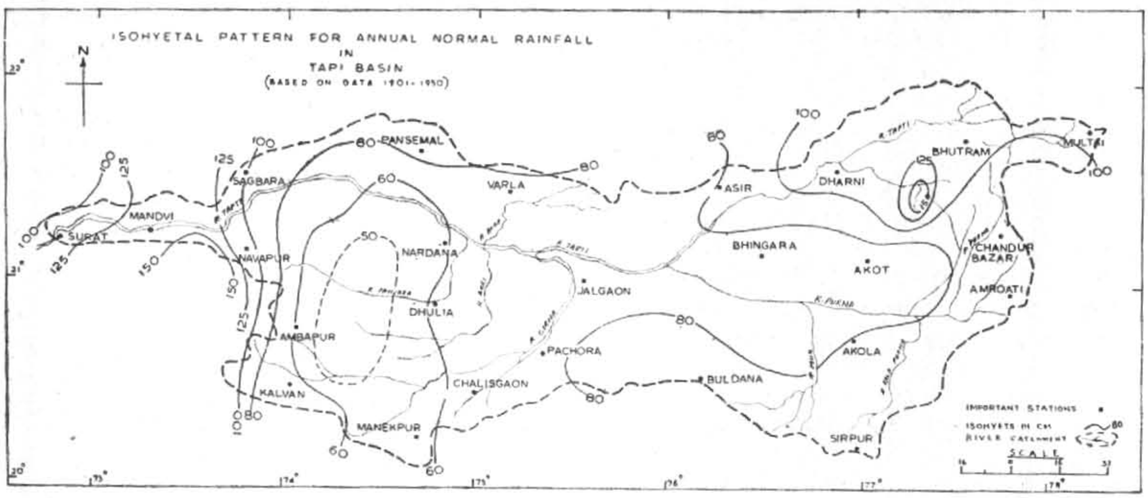

Fig. 2(a)

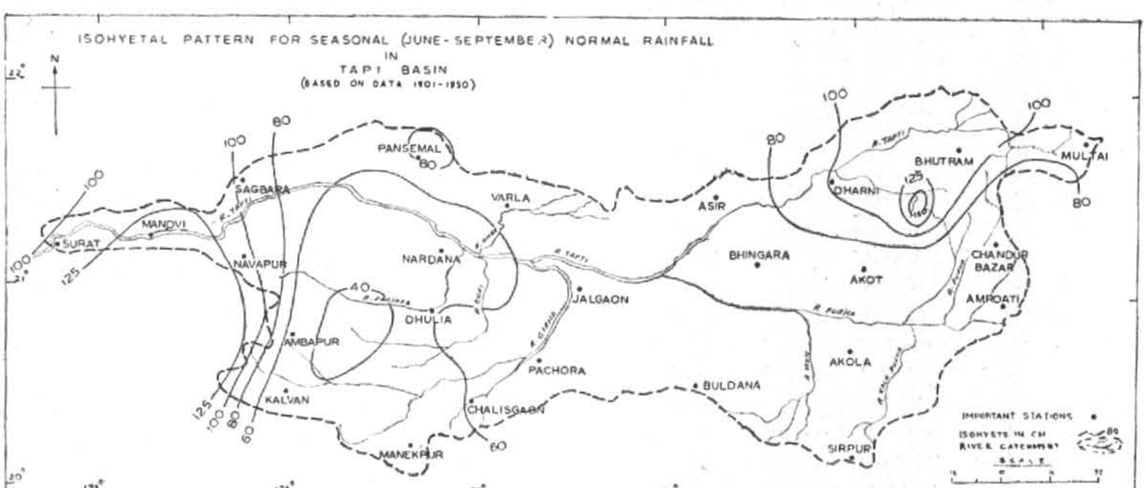

Fig. 2(b)

State raingauge stations. Out of 62 raingauge stations, only 5 are equipped with self-recording raingauges. The existing network of raingauge and observatory stations together with the topographical features of the basin is shown in Fig. 1.

The average annual rainfall in the basin, is about 80 cm of which about 86 per cent is recorded during southwest monsoon season (June to September). The month of July is the wettest for this basin and accounts for 30 per cent of the annual rainfall followed by the months of August and September which account for 20 per cent and 19 per cent of it respectively. The annual and seasonal (June to September) isohyetal pattern pertaining to Tapi basin are shown in Figs. 2(a) and 2(b) respectively. As expected, the seasonal pattern is almost similar to the annual one as 86 per cent of the annual rainfall is recorded during the monsoon season itself. Further, the eastern half of the basin receives rainfall of the order of 80 cm whereas the western half has a large variation in the spatial distribution of rainfall due to the Western Ghats. Whereas more than 100 cm of the annual rainfall occurs on the extreme western portion and coastal areas of the basin, only 50-60 cm of it is recorded on the lee side of the Western Ghats, which mainly constitutes the western half of the basin. This large variation in the rainfall over the Tapi basin renders it meteorologically inhomogeneous and thus the technique of storm transposition for evolving "Design Storm" has, therefore, not been attempted for this basin. Moreover, only those Bay depressions/storms which move in a west/westnorthwest direction either close to or through Narmada basin, have been found to cause major rainstorms in Tapi basin. Obviously the heaviest rainstorm which might have occurred over the neighbouring region in association with a Bay depression/storm having a more northerly track, cannot be considered for transposition over this basin.

3. Design storm study for the basin

3.1. *Storm selection*

For an exhaustive study of all the major rainstorms which occurred over this basin, the daily rainfall tables of India compiled by India Meteorological Department for the period 1891 to 1968 were examined and all such spells of rain during which a number of stations within the catchment area and in the neighbourhood recorded heavy rainfall on one or more of the days were picked out. For each of these selected spells arithematic averages of rainfall in the basin were calculated and all those spells of various durations which yielded at least 2·5 cm of average (Arithematic) rainfall in the basin on each day of its duration, were selected as major rainstorms for isohyetal analysis.

The flood records for river *Tapi* (Patel 1970) were also checked and a few more spells of heavy rainfall in the basin under study were then selected for isohyetal analysis. In all 40 rainstorms of durations ranging from 1-day to 4-day were analysed by isohyetal method with the catchment area taken as unit for this study. All major rainstorms with their corresponding average rainfall depths for various durations have been listed in Table 1.

It is seen that most of the rainstorms are of 2-day duration and generally occur in the months, September and July. Statistics shows that of the 40 major rainstorms, 28 have extended beyond 1-day and out of these 28 only 6 have extended beyond 2-day duration comprising of 4 rainstorms of 3-day duration and remaining 2 of 4-day duration. Further, 16 rainstorms have occurred in September, 12 in July, 7 in August and only 5 have occurred in June.

3.2. *Synoptic situations associated with rainstorms*

On examination of the synoptic situations associated with the rain-storms (listed in Table 1), it is revealed that all but a few of them were the result of Bay depressions moving westwards and that the remaining were caused either under the influence of general active monsoon conditions over Madhya Pradesh and Gujarat or due to land depressions. The portion of the basin adjoining Gujarat coast receives heavy rainfall under the influence of Bay depressions when they are still centred over central parts of Madhya Pradesh between Long. 78°E and 82°E (Abbi *et al.* 1970). This heavy rainfall is further augmented due to the orographic effects of the Western Ghats, whereas there is general decrease in rainfall on the lee side in the basin. Further, the Bay depressions which follow a westward track through the Narmada basin with Tapi basin falling in their southwestern sector are more effective in causing heavy rainfall and floods over the Tapi basin than the depression which follow relatively more northerly track. The rainstorm of August, 1968 which has contributed the highest 1-day, 2-day and 3-day average depths of precpitation in the Tapi basin, had its track through the entire Narmada basin in east-west direction before it recurved to north after reaching Rajkot.

3.3. *Depth-Duration Analysis*

The daily average rainfall depths contributed by each of the 40 rainstorms and their corresponding depth-duration curves are shown in Fig. 3. The number against each curve (or point) in this figure, refers to the serial number of the rainstorm as given in Table 1.

TABLE 1

Average isohyetal depths of precipitation for different durations of rainstorms over Tapi catchment

Serial No.	Storm period	Maximum depths (cm) 1-day	2-day	3-day	4-day
1	21-22 Jun 1893	2·8 (22)	5·4		
2	13 Jul 1894	3·0			
3	20-21 Jul 1894	8·7 (20)	14·6		
4	25-26 Jul 1894	8·7 (25)	14·8		
5	29 Jul 1896	6·0			
6	3-4 Jul 1904	3·1 (3)	5·7		
7	13-16 Sep 1904	8·2 (15)	15·5 (14-15)	19·2 (14-16)	22·0
8	22-23 Jul 1905	7·9 (22)	11·9		
9	5-6 Jul 1910	3·7 (5)	7·2		
10	16-17 Jun 1914	5·4 (16)	8·6		
11	27-28 Jun 1914	7·8 (27)	10·4		
12	13 Jul 1927	5·8			
13	3 Jul 1930	5·5			
14	9-10 Sep 1930	4·9 (10)	8·9		
15	11-13 Sep 1930	5·1 (13)	8·2 (12-13)	10·9	
16	12-13 Sep 1933	4·0 (12)	6·5		
17	14-15 Sep 1933	7·1 (15)	9·6		
18	29 Jun 1937	3·5			
19	6-8 Sep 1937	8·1 (8)	11·3 (7-8)	14·9	
20	20 Jun 1938	5·1			
21	20-21 Aug 1939	6·1 (21)	10·2		
22	25 Jun 1939	3·8			
23	1-2 Jul 1941	8·1 (1)	14·9		
24	4-5 Aug 1942	7·4 (4)	14·4		
25	14-16 Jul 1944	6·3 (15)	10·3 (15-16)	13·9	
26	17 Aug 1944	10·4			
27	21-22 Aug 1944	6·9 (21)	11·7		
28	21-24 Sep 1945	10·9 (22)	14·7 (22-23)	18·0 (21-23)	20·1
29	28-29 Sep 1947	3·5 (29)	6·1		
30	16 Sep 1949	7·5			
31	16 Sep 1950	3·0			
32	4-5 Aug 1953	5·6 (5)	8·6		
33	4-5 Sep 1954	4·7 (5)	8·3		
34	1 Sep 1958	5·8			
35	13 Jul 1959	2·2			
36	14-15 Sep 1959	7·7 (15)	15·0		
37	8-9 Sep 1961	4·7 (9)	7·5		
38	15-16 Sep 1961	4·4 (16)	6·6		
39	19-20 Sep 1962	4·7 (19)	8·7		
40	4-6 Aug 1968	11·1 (6)	19·0 (5-6)	21·1	

Figures in brackets indicate date or dates

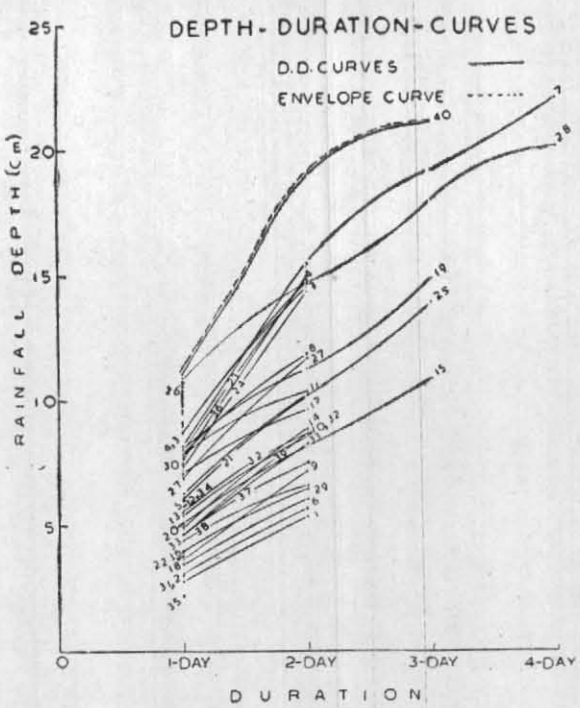

Fig. 3. Depth-duration curves

It can be seen from Fig. 3 that the depth-duration curve number 40 which corresponds to the rainstorm of 4-6 August 1968 has contributed the highest average depth of precipitation over the basin for 1-day, 2-day and 3-day durations and thus forms the Envelope Curve upto 3-day duration for all the rainstorms which occurred over the basin during the period 1891 to 1968. This is in conformity with the study conducted earlier (Pant *et al.* 1970). The isohyetal pattern for maximum 3-day (4-6 August 1968) rainstorm given in Fig. 4 shows a well distributed rainfall over the basin during 3 days with the storm centres near Navapur and Jalgaon. The depth-duration curve number 28 (corresponding to rainstorm of 21-24 September 1945) follows closely the curve of August 1968 rainstorm for 1-day and 2-day duration, whereas the depth-duration curve number 7 (corresponding to rainstorm of 13-16 September 1904) follows closely the curve of August 1968 rainstorm for 3-day duration. Further, the point 26 corresponding to rainstorm of 17 August 1944 has also contributed 1-day average of depth of precipitation in the basin comparable to that of August 1968 rainstorm.

The Envelope Curve for more than 3-day duration has not been drawn since there were only two rainstorms of 4-day duration and none of longer than 4-day duration. Moreover, the average depth of precipitation contributed in the basin by August 1968 rainstorm in 3-day is more or less of the same order of magnitude as yielded by the rainstorm of 13-16 September 1904 in 4 days.

3.4. *Maximum probable storm*

The heaviest rainstorm which has occurred over the basin so far, as discussed earlier, is the rainstorm of 4-6 August 1968 for 1-day, 2-day and 3-day duration. This may, therefore, be considered as the Standard Project Storm (S. P. S.) for the basin. For the purpose of evaluating 'Maximum Probable Storm', the Standard Project Storm has been maximised for the 'Moisture charge'.

3.4.1. *Storm maximisation* — With a view to obtain the physical upper limit to the magnitude of storm rainfall, so called, Maximum Probable Storm, an upward moisture adjustment is applied to the depth values yielded by the Standard Project Storm. This moisture adjustment factor for the rainstorm is defined as the ratio of the maximum total moisture in an atmosphere column of unit cross-section in the region to the total moisture in a similar column that prevailed during the storm period. For this purpose, the maximum dew point temperatures in respect of representative stations in Tapi basin and storm dew point temperatures prevelent during the storm period are collected. The storm period has been taken to be 4-6 August 1968 as it yielded

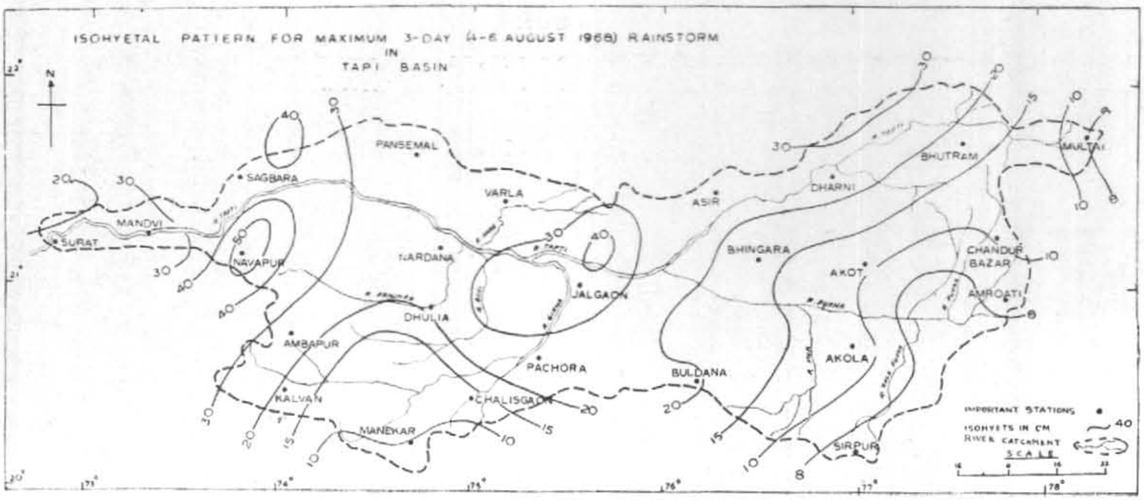

Fig. 4

TABLE 2

Monthly and annual averages of rainfall and of number of rainy days in the Tapi basin

	Rainfall (cm)	No. of rainy days	Rainfall as percentage of the annual (nearest whole number)
January	0·9	0·7	1
February	0·7	0·6	1
March	0·5	0·5	1
April	0·4	0·4	1
May	1·1	0·9	1
June	13·8	7·3	17
July	23·9	13·2	30
August	16·1	10·2	20
September	15·5	8·1	19
October	4·1	2·3	5
November	2·4	1·3	3
December	0·8	0·6	1
Annual	80·2	46·1	100

the highest average depth of precipitation over the basin for three-day duration and subsequently contributed to the Envelope Curve for the basin.

The representative stations selected in the basin were Surat, Jalgaon and Akola and the average maximum dew point temperature reduced to 1000 mb isobaric level for the fortnight of August was found to be 30·2. The prevailing dew point temperature during the storm period 4-6 August 1968 and reduced to 1000 mb isobaric level came out to be 24·6°C. Then, both the dew point temperature values were converted to the corresponding amounts of precipitable water in the air column extending from the surface (1000 mb) to mid-troposphere (500 mb) with the help of the diagram given by Pramanik and Hariharan (1951). Thus the maximisation factor for the Tapi basin by the moisture adjustment method works out to be 1·53. By using this factor the maximum probable storm rainfall for 1-day (6 August 1968) comes out to be $11·1 \times 1·53 =$ 17·6 cm and for the storm period 4-6 August 1968 as $21·1 \times 1·53 = 32·3$ cm. The storm of 6-8 August 1968 has also been maximised by Shenoy *et al.* (1970) by moisture charge method for the computation of design flood in Tapi basin upto Ukai Dam site.

3.5. *Maximum probable storm evolved by statistical method*

For the sake of comparison, how the value of the maximum probable storm depth obtained by physical method of storm maximisation under item 3·4, agrees with the value when obtained by statistical method, the maximum 1-day average depth of precipitation yielded in Tapi basin by these 40 rainstorms were picked up for statistical analysis by Duration Curve Method (Banerji *et al.* 1967). The curve showed the 500 and 1000 year return period values of 1-day average depth of precipitation over Tapi basin as 18·0 cm and 20·5 cm respectively, which may be taken as a fairly good comparison with the value of 17·0 cm obtained by Physical Method, keeping in view the inherent limitations of these two methods. By using the Duration Curve, described above, we find that the value of maximum probable storm depth for one day of 17·0 cm has a return period of 370 years.

TABLE 3

Highest 24-hr (observational day) rainfall at selected stations in Tapi basin for monsoon months

Station	June		July		August		September	
	Amt. (cm)	Date	Amt. (cm)	Date	Amt. (cm)	Date	Amt. (cm)	Date
Surat	**26·0**	**27,1922**	**45·9**	**2,1941**	22·9	2,1933	38·9	23,1945
Dhulia	13·4	20,1910	14·9	2,1883	**15·0**	**17,1944**	13·7	15,1904
Nandurabar	13·2	29,1945	**16·8**	**5,1910**	14·0	17,1944	14·0	21,1945
Bhusaval	14·8	21,1920	16·3	8,1911	**21·7**	**16,1944**	17·2	22,1945
Malegaon	11·1	27,1914	**15·9**	**26,1896**	13·7	7,1954	13·2	12,1894
Burhanpur	16·7	28,1891	20·8	2,1883	19·1	26,1895	**25·9**	**12,1894**
Multai	15·6	9,1881	16·8	15,1882	20·2	26,1895	**23·6**	**18,1888**
Buldana	15·3	13,1909	15·3	2,1883	15·3	23,1917	**33·8**	**9,1930**
Amraoti	15·5	19,1927	22·0	23,1921	19·6	8,1886	**23·5**	**15,1933**
Akola	18·8	27,1955	18·9	20,1894	22·5	11,1900	**36·5**	**15,1959**
Dharni	16·8	20,1938	**22·9**	**2,1930**	21·8	3,1930	18·6	15,1933
Pansemal	12·1	3,1949	13·2	25,1951	18·3	24,1939	**32·0**	**29,1954**
Malkapur	13·7	17,1893	21·6	2,1883	13·7	25,1877	**22·7**	**15,1959**
Kalvan	13·1	13,1882	18·1	25,1952	16·9	1,1898	**23·1**	**11,1882**
Jalgaon	11·7	27,1889	15·2	22,1905	11·9	4,1942	**18·3**	**13,1930**

Note — The bold figures are the highest 24-hour rainfall amounts with the dates of their record

4. Other climatological data

Some climatological data like rainfall, temperature and relative humidity in respect of selected stations in the basin are briefly discussed.

4.1. *Rainfall* — The monthly and annual averages of rainfall and number of rainy days in the Tapi catchment are given in Table 2. The average monthly rainfall as percentage of the annual rainfall in the basin is also included in the same table. These figures have been obtained on the basis of 50-year normal rainfall and number of rainy days data (India met. Dep. 1962).

A statement giving the heaviest 24-hour rainfall amounts for each of the monsoon months (June to September) at 15 selected stations in the basin, based on rainfall record upto 1960 along with the date of their record is given in Table 3. As can be seen from this table that Surat has, so far, recorded the heaviest 24-hour rainfall of 45·9 cm in the month of July.

4.2. *Maximum and minimum temperatures*— Monthly and annual mean daily maximum and mean daily minimum temperatures in respect of 6 observatory stations in the Tapi basin, based on the data for the period 1931 to 1960 compiled by India Meteorological Department (1967) are given in Table 4(a). The highest maximum and lowest minimum temperatures at these stations recorded, so far, in each of the month are also given in Table 4(b).

It can be seen that May is the hottest month for almost the entire basin except for Surat which records higher temperatures in the month of April. The months of December and January are the coldest months for Tapi basin. The maximum temperatures in the basin fall appreciably during southwest monsoon season and then rise slightly in October. From November onward, the maximum temperature again starts falling gradually becoming lowest in December and January and then again there is a progressive rise in the maximum temperature till they attain highest values in May. Similarly, the minimum temperatures in the basin increase gradually from February and reach their highest value in May. From June onwards, there is a progressive fall in minimum temperatures and become lowest in December/January. Further the diurnal variation in temperature over the basin is maximum in the months of December and January when it

TABLE 4 (a)

Mean maximum and mean minimum temperatures (°C) at observatory stations in the Tapi basin

		Surat	Jalgaon	Malegaon	Amraoti	Akola	Buldana*
Jan	Max.	31·4	30·6	30·1	28·9	30·2	27·4
	Min.	14·8	12·7	11·5	15·5	13·7	15·4
Feb	Max.	33·1	33·2	32·6	21·8	32·8	30·7
	Min.	16·4	14·3	12·8	17·2	15·2	17·9
Mar	Max.	36·1	37·6	36·5	36·2	37·1	34·2
	Min.	20·1	18·7	17·0	21·2	19·4	21·6
Apr	Max.	37·3	41·1	39·4	39·7	40·5	37·0
	Min.	23·7	24·1	21·8	25·2	24·6	24·9
May	Max.	36·2	42·6	40·7	42·2	42·4	38·3
	Min.	26·6	27·2	24·3	27·8	28·1	26·2
Jun	Max.	33·7	38·1	36·1	37·0	37·4	33·9
	Min.	27·1	26·0	24·2	25·7	26·2	23·5
Jul	Max.	30·5	32·1	31·1	30·3	31·4	28·7
	Min.	25·7	24·0	23·0	23·4	23·9	21·9
Aug	Max.	30·3	31·2	30·7	29·8	30·7	27·0
	Min.	25·4	23·4	22·3	23·0	23·5	21·1
Sep	Max.	31·6	31·8	31·1	30·6	31·5	28·1
	Min.	24·1	22·9	21·3	22·7	23·1	21·2
Oct	Max.	35·5	34·1	32·7	32·1	33·3	29·8
	Min.	23·1	19·2	18·8	20·8	20·0	20·5
Nov	Max.	34·9	32·0	31·0	30·1	31·0	28·3
	Min.	19·2	14·5	14·3	17·4	15·0	17·0
Dec	Max.	32·8	30·3	29·9	28·6	29·6	27·6
	Min.	16·0	12·0	11·7	15·1	12·6	15·1
Annual	Max.	33·6	34·6	33·5	33·1	34·0	30·9
	Min.	21·9	19·9	18·6	21·3	20·4	20·5

* Based on data from 1951 to 1960

becomes about 16°C and reaches its lowest value in the months of July and August when it becomes about 7°C.

Finally, the highest ever recorded maximum temperature in the basin, so far, was at Jalgaon and Akola when it reached the value of 47·8°C at both these stations in the month of May whereas the lowest minimum temperature recorded, so far, was at Malegaon when it reached—0·6°C in the month of (early) February.

4·3. *Relative humidity* — The monthly and annual mean relative humidity in respect of 6 observatory stations in the basin, recorded at both the hours of observation, *viz.*, at 0830 and 1730 IST are given in Table 5. It can be seen that the relative humidity in the basin is highest during the monsoon months, July to September (except June) and lowest in the month of April. Further, Surat being a coastal station, records comparatively higher values of relative humidity at both the hours of observations, than other observatory stations in the basin.

5. Conclusions

(*i*) The average annual rainfall in Tapi basin is about 80 cm, of which 86 per cent is recorded during southwest monsoon season (June to September).

(*ii*) The eastern half of the Tapi basin receives rainfall, on an average, about 80 cm. whereas the western half has a large spatial variation in its rainfall distribution ranging from 50 to 125 cm due to orographic features.

TABLE 4(b)

Tapi catchment—Highest maximum and lowest minimum temperatures (°C) with date of record

		Surat		Jalgaon		Malegaon		Amraoti		Akola		Buldana*	
		Temp. (°C)	Date of record	Temp. (°C)	Date of record	Temp. (°C)	Date of record	Temp. (°C)	Date of record	Temp. (°C)	Date of record	Temp. (°C)	Date of record
Jan	H	38·3	20,1952	35·6	27,1939	35·0	31,1932	35·0	29,1889	36·2	12,1958	32·8	31,1956
	L	4·4	31,1929	1·7	7,1945	0·6	16,1935	6·1	14,1934	3·9	8,1937	10·0	22,1953
Feb	H	41·7	28,1953	40·6	26,1953	39·4	26,1953	38·9	26,1953	40·0	28,1953	36·7	28,1953
	L	5·6	1,1929	3·9	1,1943	—0·6	1,1929	5·0	9,1887	2·2	9,1887	4·4	11,1950
Mar	H	43·9	28,1945	43·9	26,1953	45·6	28,1889	43·9	28,1892	44·4	20,1892	38·9	26,1953
	L	10·6	3,1898	8·7	23,1950	5·6	4,1888	8·9	4,1898	5·6	2,1908	14·8	5,1957
Apr	H	45·6	15,1952	47·2	25,1958	44·4	23,1925	46·1	30,1898	46·1	29,1942	42·2	25,1958
	L	15·0	3,1903	15·6	11,1960	9·4	1,1905	12·8	1,1905	11·1	1,1905	17·8	15,1955
May	H	45·6	1,1956	47·8	21,1947	46·7	23,1916	46·7	25,1954	47·8	22,1947	42·2	23,1954
	L	19·4	4,1888	21·2	10,1960	16·7	4,1881	18·3	4,1917	11·9	19,1960	20·0	16,1960
Jun	H	45·6	10,1901	46·1	7,1953	44·4	11,1915	46·7	2,1923	47·1	1,1923	41·7	7,1953
	L	21·7	17,1916	21·7	17,1955	17·8	19,1932	19·4	16,1916	20·0	16,1916	19·4	17,1955
Jul	H	38·9	7,1902	39·4	11,1951	37·8	3,1920	39·4	1,1931	40·6	2,1900	34·4	14,1952
	L	20·6	23,1889	21·1	12,1938	18·3	14,1953	18·9	27,1890	20·6	12,1941	18·9	6,1949
Aug	H	37·2	31,1932	37·2	16,1947	37·2	2,1899	36·7	16,1902	37·8	25,1950	35·0	23,1959
	L	21·1	14,1887	20·0	27,1942	16·1	16,1889	18·3	31,19[illegible]	18·3	27,1944	16·6	19,1959
Sep	H	41·1	26,1951	38·9	25,1951	38·3	10,1899	38·3	30,1899	35·0	10,1899	33·0	22,1960
	L	20·6	9,1884	17·2	30,1940	16·1	29,1942	17·2	2,1893	17·2	30,1904	17·9	16,1959
Oct	H	41·1	17,1952	38·3	11,1951	40·0	8,1899	39·4	7,1899	40·0	7,1899	33·9	11,1951
	L	14·4	20,1893	10·0	30,1952	10·6	31,1933	12·8	26,1889	10·0	26,1889	14·4	31,1957
Nov	H	39·4	20,1957	36·5	17,1957	36·7	1,1908	35·6	3D,1899	36·1	3,1899	32·2	17,1957
	L	10·6	19,1881	5·6	19,1950	5·6	25,1910	8·9	29,1884	5·6	29,1912	11·7	10,1949
Dec	H	38·9	2,1953	35·0	2,1953	35·0	2,1896	33·9	9,1913	36·7	1,1896	32·8	29,1948
	L	6·7	27,1903	1·7	3,1937	2·8	28,1926	8·3	3,1937	3·9	8,1883	11·0	26,1960
Annual	H	45.6		47·8		46·7		46·7		47·8		42·2	
	L	4·4		1·7		—0·6		5·0		2·2		4·4	

H—Highest maximum temperature, D—Days, L—Lowest Minimum temperature, *—Based on data from 1951 to 1960

TABLE 5

Mean Relative Humidity at observatory stations in Tapi Basin

		Surat	Jalgaon	Malegaon	Amraoti	Akola	Buldana*
Jan	I	63	58	53	49	57	54
	II	41	27	27	30	29	35
Feb	I	62	45	43	40	46	42
	II	35	17	21	22	22	26
Mar	I	63	38	35	33	34	42
	II	33	13	18	25	18	27
Apr	I	64	39	33	30	30	39
	II	40	14	15	23	16	24
May	I	69	54	43	37	39	51
	II	57	18	23	21	19	25
Jun	I	77	72	67	65	66	75
	II	70	42	48	43	43	50
Jul	I	87	85	76	84	81	86
	II	81	65	66	69	68	71
Aug	I	86	87	77	83	82	88
	II	79	70	65	69	67	78
Sep	I	85	86	77	81	81	86
	II	72	60	63	66	64	69
Oct	I	70	70	65	60	66	67
	II	48	39	40	45	41	49
Nov	I	59	61	59	48	59	54
	II	40	30	34	33	35	41
Dec	I	61	63	56	50	60	53
	II	41	31	30	33	32	37
Annual	I	71	63	57	55	58	61
	II	53	35	37	40	38	44

Note—I: Observations at 0830 IST   II: Observations at 1730 IST   *—Based on data from 1951 to 1960 (*iii*) The rainstorms in the Tapi basin, generally occur in association with Bay depressions having due west/west-northwest movement and passing either close to or through Narmada basin.

(*iv*) The rainstorms in Tapi basin are mostly of 2-day duration and generally occur in the months of July and September.

(*v*) The rainstorm of 4-6 August 1968 has so far, yielded the highest average depth of precipitation of Tapi basin for all the durations upto three days during the period 1891 to 1968, and its Depth-Duration Curve itself forms the Envelope Curve for the basin.

(*vi*) The Maximisation Factor, based on dew point temperatures, obtained for August 1968 rainstorm was found to be 1·53 and thus the value of maximum probable storm for one day worked out to be 17·0 cm.

Acknowledgements

The authors are grateful to Dr. P. Koteswaram, Director General of Observatories for his encouragement and interest in hydrometeorological studies. They are also thankful to Sarvashri T. C. Jasra, Gurcharan Singh, L. D. Malik and S. D. Gaur for their valuable assistance.

REFERENCES

Abbi, S. D. S., Gupta, D. K. and Hem Raj	1970	*Indian J. Met. Geophys.*, **21**, **4**, pp. 583-590.
Banerji, S. and Gupta, D. K.	1967	Proc. International Symp. on Floods and their computation, Leningrad.
India met. Dep.	1962	*Monthly and Annual Normals of Rainfall and of Rainy Days, XXXI, Pt. III.*
	1967	*Climatological Tables of Observatory stations in India* (1931-1960).
Pant, P. S., Abbi, S. D. S. and Gupta, D. K.	1970	Proc. Seminar on Flood Control and the use of River Water Resources with special reference to Western India, Surat.
Patel, N. V.	1970	*Ibid.*
Pramanik, S. K. and Hariharan, P. S.	1951	*Indian J. Met. Geophys.*, **2**, **2**, pp. 138-141.
Rao, B. S.	1970	Proc. Seminar on Flood Control and the use of River Water Resources with special reference to Western India, Surat.
Shenoy, R. C., Das, T. V. and Changraney, T. G.	1970	*Ibid.*