551·578·1 : 551·515

A brief study of rainfall and spillway design storm for the Godavari basin up to Paithan dam site

O. N. DHAR, P. R. MHAISKAR and G. C. GHOSE

Institute of Tropical Meteorology, Poona

(*Received 13 February 1967*)

ABSTRACT. Mean monthly and annual rainfall for the Godavari basin up to Paithan dam site have been worked out by the isohyetal method. Mean annual rainfall has been found to be of the order of 29 inches.

The study has revealed that in the central parts of the catchment coefficient of variability is the highest and is of the order of 40 to 44 per cent for monsoon (June to October) rainfall.

Seventy-three heaviest rain spells, one for each year of the 73-year period (1891 to 1963), have been studied by depth-duration method as well as by the Gumbel's statistical method and the design storm rainfall depths have been worked out for the return periods of 100, 200, 500 and 1000 years.

1. Introduction

The rainfall study of the upper Godavari basin has been made to determine the design storm depths required for estimating the spillway design flood. These studies help the design engineers in fixing the spillway capacity of the proposed dam. In the past, inadequate spillway capacities of dams have been responsible for causing dam disasters during abnormal floods. The collapse of Kadam dam in August 1958, Panshet dam in July 1961 and the protective bund of the Kharagpur hill lake in Bihar in October 1961, are but a few instances of dam disasters in recent years in this country. It is, therefore, essential that while constructing major reservoirs or dams, their spillway capacities should be carefully estimated on the basis of analysis of past recorded rain storms in that region. To avoid any future catastrophy due to dam failures it is also necessary that the spillway capacities of the existing old dams in the country should be re-estimated on the basis of later data.

2. The Upper Godavari basin up to Paithan dam site

The Godavari rises at an altitude of 3500 ft a.s.l. in the Sahyadri range of the Western Ghats near the town of Trimbuk in the Nasik district (Fig. 1). In its upper reach up to Paithan dam site the Godavari drains an area of 8400 sq. miles which is about 7 per cent of the total drainage area of the entire basin. The major tributaries in its upper reach up to Paithan are —

(*i*) The *Darana* — It originates from the hills near about Igatpuri and joins the main river 40 miles down stream from the source.

(*ii*) The *Kadwa* — It drains the northern portion of the Sahyadri range and joins the main stream near about Niphad.

(*iii*) The *Pravara* and the *Mula* — The Godavari receives the combined water of the *Pravara* and the *Mula* rivers which drain the Akola hills in the southwest, at Toka which is about 135 miles from its source.

(*iv*) The *Shiv* — This tributary drains the western slopes of the Ajanta range of hills in the northeast and joins the main river near about Gangapur.

3. Raingauge network

The existing network of reporting raingauges in and around the basin whose data are available are shown in Fig. 1. There are 27 reporting raingauges within the basin but the daily rainfall data from 1891 are available in respect of 17 stations only. On the basis of existing network of raingauges within the basin, one raingauge represents about 310 sq. miles of the basin area.

The following five meteorological observatories maintained by the India Meteorological Department, with the date of their installation, are functioning in and near the basin —

Aurangabad	October 1891	located within the basin
Chikalthana	October 1951	
Nasik	November 1939	
Malegaon	May 1877	
Ahmednagar	February 1890	

There is only one self-recording raingauge within the basin upto Paithan that is Chikalthana Observatory, the recording raingauge of which has been functioning since 15 October 1951.

4. Mean monthly and annual rainfall

Monthly and annual normal rainfall data (1901 to 1950) of about 100 raingauge stations in and around the basin were utilised for drawing mean

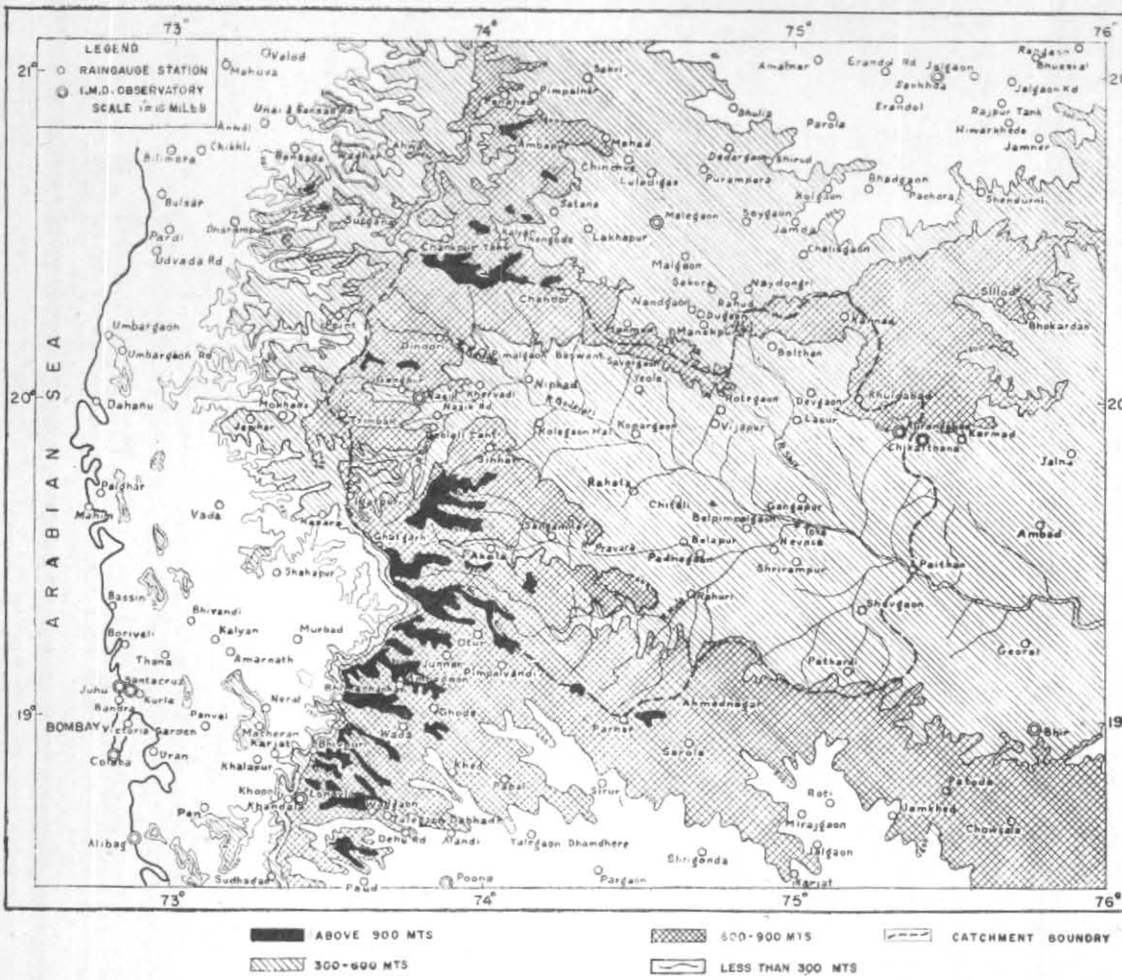


Fig. 1. Upper Godavari catchment upto Paithan dam site

monthly and annual isohyetal maps. While drawing the isohyetal maps due weight was given to the orography of the basin as can be seen from Fig. 1. However, it may be mentioned that due to sparse network of raingauges over and near the Western Ghats, the isohyetals drawn over this region may be taken as tentative. Mean monthly and annual isohyetal maps of the basin were first drawn and monthly and annual rainfall was obtained by planimetering of the monthly and annual isohyetal maps. At Fig. 2 mean annual rainfall map of the basin is reproduced. From an examination of this map the basin may broadly be divided into following three rainfall zones —

(*i*) *Heavy rainfall zone* — This zone runs almost parallel to the Western Ghats on the lee-side and has a width of 15 to 20 miles. In this zone rainfall steeply decreases from west to east from about 140 inches near Igatpuri to about 50 inches in the plains area. Total area of this zone is about 650 sq. miles which is about 8 per cent of the total basin area upto Paithan. Apparently, the bulk of run-off in the upper reaches comes from this zone.

(*ii*) *The Central zone of low rainfall* — This zone is located in the middle of the basin and is enclosed by an isohyetal of 20 inches. This zone is the region of lowest rainfall within the basin. The area of this zone is about 1000 sq. miles and represents roughly 12 per cent of the total basin area.

(*iii*) *The Intermediate zone of moderate rainfall* — The remaining portion of the basin comprising of about 6750 sq. miles (*i.e.*, 80 per cent of the total basin area) falls in this category. Rainfall in this region varies 20 to 50 inches annually.

The month-wise distribution of catchment rainfall based on rainfall data of the period 1901 to 1950 is shown in Table 1. From this table it is evident that the basin receives more than 90 per cent of the annual precipitation during the southwest monsoon months of June to October. Normally, monsoon sets over this region by about 10 June and

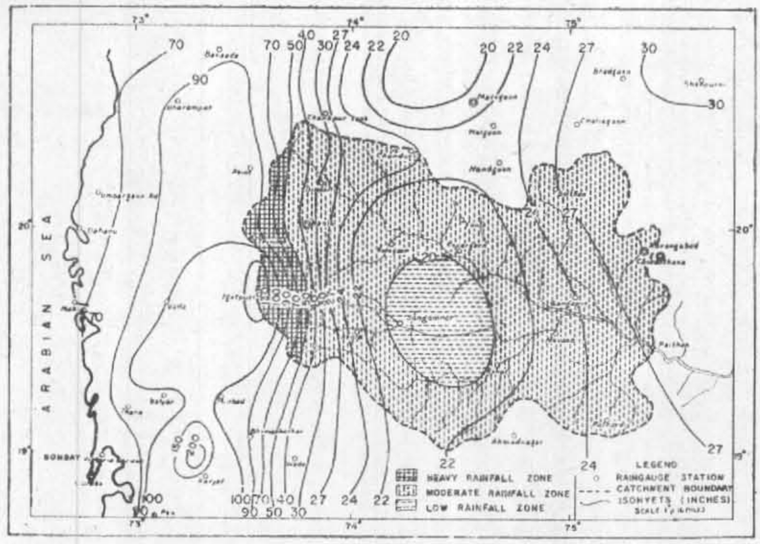


Fig. 2. Normal annual isohyets (inches) for 1901—1950

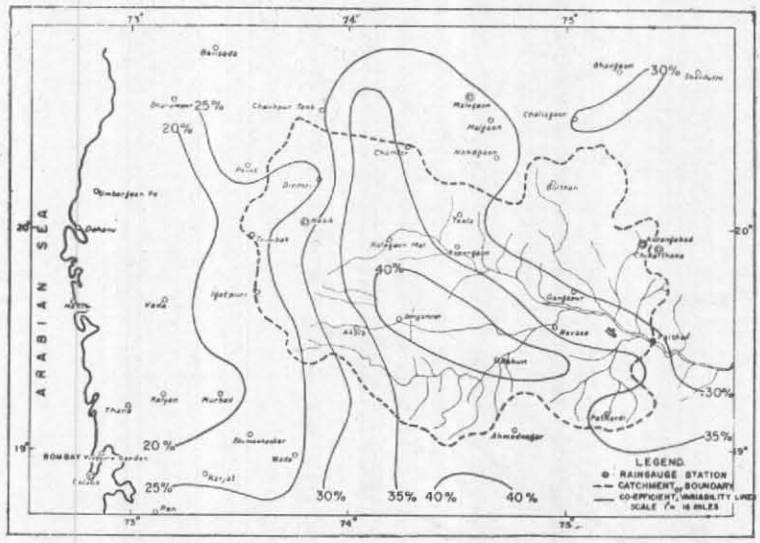
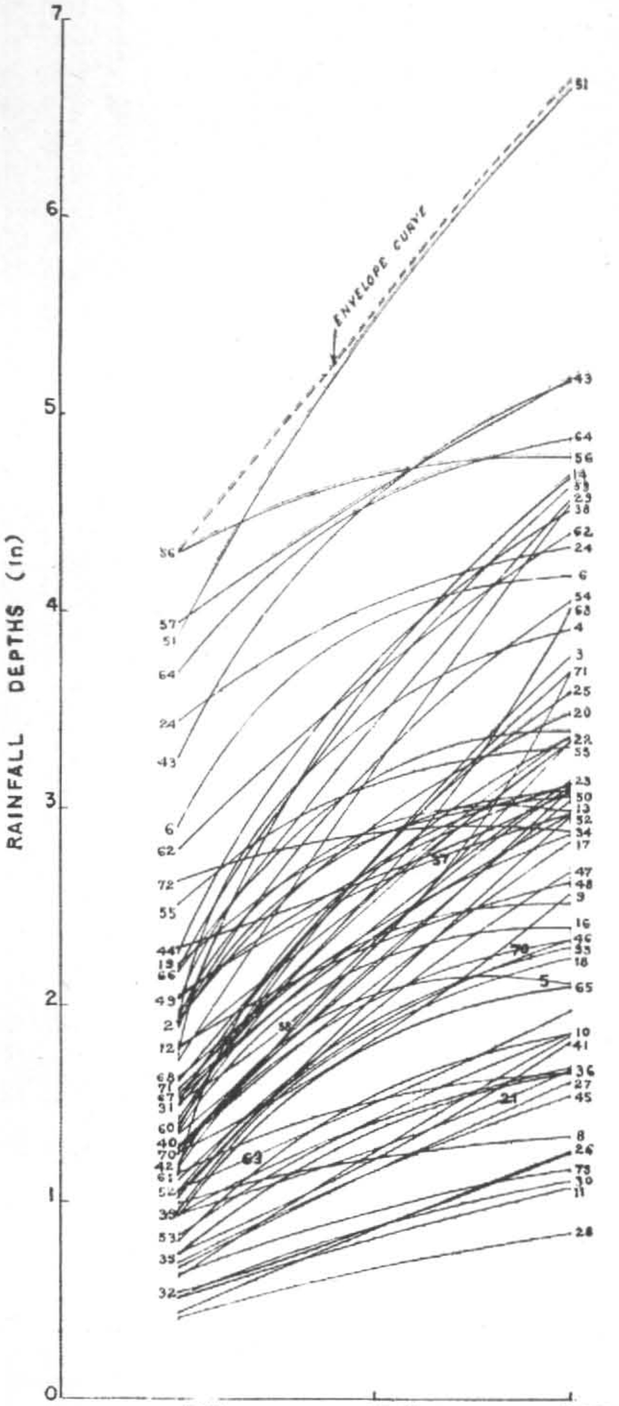


Fig. 3. Coefficient of variability of monsoon rainfall (June—October)

withdraws in the beginning of the first week of October. It also shows that July is the chief rainy month of the year during which about 25 per cent of the annual rainfall is received. Contrary to expectations, the basin receives more rainfall in September than in August.

5. Variability of rainfall over the basin

While working out the mean montly and annual rainfall of the basin it has been noticed that both annual and monsoon rainfall varies considerably over the basin from year to year. In order to have an idea of the rainfall variability over the basin coefficients of variability ($C = \sigma M \times 100$) were calculated for 36 rainfall stations in and near the basin using the data for the period 1901 to 1950. Coefficients of variability were determined for individual stations for the annual as well as for the monsoon (June to October) rainfall. It was, however, noticed that there was not much difference between the annual and monsoon coefficients of variability at individual stations. Fig. 3 shows the isolines of coefficient of variability for the monsoon (June to October) period. It can be seen from this figure that the coefficient of variability is the highest in the central parts of the basin and is of the order of 40 to 44 per cent. Variability along the Western



Curve no.	RAIN SPELL
1	31 AUG - 2 SEPT 1891
2	1 - 3 SEPT 1892
3	19 - 21 JUNE 1893
4	20 - 22 JULY 1894
5	6 - 8 SEPT 1895
6	25 - 27 JULY 1896
7	23 - 25 SEPT 1897
8	31 JULY - 2 AUG 1898
9	11 - 13 JUNE 1899
10	31 JULY - 2 AUG 1900
11	8 - 10 AUG 1901
12	16 - 18 JULY 1902
13	1 - 3 OCT 1903
14	13 - 15 SEPT 1904
15	4 - 6 JULY 1905
16	19 - 21 JULY 1906
17	13 - 15 AUG 1907
18	2 - 4 AUG 1908
19	12 - 14 JUNE 1909
20	29 - 31 JULY 1910
21	6 - 8 JULY 1911
22	21 - 23 JULY 1912
23	26 - 28 JUNE 1913
24	26 - 28 JUNE 1914
25	25 - 27 JUNE 1915
26	5 - 7 AUG 1916
27	25 - 27 AUG 1917
28	21 - 23 AUG 1918
29	28 - 30 SEPT 1919
30	31 JULY - 2 AUG 1920
31	17 - 19 SEPT 1921
32	15 - 17 JUNE 1922
33	20 - 22 SEPT 1923
34	27 - 29 AUG 1924
35	22 - 24 JUNE 1925
36	14 - 16 AUG 1926
37	12 - 14 JULY 1927
38	18 - 20 SEPT 1928
39	12 - 14 JULY 1929
40	9 - 11 SEPT 1930
41	3 - 5 JULY 1931
42	3 - 5 SEPT 1932
43	10 - 12 SEPT 1933
44	2 - 4 AUG 1934
45	27 - 29 AUG 1935
46	27 - 29 JUNE 1936
47	23 - 25 JULY 1937
48	6 - 8 OCT 1938
49	25 - 27 AUG 1939
50	22 - 24 JUNE 1940
51	1 - 3 JULY 1941
52	29 JUNE - 1 JULY 1942
53	10 - 12 JULY 1943
54	12 - 14 JULY 1944
55	21 - 23 SEPT 1945
56	18 - 20 NOV 1946
57	28 - 30 SEPT 1947
58	21 - 23 NOV 1948
59	22 - 24 SEPT 1949
60	11 - 13 JULY 1950
61	14 - 16 OCT 1951
62	24 - 26 JULY 1952
63	19 - 21 JUNE 1953
64	28 - 30 SEPT 1954
65	2 - 4 OCT 1955
66	2 - 4 OCT 1956
67	21 - 23 JUNE 1957
68	10 - 12 JULY 1958
69	20 - 22 JULY 1959
70	7 - 9 SEPT 1960
71	8 - 10 OCT 1961
72	8 - 10 SEPT 1962
73	26 - 28 AUG 1963

Fig. 4. Depth-duration curves for heavy rain spells over the Godavari basin up to Paithan dam site

TABLE 1

Mean monthly and annual rainfall (inches) for the Godavari basin upto Paithan

	Mean rainfall (inches)	Per cent of annual		Mean rainfall (inches)	Per cent of annual
Jan	0·21	0·7	Aug	5·51	19·2
Feb	0·10	0·3	Sep	6·37	22·2
Mar	0·11	0·4	Oct	1·97	6·9
Apr	0·24	0·8	Nov	1·24	4·3
May	0·62	2·2	Dec	0·23	0·8
Jun	4·84	16·9	Annual	28·73	100
Jul	7·29	25·4	Jun to Sep	24·01	83·7
			Jun to Oct	25·98	90·6

TABLE 2

Highest rainfall amounts (inches) in 24-hr at raingauge stations in the upper Godavari basin

Station	Highest rainfall (inches)	Date	Station	Highest rainfall (inches)	Date
Akola	5·3	25-7-1952	Niphad	5·1	2-7-1941
Aurangabad	9·7	2-9-1891	Parner	5·9	14-9-1902
Bolthan	7·0	14-10-1951	Pathardi	6·5	12-9-1926
Chandor	8·3	3-11-1931	Pimpalgaon	9·4	25-7-1952
Dindori	7·5	2-7-1941	Rahuri	6·1	19-11-1946
Igatpuri	17·7	21-7-1894	Sangamner	4·9	15-9-1889
Koparagaon	13·0	15-10-1951	Shivgaon	9·9	7-9-1934
Nasik	6·9	21-9-1923	Sinnar	6·6	23-9-1901
Nevasa	8·6	9-9-1950	Trimbuk	16·2	2-7-1941
			Yeola	10·9	15-10-1951

Ghats varies from 20 to 25 per cent. In the north-eastern part of the catchment coefficient of variability is of the order of 25 to 30 per cent.

6. The highest 24-hr point rainfall within the basin

The available daily rainfall data of all raingauge stations within the basin was examined to determine the highest 24-hr rainfall received at individual station from 1891 onwards. Table 2 gives the highest 24-hr rainfall amounts received at the 19 raingauge stations within the basin for which long term rainfall records are available. It is seen that the upper reaches of the Godavari basin point rainfall are of the order of 18 inches (Igatpuri) and 16 inches (Trimbuk) in 24 hr. It is interesting to note that the heaviest falls in 24-hr generally occurred either in July or September and occasionally in October and November, but none in the months of June or August.

7. Design storm analysis

Considering the orography of the basin, design storm has been worked out by the depth-duration method taking the catchment up to Paithan as the unit of study. For undertaking depth-duration analysis, daily rainfall data of nearly 100 reporting raingauges in and around the basin was examined for the period 1891 to 1963 for all the major rain spells. Finally, for each year of 73-year period, one heaviest rain storm was selected for detailed isohyetal analysis. Fig. 4 shows the depth-duration curves of these 73 rain storms for duration of 1-day, 2-day and 3-day. It is seen that the rain storms of 1 to 3 July 1941 (curve No. 51), 18 to 20 November 1946 (curve No. 56), 10 to 12 September 1933 (curve No. 43) , 28 to 30 September 1947 (curve No. 57), and 28 to 30 September 1954 (curve No. 64), produced maximum depths of rainfall over the

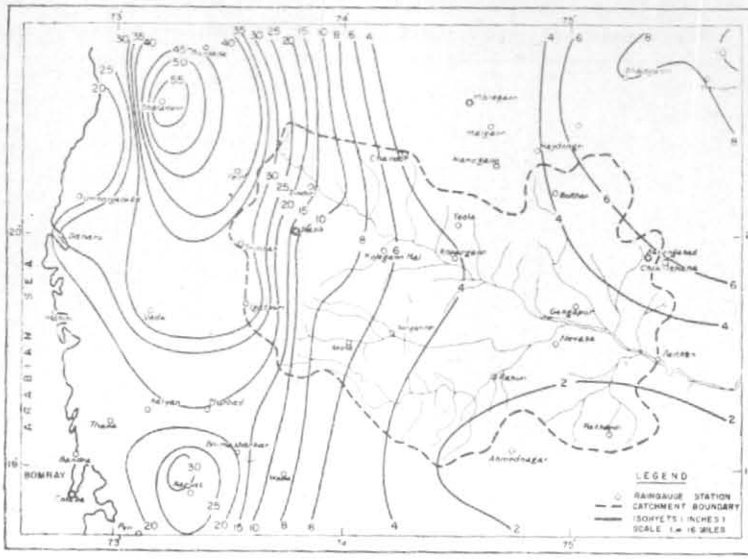


Fig. 5. Total storm isohyets (inches) for 1 to 3 July 1941

basin for different durations. The envelope depth-duration curve shown in Fig. 4 gives the maximum depth of rainfall over the basin for durations of 1-day, 2-day and 3-day. Figs. 5 and 6 show total isohyetal patterns of the July 1941 and September 1933 rain storms over the upper Godavari basin.

The maximum rainfall depths over the basin as obtained from the envelope depth-duration curve of Fig. 4 are as follows —

Storm duration (days)	Maximum rainfall depth (inches)	Percentage of 3-day depth
One	4·3	64
Two	5·5	82
Three	6·7	100

8. Frequency analysis of storm rainfall data

The weighted average rainfall data of 73 rain storms was subjected to frequency analysis using Gumbel's (1954) method. Fig. 7 gives the computed lines of maximum storm rainfall for different return periods and durations. For each of the computed lines the formal theoretical relationships are as follows —

Duration	Relationships
1-day	$Y_1 = 1{\cdot}2023 + 0{\cdot}7180\, b_1$
2-day	$Y_2 = 1{\cdot}9671 + 0{\cdot}8629\, b_2$
3-day	$Y_3 = 2{\cdot}4542 + 0{\cdot}9832\, b_3$

where Y is the extreme rainfall value in inches for the respective durations and b is the reduced variate related to the return period T years by the relation $b = -\log\log\{T/(T-1)\}$. From the computed lines of Fig. 7 rainfall depths for different durations have been picked up for return periods of 100, 200, 500 and 1000 years. The values are given in Table 3.

It can be seen from Table 3 that the maximum rainfall values obtained from the depth-duration envelope curve of Fig. 4 almost correspond with the 100-year values obtained by frequency analysis method. It can also be seen from this table that percentage ratios of 1-day, 2-day rainfall depths to 3-day depths for various return periods are more or less of the same order as for the envelope values. Taking the envelope values as the base, percentage ratios of 200, 500 and 1000-year values to envelope values were also determined and the same are shown in Table 4.

It is noticed that 1-day envelope values should be increased by about 16, 33 and 44 per cent to obtain 200, 500 and 1000-year values of design rainfall respectively. In other words to obtain 1000-year values of design storm, the envelope depths of 1-day and 2-day duration may be increased by 44 per cent and of 3-day depth by 37 per cent. It is also seen from Table 4 that percentage ratios for each return period do not differ much from one duration to another. The highest percentage ratios for each return period may be taken for this catchment as the conversion factors for obtaining design rainfall depth of 200, 500 or 1000-year return period from the envelope rainfall depths.

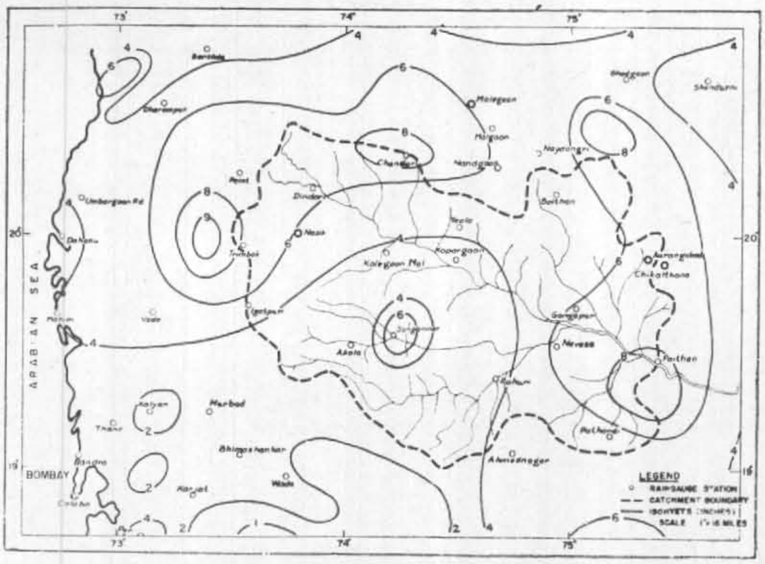


Fig. 6. Total storm isohyets (inches) for 10–12 September 1933

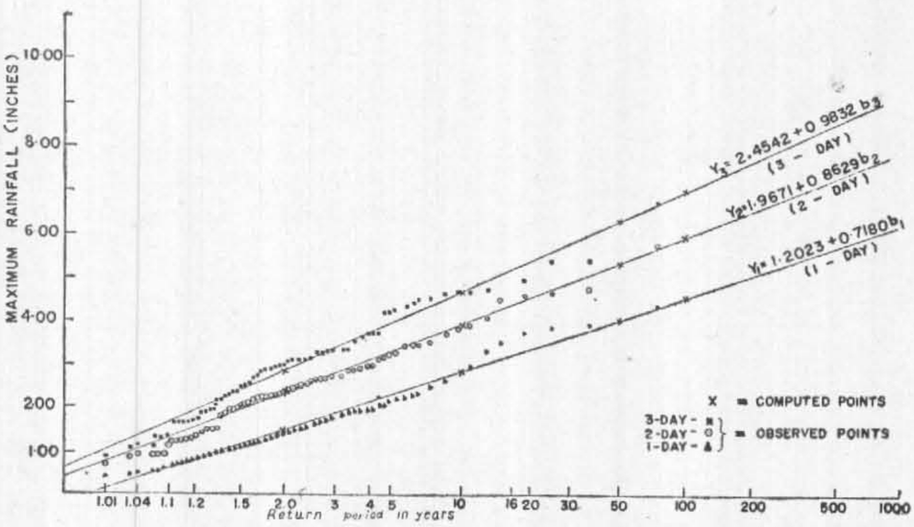


Fig. 7. Computed Gumbel lines for 1, 2 and 3-day maximum rainfall

9. Conclusions

From the foregoing the following conclusions can be broadly drawn—

(*i*) The mean annual rainfall of the Godavari basin up to Paithan dam site is of the order of 29 inches. Total monsoon rainfall (June to October) is about 90 per cent of the annual rainfall. July is the rainiest month, during which nearly a quarter of the annual rainfall is received. The basin as a whole receives more rainfall in September than in August.

(*ii*) Coefficient of variability of rainfall is the highest (of the order of 40 per cent) in the central parts of the catchment which receive mean annual rainfall of 20 inches or less. Coefficient of variability is comparatively less over the western and eastern parts of the basin.

(*iii*) The envelope curve of depth-duration analysis (D.D.) for various durations correspond to 100-year design storm (Gumbel's analysis). It is also noticed that for this catchment, the design storm-depths for different durations for a return period of 1000 years can be obtained by increasing

TABLE 3

Maximum rainfall depths (inches) for different durations and return periods

Storm duration	Rainfall depths (inch) obtained by Gumbel's method for return periods (years)				Storm depths (inch) obtained by envelope curve method	1-day, 2-day rainfall depths (Gumbel's method as percentage of 3-day depths for return periods			
	100	200	500	1000		100	200	500	1000
1-day	4·5	5·0	5·7	6·2	4·3	64	65	66	67
2-day	5·9	6·5	7·3	7·9	5·5	84	84	85	86
3-day	7·0	7·7	8·6	9·2	6·7	100	100	100	100

TABLE 4

Percentage ratios of 200, 500 and 1000-year storm rainfall depths to envelope values for different durations

Storm duration	Percentage ratios		
	200-year	500-year	1000-year
1-day	116	133	144
2-day	118	133	144
3-day	115	128	137
Highest ratio	118	133	144

the D.D. envelope curve values by about 44 per cent for 1 and 2-day and 37 per cent for 3-day durations respectively.

10. Acknowledgement

The authors are grateful to Shri P. Jagannathan, Assistant Director, Institute of Tropical Meteorology for his encouragement and guidance. Thanks are also due to S/Shri T'khe and A. K. Kulkarni of the C. and H. Division for their valuable assistance in the preparation of this note.

REFERENCE

Gumbel, E. J. 1954 Applied Mathematics Series, No. 33, National Bur. Standards, U. S. Dep. Comm., Washington.