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Rainfall Intensity-Duration-Frequencies for India, for local drainage design*

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(*Received 17 February 1960*)

1. Introduction

In recent years there has been increasing demand from the Central Water and Power Commission and other engineering organisations in India for detailed information of rainfall in connection with the design of local drainage works such as storm sewers, road culverts and railway bridges over small streams. Such information is also required for reviewing the adequacy of waterways in existing bridges and other such structures, which is being undertaken in a systematic way for the whole country. This paper presents the results of analysis carried out in order to derive the rainfall data for such designs.

1.1. The problem presented by local drainage design requires techniques different from those usually employed for fixing the design storm in connection with storage reservoirs and spillways of medium size or big dams. As the extent of the drainage basins involved in local drainage works is small, of the order of a few square miles to a few hundred square miles, the times of concentration will also be of the order of hours and not days, so that even intense rainfall of short duration suffice to cause heavy outflows. The structures are usually designed on the basis of flood of a specific average return period derived from the rainfall intensity for such a return period. The rainfall of any return period for a given duration is the maximum amount of rainfall in that duration which will be equalled or exceeded once every '*n*' years on the average, over a long period of time. Hence, intensities of rainfall of different durations, from a few minutes to say, 24 hours and for various returns periods from 2 years upto 40 or 50 years over all parts of India will be the data required for fixing the design flood of the local drainage structures.

2. Methods of approach

The following two methods have generally been followed by various workers for deriving rainfall intensities under discussion.

(1) The derivation and use of formulæ (semi-empirical) connecting rainfall intensity with duration, area and frequency.

(2) Detailed spatial analysis of rainfall data and developing generalised charts and relations for obtaining the intensity of storms of any required duration and any return period.

Various formulæ have been given connecting the three parameters—duration, intensity and frequency (Meyer 1928, Yarnell 1935, Bernard 1938). These formulæ have been derived from studies of actual storm rainfall data of particular regions and are applicable

*A brief summary of the paper was presented at the ECAFE-WMO Seminar on 'Hydrologic Network and Methods' held at Bangkok in July 1959 generally to those regions only. The formulæ are of the form—

$$i = \frac{K\ F^x}{t^n}$$

where i=average intensity of rainfall in inches per hour; F=average period of recurrence in years, t=duration of rain: K, x and n are constants whose value depend upon the geographical location.

2·1. Yarnell's (1935) publication of generalised charts showing the geographical distribution over the U.S.A. of rainfall intensities of different duration and of various return periods is a classic example of the second method of approach. In recent years, the U. S. Weather Bureau (1953) has derived more comprehensive generalised charts utilising the data of over 1000 S.R. raingauge stations in the country, covering periods of 5 to 50 years and applying the techniques of extreme-value statistical analysis. Following more or less the same methods, Bruce (1959) has very recently derived Rainfall Intensity-Duration-Frequency maps for Canada.

2·2. The derivation of similar charts for India is beset with a serious handicap as the network of recorder raingauge stations is very inadequate and the period of data available even for these few stations is very short. It was, therefore, necessary to find out methods by which the 24-hour rainfall data which are available for a fairly close network of stations for a long period of years can be used to make up for the inadequacy of recorder rainfall data, for deriving generalised charts.

3. Method of analysis

3·1. *Analysis of recorder raingauge data: Relation between 2-year 1-hour rainfall and 2-year 24-hour rainfall*—Recorder raingauge data in usable form were available for 38 stations for periods varying from 5 to 15 years. The hourly (clock hour) rainfall data of each of these stations were arranged in descending order of magnitude and given rank numbers 1, 2 etc. While tabulating the amounts not more than one clock hour amount was taken in any 6-hour period. This restriction was observed in order to treat the different values chosen as independent occurrences. The return period for any value was taken as t/m where t is the number of years of record and m is the rank number. The amounts were plotted against the return periods on logarithmic paper. The line of best fit was drawn by inspection. In most cases, this was a straight line. The plotting for Bangalore and Begumpet are shown in Fig. 1. From this line, the 2-year 1-hour rainfall amount for the station was obtained. The 2-year 1-hour rainfall is the maximum amount of rainfall in one hour which will be equalled or exceeded on the average once in 2 years. In the same way the 2-year 1-hour rainfall was obtained for all the stations. Next, the 24-hour rainfall data of the stations for the years covered by the recorder raingauge data, were analysed following the same procedure and the 2-year 24-hour rainfall amounts were obtained. For the same stations, the 2-year 24-hour rainfall amounts were also obtained by using the daily rainfall data for a longer period (40 years). The values for the 2-year 24-hour rainfall obtained from short term and long term data were practically the same in most cases. The ratio of the 2-year 24-hour rainfall to the 2-year 1-hour rainfall was found for all the stations. The values of this ratio were plotted on a map and isopleths were drawn. These are shown in Fig. 2. The distribution of the values of the ratio showed smooth and systematic variation so that the isopleths could be drawn fairly objectively.

The values of the 3-year 1-hour and 5-year 1-hour rainfall were also picked out for the stations which had data for 7 years or longer. For these stations the 3-year 24-hour and 5-year 24-hour rainfall amounts were also obtained from the relevant curves. The ratios for the 24-hour rainfall and

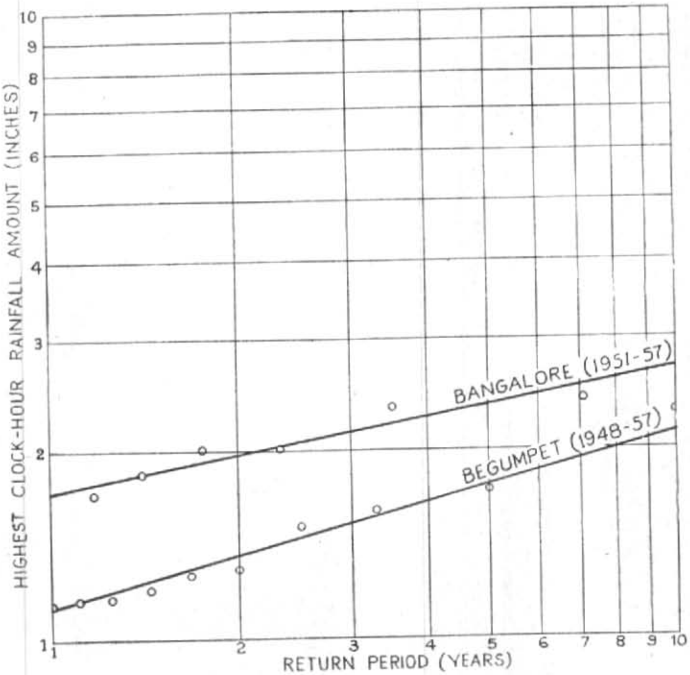

Fig. 1. Frequency curves of clock-hour rainfall

1-hour rainfall for the same return period were computed. It was found that the ratio of the 24-hour rainfall to 1-hour rainfall for a station was the same for all the return periods, that is the ratio n-year 24-hour rainfall to n-year 1-hour rainfall of a station was the same for all values of n.

3.2. *Analysis of daily rainfall data*—A large number of daily rainfall stations were selected to give a good coverage over the country. The 24-hour rainfall data of these stations for 40 years were analysed by the return period method and the 24-hour rainfall values were obtained for various return periods, 2 years to 40 years. In the case of most of the stations, the logarithmic linear fit was found to be fairly satisfactory for the plot of intensities against return periods. The 2-year 24-hour rainfall amounts of all the stations were then plotted on a map and isopluvials were drawn on it. These are shown in Fig. 3.

4. 2-year 1-hour rainfall map

The 2-year 24-hour rainfall values of a large number of stations obtained from Fig. 3 were divided by the relevant values of the ratio of the 2-year 24-hour to 2-year 1-hour rainfall picked out from Fig. 2. In this way, the 2-year 1-hour rainfall amounts for all the stations were obtained. These were plotted on a map and the isopluvials were drawn. Thus using the daily rainfall data of a large number of stations in conjunction with the analysed data of the available limited number of recorder raingauge stations, a generalised chart of 2-year 1-hour rainfall for the whole of India was obtained. This chart is given in Fig. 4.

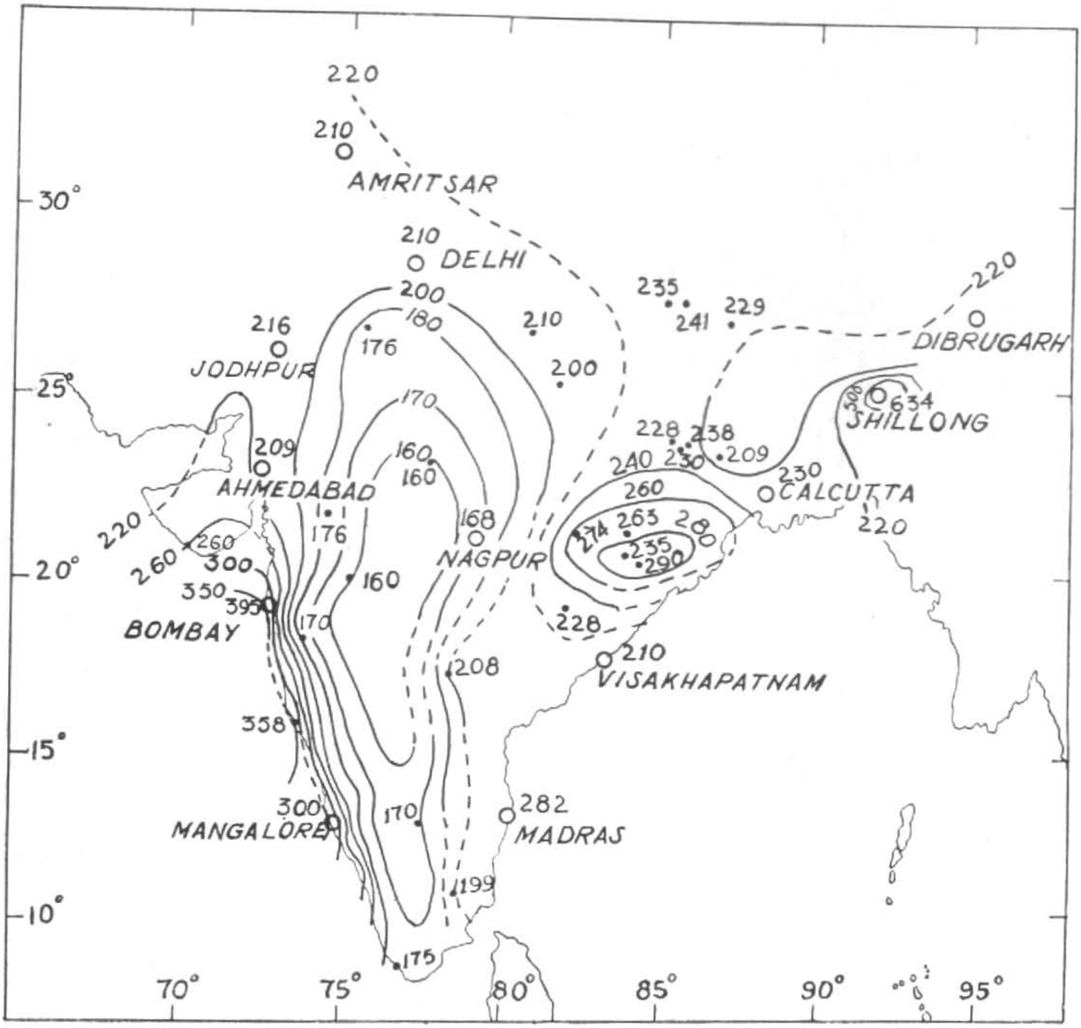

Fig. 2. Ratio of 2-year 24-hour rainfall to 2-year 1-hour rainfall (percentage)

TABLE 1

Ratio of 2-year t-hour rainfall to 2-year 1-hour rainfall

	$t=$	2	3	6
Region I		1·33	1·45	1·53
Region II		1·34	1·49	1·69

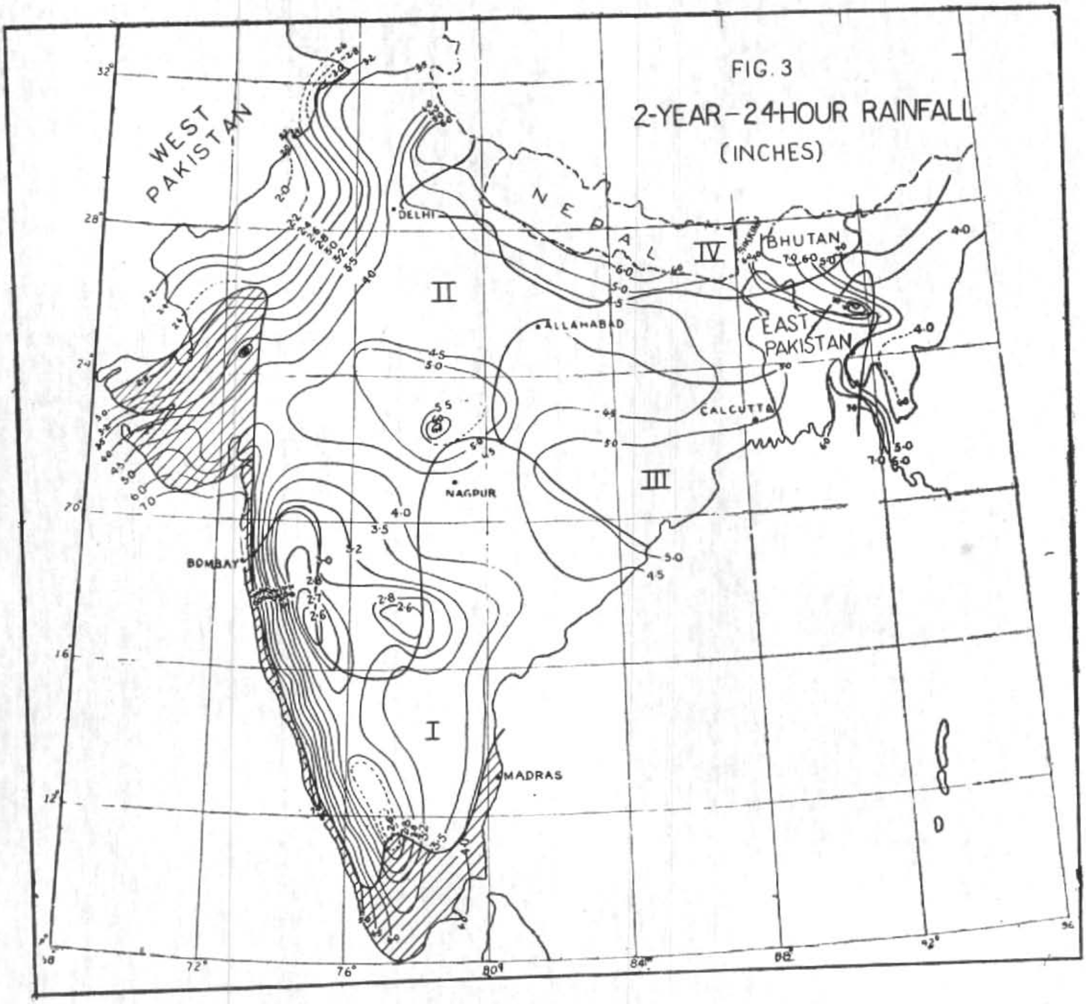

Fig. 3

(Undefined zone shown hatched)

5. 2-year 2-hour, 2-year 3-hour, etc rainfall charts

The procedure that was adopted in 3·1 to obtain the 2-year 1-hour rainfall amounts of the recorder raingauge stations was applied to the 2-hour, 3-hour and 6-hour rainfall data of the stations and from the intensity *versus* return period curves, the values of the 2-year 2-hour, 2-year 3-hour and 2-year 6-hour rainfall values were obtained. When these derived values of 2-year rainfall of different durations, were examined, an interesting fact emerged, namely, the ratio of the 2-year t-hour rainfall to 2-year 1-hour rainfall was practically the same for all stations in the same region for each value of t. It was found that the ratios of rainfall of t-hour to rainfall of 1-hour are covered for the whole country by two sets of mean values given in Table 1.

These ratios were used with the 2-year 1-hour rainfall amounts picked out from Fig. 2 to obtain the 2-year 2-hour, 2-year 3-hour and 2-year 6-hour rainfall amounts for a large number of stations. Separate

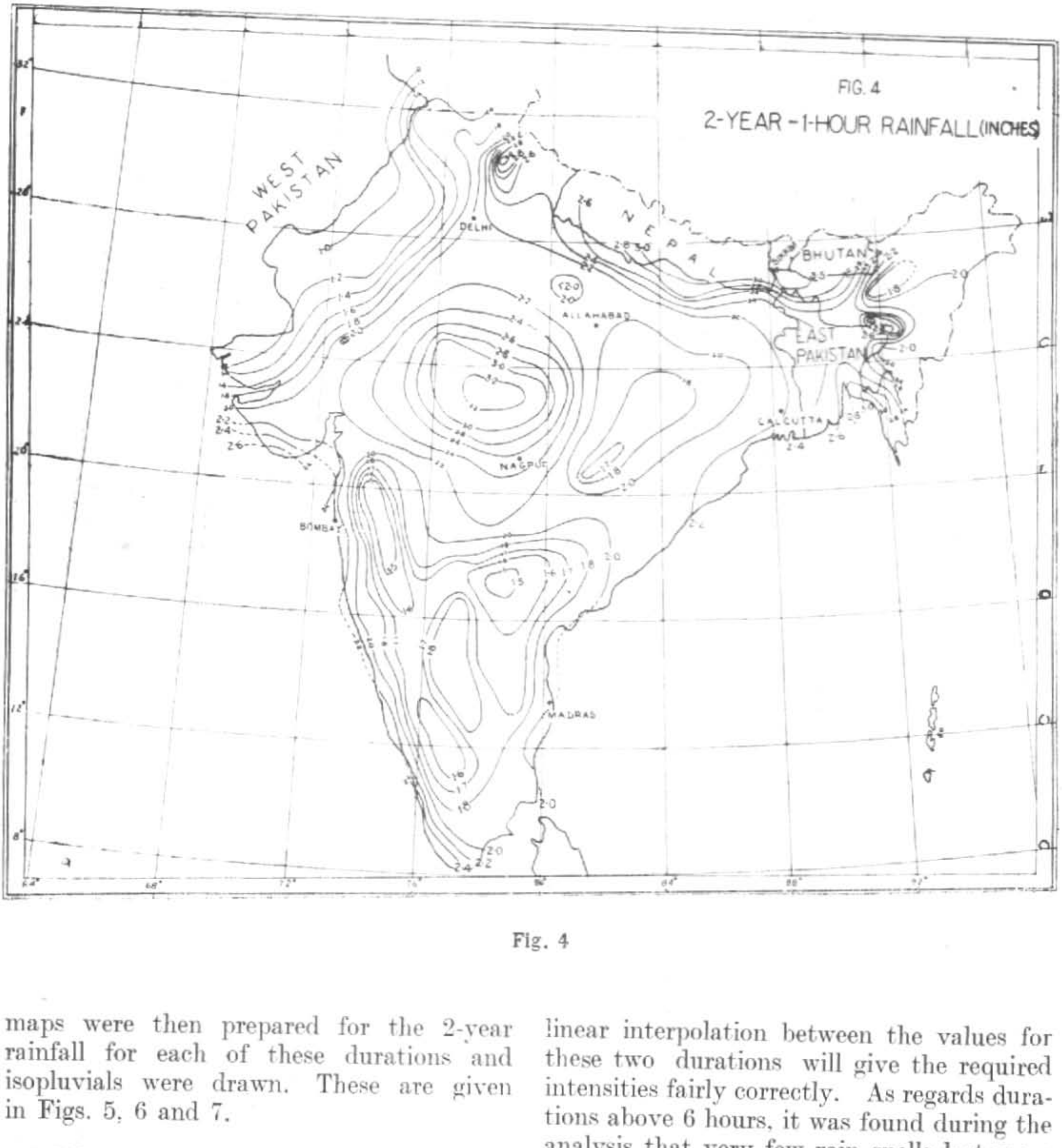

Fig. 4

maps were then prepared for the 2-year rainfall for each of these durations and isopluvials were drawn. These are given in Figs. 5, 6 and 7.

While drawing the isopluvials in the different maps, necessary adjustments were made for consistency with the actual values of the recorder raingauge stations.

6. Derivation of rainfall charts for durations less than 1 hour and between 6 hours and 24 hours

For durations intermediate between 3 and 6 hours, considering the fact that the variation between 3 and 6 hours is small, linear interpolation between the values for these two durations will give the required intensities fairly correctly. As regards durations above 6 hours, it was found during the analysis that very few rain spells last more than 6 consecutive hours and that on days of heavy rainfall, generally, 80 to 90 per cent of the 24-hour rainfall occur within a period of 6 hours or so. Therefore, it was considered neither necessary nor feasible to derive separate charts for durations between 6 and 24 hours. Extension of the study to cover duration of rainfall less than an hour has not been possible as the data required are not readily available.

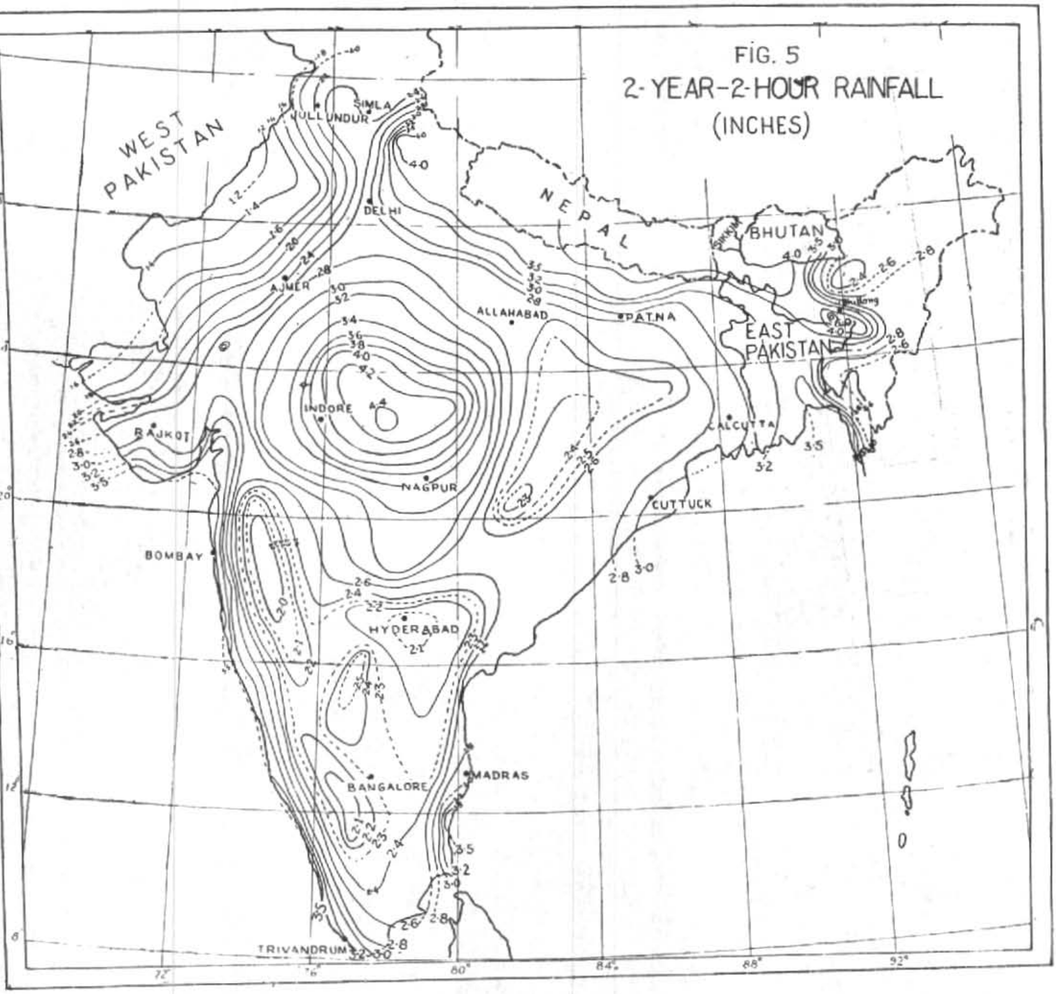

Fig. 5

7. Relation between 2-year rainfall and longer return period rainfall of the same duration

From the analysis of the 24-hour rainfall data mentioned in 3·2 the ratios of the n-year 24-hour rainfall amount to 2-year 24-hour rainfall amount were obtained for all stations for values of n from 5 to 40 years. The ratios for all stations for each value of n were plotted on a map and the maps were examined. It was found that the whole of India could be divided into four zones over each of which, the ratio of the 2-year 24-hour rainfall to n-year 24-hour rainfall was constant for each value of n. These ratios are given in Table 2. The boundaries of the zones are shown in Fig. 3. The shaded areas along the east and west coast of India are areas for which the ratios are uncertain. An examination of Table 2 shows that in Zones I and IV the ratios for different values of n are practically the same so that a single set of values can be adopted for these two areas. The ratios are distinctly higher in Zones II and III so that these zones have to be treated separately.

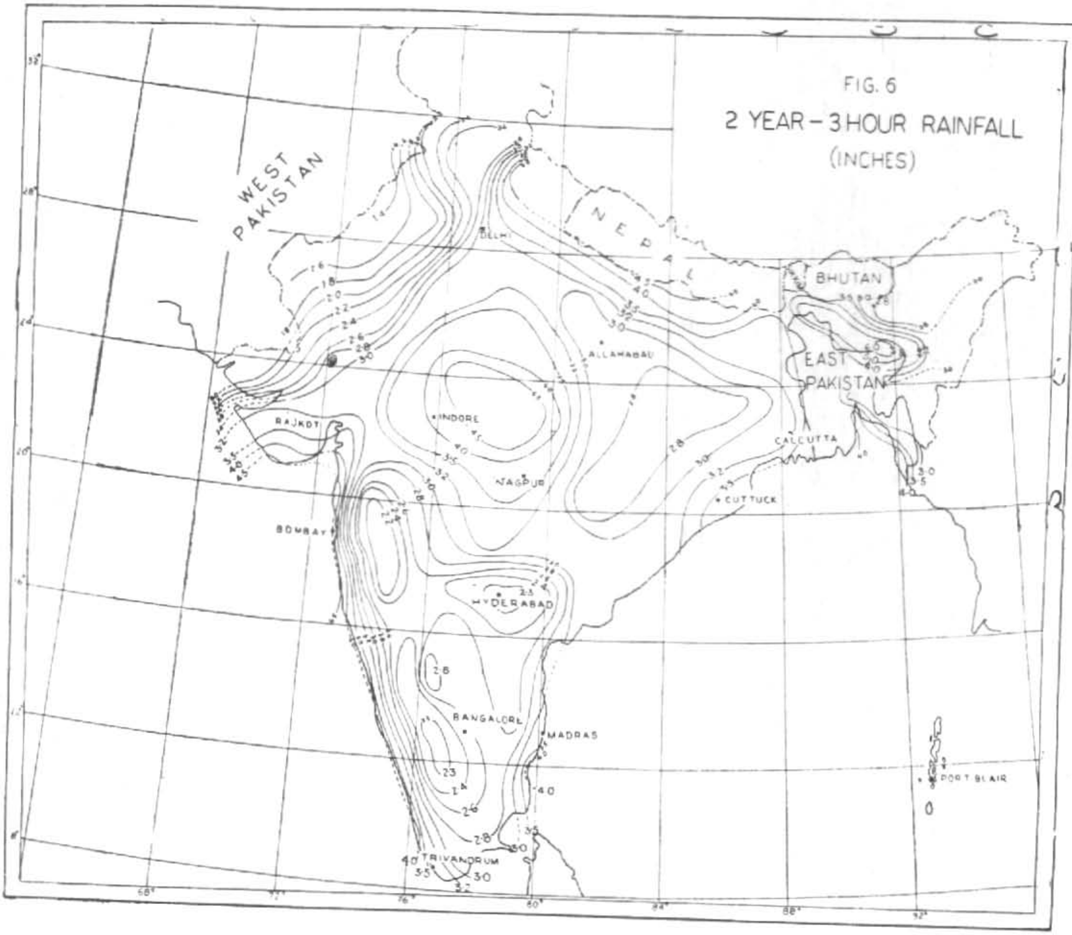

Fig. 6

TABLE 2

Ratio of *n*-year 24-hour rainfall to 2-year 24-hour rainfall

Zone	$n = 5$	10	20	30	40
I	1·20	1·38	1·54	1·65	1·73
II	1·26	1·46	1·74	1·90	2·04
III	1·31	1·60	2·03	2·27	2·52
IV	1·19	1·32	1·52	1·61	1·71

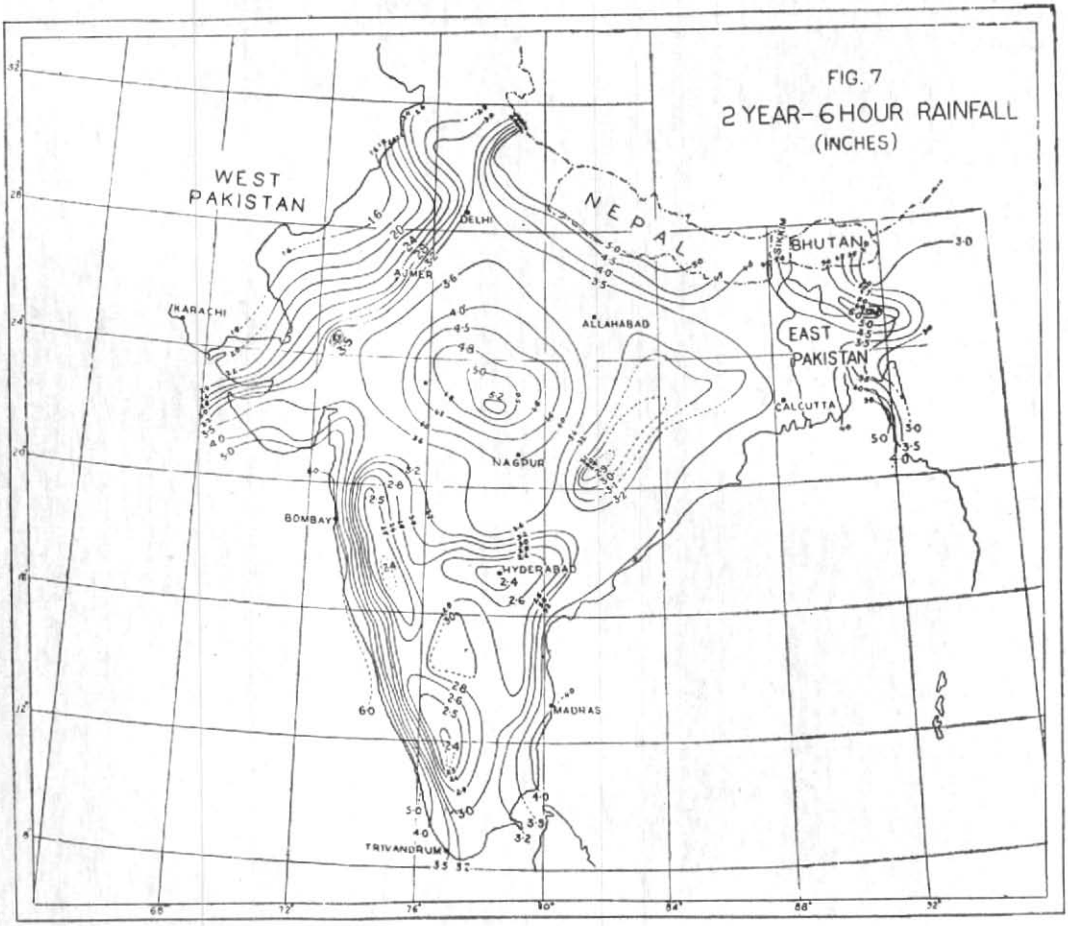

Fig. 7

These ratios enable us to derive the rainfall amounts for any return periods upto 40 years from the 2-year value picked out from Figs. 3 to 7, by taking advantage of the fact that the ratio of n-year 24-hour rainfall to n-year 1-hour rainfall of a station is the same for all values of n (*vide* last para of 3.1.).

8. Discussion

8.1. As a result of the analysis described in the preceding sections, generalised charts for India of 2-year return period rainfall of durations 1, 2, 3, 6 and 24 hours have been derived. The relations between rainfall of 2-year return period and rainfall of longer return periods upto 40 years have also been obtained for different parts of the country. It has been shown that over wide areas, rainfall of longer durations bear fixed proportions with 1-hour rainfall of the same period of recurrence. The charts in Figs. 3 to 7 and the relations derived enable the estimation of the rainfall intensities for local drainage design over any part of India.

8.2. *Limitations*—While using the charts presented in this paper for the computation of design rainfall, the following limitations of the charts have to be borne in mind.

(1) The isopleths in Fig. 1 being based on a very small number of plotted data may show some changes in detail when more data become available and may require modifications particularly in regions of pronounced orographic features.

(2) The logarithmic linear fit which has been assumed in the rainfall amount *versus* return period plots, while apparently satisfactory as seen from the plots for the different stations may not satisfy rigorous theoretical requirements. It may be mentioned here that in a few cases of the 24-hour rainfall intensity *versus* return period plottings, it was seen that the points could best be fitted by two straight lines of different slopes, one for return period upto 5 years and the other, for the longer return periods. Such 'dog-leg' (two straight lines) in the frequency curve has also been noticed by Potter (1958) in the case of frequency distribution of the maximum annual peak rates of runoff. He has suggested that this character of the frequency curve might be the result of sampling from two populations of maximum annual peaks. However, as the separation of the frequency relation into two parts, each part being fitted by a straight line is arbitrary, a single straight line has been fitted even in such cases, in this analysis. The departure of the actual relation from the linear fit, though small, would have introduced corresponding errors in the final charts of rainfall intensities.

9. Use of the charts to obtain the design rainfall for local drainage work

9.1. Let us assume that the design rainfall is required for a particular drainage basin, the period of concentration of which is, say, 6 hours. We refer to Fig. 7, and obtain by inspection the 2-year 6-hour point rainfall over the problem basin. Let this be r inches. If it is intended to provide for a flood of, say, 30 years recurrence period, we find the ratio of 30 years to 2-year rainfall for the area in question from the zonal values of this ratio given in Table 2. Let this be R. Then $R \times r$ inches will be the 6-hour point rainfall which may be expected to occur over the basin on the average once in 30 years.

9.2. *Area-intensity relation of storm rainfall*—Having got the point-rainfall as in 8·1, it is necessary to know the area-intensity relation of storm rainfall in order to obtain from the point-rainfall value, the average rainfall over the area A of the drainage basin. Parthasarathy *et al.* (1960) have shown that in the case of large area storms of 1 to 4 days duration in India, the area-intensity relation of raifall is of the form $100\ i/I = 100 - C\sqrt{A}$ where I is the maximum rainfall at centre of the storm, i the average rainfall over an area A square miles surrounding the point of maximum rainfall and C is a constant. It has been shown in that paper that C has the same value for each region and is independent of the magnitude of the maximum rainfall I and that its variation from one region to another though not systematic is not large. The area-intensity relationships of shorter duration storms (less than 24 hours) are very likely to be of a similar form. If these are derived, they can be used with the derived point-rainfall value of $R \times r$, to compute the design rainfall for the proposed construction.

In *Technical Note No. 29* of the U.S. Weather Bureau (1958), the area-depth relationship of rainfall of short duration has been discussed and curves of this relationship are given for different parts of the United

States based on analysis of data of dense networks of recorder raingauges. While the general features of the area-depth relationship mentioned above hold in these cases the area-depth curve is found to vary significantly with duration.

10. Theoretical relations between intensity, duration and frequency of rainfall

10.1. It has been mentioned in Sec. 2 that various formulæ have been derived connecting the intensity, frequency and duration of rainfall. Bernard obtained for the New York area the relation

$$i=(28\, F^{0\cdot 22})/(t+9/F^{0\cdot 20})^{0\cdot 75}$$

Sherman found for the Boston area, the relation

$$i = 15\cdot 6\ (1\cdot 6\ F-0\cdot 6)^{0\cdot 22}/(t+b)^{0\cdot 7}$$

For other areas in U.S.A., similar formulæ have been found to fit the observed data. Bernard (1942) has summarised these various studies of intensity-frequency relations in the U.S.A; Mc Callum (1959) studied the intensity-duration relations of rainfall over East Africa. He plotted log i against log t and fitted a straight line to the plotted points by the method of least squares and found the relation between i and t to be of the form

$$i=c \times t^{-b}$$

where the constants c and b varied from one region to another. Over the area studied by him c varied from 1·54 to 3·4 and b from 0·55 to 0·83.

As, in the course of this study, it has been found that simple relations exist between 1-hour rainfall and rainfall of longer durations and also between rainfall of one periodicity and rainfall of higher periodicities, attempt has been made to derive expressions to define these relations.

10·2. *Intensity-duration-frequency relations of rainfall in India*

(*i*) *Intensity versus duration*—Using the two sets of ratios of the t-hour rainfall to 1-hour rainfall mentioned in Section 5, the relations between R_t, rainfall in t hours and R_1, rainfall in 1 hour has been found to be :

$$R_t = 1\cdot 21\ R_1 t^{0\cdot 176} \quad \text{for Region I} \qquad (1)$$

and $$R_t = 1\cdot 21\ R_1 t^{0\cdot 116} \quad \text{for Region II} \qquad (2)$$

for values of t from 2 to 24 hours. The above equations were found to be good fit at 99 per cent level of significance.

(*ii*) *Intensity versus return period*—Empirical formulæ connecting the n-year rainfall with 2-year rainfall of same duration were derived for the four zones. Assuming the relation between rainfall amount r and return period n to be of the form $r=an^k$, r_n/r_2 was plotted against $n/2$ on logarithmic paper, and a straight line was fitted by the method of least squares. The equations for the straight lines fitted for the four zones were :

$$r_n = r_2\ (n/2)^{0\cdot 1909} \quad \text{for Zone I} \qquad (3)$$

$$r_n = r_2\ (n/2)^{0\cdot 2406} \quad \text{for Zone II} \qquad (4)$$

$$r_n = r_2\ (n/2)^{0\cdot 3011} \quad \text{for Zone III} \qquad (5)$$

$$r_n = r_2\ (n/2)^{0\cdot 1802} \quad \text{for Zone IV} \qquad (6)$$

The value of χ^2 defined by

$$\Sigma\ [\ (r_n/r_2)_{\text{obs.}} - (r_n/r_2)_{\text{cal.}}]^2\ /\ (r_n/r_2)_{\text{cal.}}$$

is found to vary between 0·00055 and 0·00189 for the four zones showing that the relations are good fit even at 99 per cent level of significance.

(*iii*) *Amount, duration and return period* —Combining the equations (1) and (2) with each of the equations (3) to (6), we obtain the following relations connecting R, t and n

$$R_{n,t} = 1\cdot 21\ R_{2,1}\ (n/2)^a . t^b \qquad (7)$$

where $R_{n,t}$ is the n-year t-hour rainfall and $R_{2,1}$ is the 2-year 1-hour rainfall; a and b are constants, a having the values of 0·192, 0·241, 0·301 and 0·180 in the Zones I to IV respectively and b having either of the values 0·176 and 0·116.

If $i_{n,t}$ is the average rate of rainfall per hour (intensity) for duration t hours and return period n years,

Since $i_{n,t} = R_{n,t}/t$

Therefore $i_{n,t} = \frac{1}{t} \times 1 \cdot 21\ R_{2,1}\ (n/2)^a\ t^b$

$= 1 \cdot 21\ R_{2,1}\ (n/2)^a\ (1/t^{1-b})$

$= 1 \cdot 21\ R_{2,1}\ (n/2)^a\ (1/t^c)$

where $c = 1 - b$ and has either of the values 0·824 and 0·884. This equation connecting rainfall intensity duration and frequency is of the same form as the equations found for different parts of the U.S.A. In the latter equations a has values varying from 0·183 to 0·27 and b values varying from 0·7 to 0·855. It may be seen that the corresponding values for India vary from 0·180 to 0·301 in the case of a and 0·824 and 0·884 in the case of b.

11. Summary

Utilising some simple relation between 24-hour rainfall and 1-hour rainfall obtained by analysis of the available small number of recorder raingauge stations, generalised charts of 2-year rainfall of durations 1-hour, 2-hour, 3-hour, 6-hour and 24-hour have been derived. Factors are also given for obtaining from the 2-year return period rainfall, the rainfall of longer return periods upto 40 years. The use of these charts for obtaining rainfall intensities required in dealing with local drainage problems have been explained. The limitations of the charts are also given. It may be pointed out that with all the limitations the rainfall intensities that have been derived and presented in the charts represent the best estimates possible with the limited basic data that are available and are intended to serve as provisional estimates of rainfall-intensity-duration frequency data for India.

12. Acknowledgement

The authors wish to thank the various members of the staff of the Hydrology Section, specially Sarvashri Jain, Reen and Vatsal who helped in the collection and tabulation of the basic data, Sarvashri Kamble and Dutta Roy who helped in preparation of rainfall maps and Sarvashri O.P. Gupta and J. Narayana for the preparation of manuscript. Thanks are also due to the Director General of Observatories for the continued interest which he evinced in the progress of this study.

REFERENCES

Bernard, M.	1938	Modified rational method of estimating flood flows in low Dams—App. A. Nat. Resources Commission, U.S.A.
	1942	*Physics of the Earth*—IX, Hydrology—McGraw-Hill, New York.
Bruce, J. P.	1959	Rainfall Intensity-Duration-Frequency Maps for Canada—Cir. 3243, Tech. 308, Meteorological Branch, Ministry of Transport, Canada.
Mc Callum	1959	*Mem. East African met. Dep.*, **3**, 7.
Meyer	1928	*Elements of Hydrology*, John Wiley and Son Inc., New York.
Parthasarathy, K., Veeraraghavan, K. and Ved Prakash	1960	*Indian J. Met. Geophys.*, **11**, 1, pp. 19-24.
Potter, W. D.	1958	*Trans. Amer. geophys. Un.*, **39**.
U. S. Weather Bureau	1953	*Tech. Pap.*, **24**.
	1958	*Ibid.*, 29.
Yarnell, D. L.	1935	*Misc. Publ. U.S. Dep. Agric.*, 204.