551·578·11

Size distribution of Raindrops—Part III

V. N. KELKAR

Department of Physics, Nowrosjee Wadia College, Poona

(Received 8 September 1960)

ABSTRACT. Average values of liquid water in mm^3 of raindrops of different diameter groups per m^3 of air are given in the form of a table, for 21 different intensities of precipitation. The results are shown graphically for six different intensities in the form of histograms. The total amount of liquid water W in mm^3/m^3 of air has been found to be a function of the intensity of precipitation. The formulæ suggested by Best (1950) have been verified with certain limitations.

Several drop-size distribution parameters have been worked out and their variation with the intensity of precipitation represented by formulæ, wherever possible.

1. Introduction

In part II of this series (Kelkar 1960) the space distribution of raindrops belonging to different size groups was dealt with. In this paper the results are presented in the alternative form of the liquid water content per m^3 of air.

2. Results

The results are based on the data reported in part I (Kelkar 1959) and are confined to general rains. Table 1 gives average values of the liquid water content in mm^3 of raindrops of different diameter groups per m^3 of air, for 21 different average values of the rates of precipitation ranging from 0·20 mm/hr to 34 mm/hr. The total amount of liquid water W in mm^3 per m^3 of air is also given in a separate column. The mode of the liquid water distribution curve is not necessarily the same as that of the drop frequency curve, but is often shifted towards a larger diameter group.

The distribution of liquid water per m^3 of air amongst different diameter groups is shown in Fig. 1 in the form of histograms for six different intensities of precipitation, *viz.*, 0·20, 0·57, 1·5, 5·4, 13 and 34 mm/hr. As the intensity of precipitation increases the spectrum extends towards larger diameter and the mode of the distribution curve generally shifts towards larger diameter groups. Comparison with the corresponding drop frequency curves given in part II (Kelkar 1960) is interesting as it brings out clearly the complementary aspects of the two distributions.

The total amount of liquid water per m^3 of air, W, is a function of the intensity of precipitation I in mm/hr. Fig. 2 shows the logarithmic plot of W against I to be linear. The relation between W and I is found to be

$$W = 71\, I^{0.88}\ \mathrm{mm^3/m^3}.$$

This is in almost exact agreement with the results of some of the other workers. Marshall and Palmer (1948) obtain the formula

$$W = 72\, I^{0.88}\ \mathrm{mm^3/m^3}.$$

From the data of Laws and Parsons (1943) Best (1950) obtains the result

$$W = 72\, I^{0.867}\ \mathrm{mm^3/m^3}.$$

Best (1950) has shown that most of the available data on the drop-size distribution is in accordance with the formulae

$$1 - F = \exp[\,-\,(x/a)^n\,]$$

$$a = A\, I^p$$

where F=fraction of liquid water in the air comprised of drops with diameter less than x.

TABLE 1

Amount of liquid water in mm³/m³ of air

Average intensity of precipitation (mm/hr)	0·00—0·25	0·25—0·50	0·50—0·75	0·75—1·00	1·00—1·25	1·25—1·50	1·50—1·75	1·75—2·00	2·00—2·25	2·25—2·50	2·50—2·75	2·75—3·00	3·00—3·25	3·25—3·50	3·50—3·75	3·75—4·00	Total amount of liquid water in mm³/m³ of air
0·20	0·3	4·6	3·6	2·9	2·0	2·0	0·1										16
0·33	0·1	2·5	12	6·8	3·0	1·9	1·3	0·7	1·0								29
0·46	—	1·8	16	13	2·6	1·9	1·8	1·1	1·0								39
0·57	0·1	2·6	12	15	6·0	3·9	2·7	1·0	0·5								44
0·64	0·1	3·0	18	17·6	6·2	2·8	1·3	1·7	1·0								52
0·76	0·2	2·9	14	13	6·0	4·0	4·1	4·2	2·8	0·7	0·6						53
0·87	0·2	1·5	13	26	10	5·7	3·3	2·1	0·4	0·2	0·3						63
1·1	0·1	2·0	12	22	13	8·6	5·5	4·3	1·2	0·7	—	0·4					70
1·5	—	1·7	18	34	21	9·5	5·2	5·9	9·5	0·7	—						106
1·9	—	2·2	20	28	24	20	8·9	5·3	4·9	5·0	3·9						122
2·3	—	2·0	16	67	59	40	13	6·3	1·8	0·6							206
3·5	—	1·8	12	35	75	58	21	7·2	2·3	1·2							214
4·1	—	1·1	10	63	66	51	20	24	7·2	1·4							244
4·6	0·1	2·2	19	40	76	99	20	9·7	0·8	0·6							267
5·4	—	0·6	14	32	65	80	52	50	25	2·7	0·9	—	—	—	—	—	322
6·2	—	2·6	20	46	81	99	69	28	5·1	4·0	1·0	—	3·2	—	—	—	359
8·6	—	—	5·3	17	92	134	108	67	5·6	6·3	—	1·0	—	—	—	—	438
9·9	—	2·2	17	31	57	110	120	74	35	32	10	4	—	—	2·5	3·0	498
13·0	—	0·7	15	27	64	164	159	95	60	40	9·5	—	1·6	—	—	—	636
18·0	—	1·2	13	20	66	176	160	181	85	50	42	21	1·6	18	—	—	835
34·0	2·3	21	56	44	79	215	270	350	255	161	95	18	6·4	–	–	–	1573

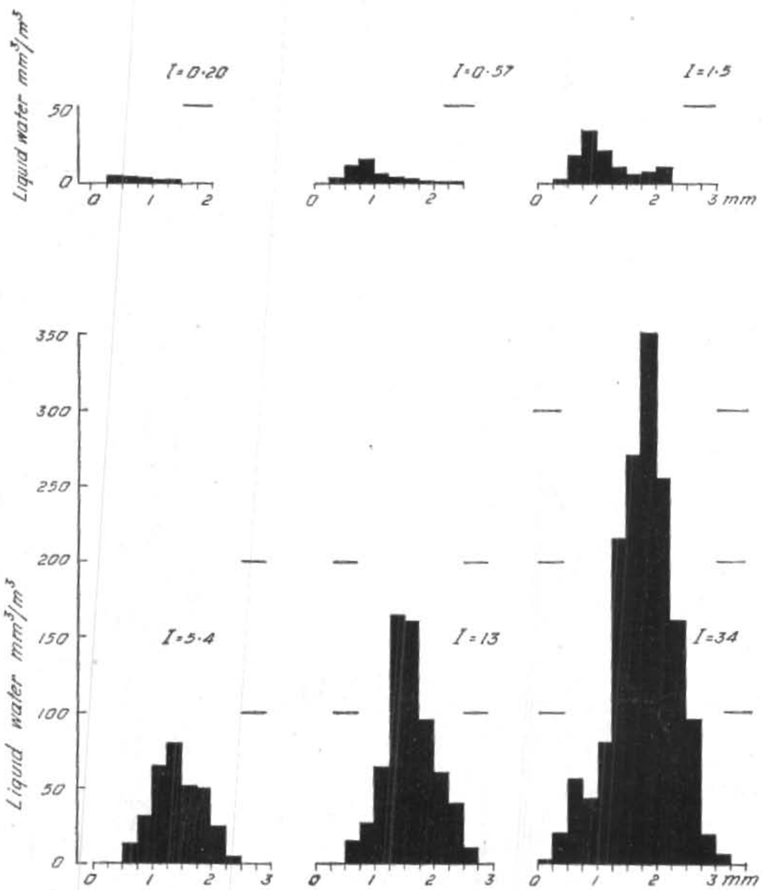

Fig. 1. Distribution of liquid water per m³ of air amongst raindrops grouped according to diameters

From the first of these equations it follows that

$$\log \log_{10} [1/(1—F)] = —0\cdot36 + n (\log_{10} x — \log_{10} a)$$

and that $\log \log_{10} [1/(1—F)]$ plotted against $\log_{10} x$ should be a straight line with slope n.

The whole of the present data has been divided into six groups and the average values calculated. These have been used to plot $\log \log_{10} [1/(1—F)]$ against $\log_{10} x$. Fig. 3 shows that the points do lie on a straight line particularly for the higher intensities. For low intensities, the relation is satisfied for values of x greater than 0·5 mm. This seems to be due to the fact that in these latitudes the distribution curves are different from those obtained in temperate latitudes and that the highest ordinates do not correspond to the smallest drops. The values of F are too small for diameters less than 0·5 mm. Omitting these points straight lines have been drawn and the parameters a and n have been calculated for each of the intensities of precipitation and are given in Table 2.

By the method of least squares the following relation between a and I is obtained—

$$a = 1\cdot054\ I^{0\cdot176} \text{ mm.}$$

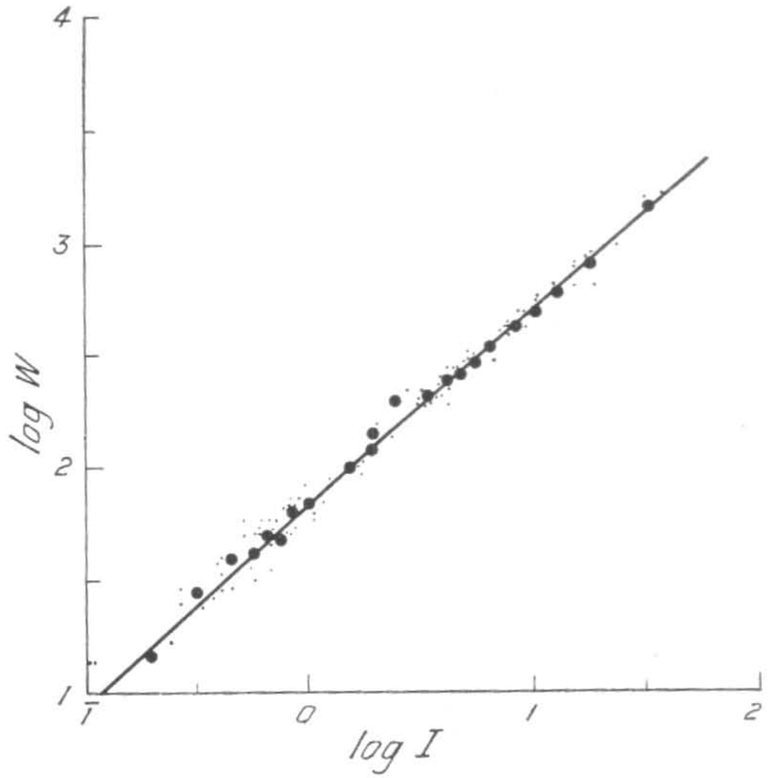

Fig. 2. Variation of total liquid water per m^3 of air with intensity of precipitation

TABLE 2

Range of I (mm/hr)	Mean I (mm/hr)	No. of papers	n	a (mm)	W (mm^3/m^3)
0·0—0·6	0·40	20	1·93	0·91	31
0·6—1·1	0·83	20	1·70	0·97	56
1·1—3·8	2·45	20	1·94	1·18	156
3·8—7·3	5·10	20	4·00	1·46	296
7·3—20	12	20	3·67	1·80	590
20 —41	34	4	3·43	1·88	1573

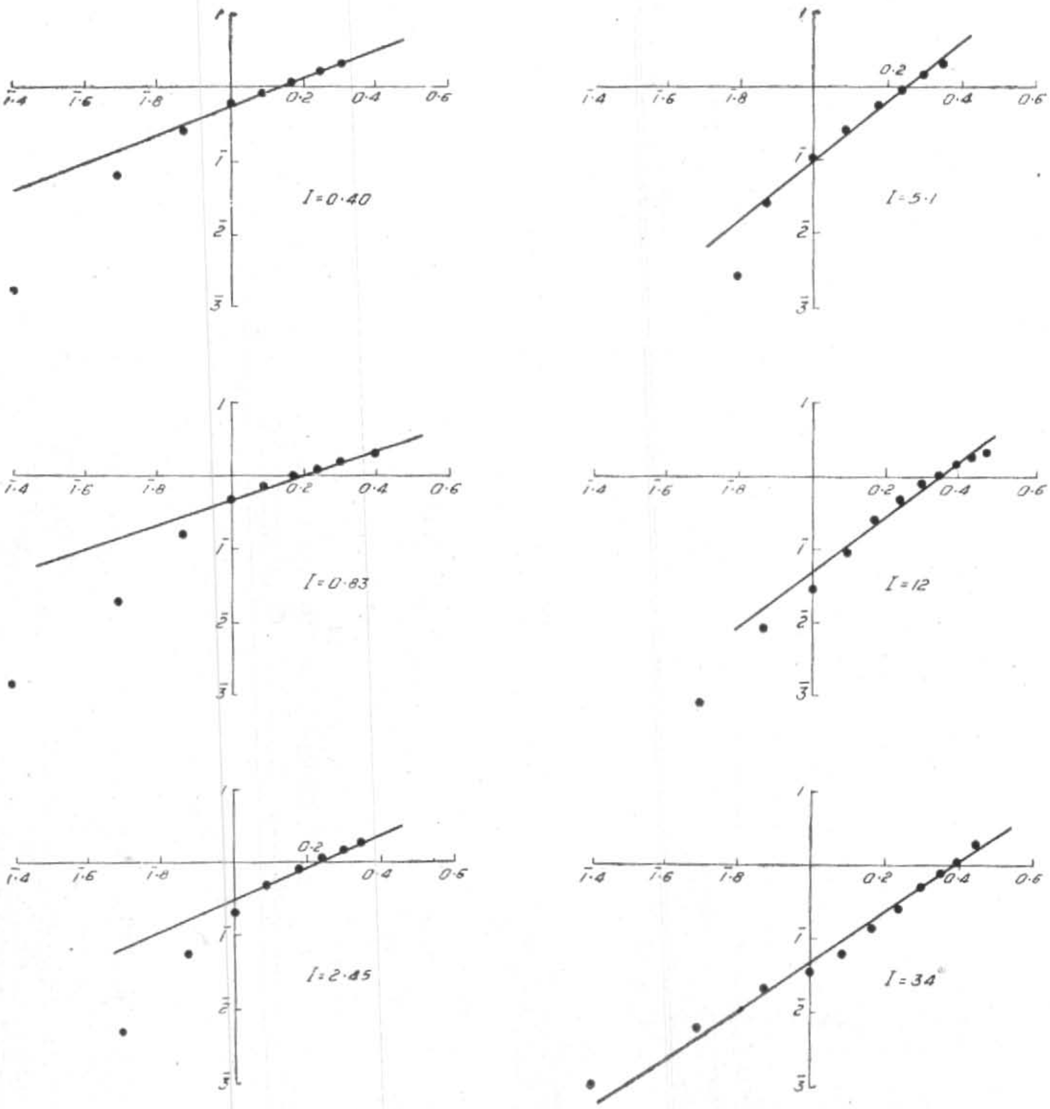

Fig. 3. Verification of A. C. Best's formula log $\log_{10}$ $[1/(1-F)]$ plotted against $\log_{10} x$

3. Drop-size distribution parameters

The characteristics of the drop-size spectrum of raindrops can be represented by several parameters. In the following, the variation of these parameters with intensity of precipitation is discussed. Except when otherwise mentioned these parameters refer to the space distribution of raindrops.

(a) *The mean diameter d_m, i.e., the sum of all the drop diameters divided by the total number of drops*—The variation of the mean diameter with the intensity of precipitation is given by

$$d_m = 0 \cdot 63\ I^{0.25} \text{ mm}.$$

(b) *The mode diameter, i.e., the diameter corresponding to the maximum number of drops*—It is observed that the value 0·63 mm (0·50—0·75 mm) persistently occurs throughout the whole range of values of the intensity of precipitation. At higher

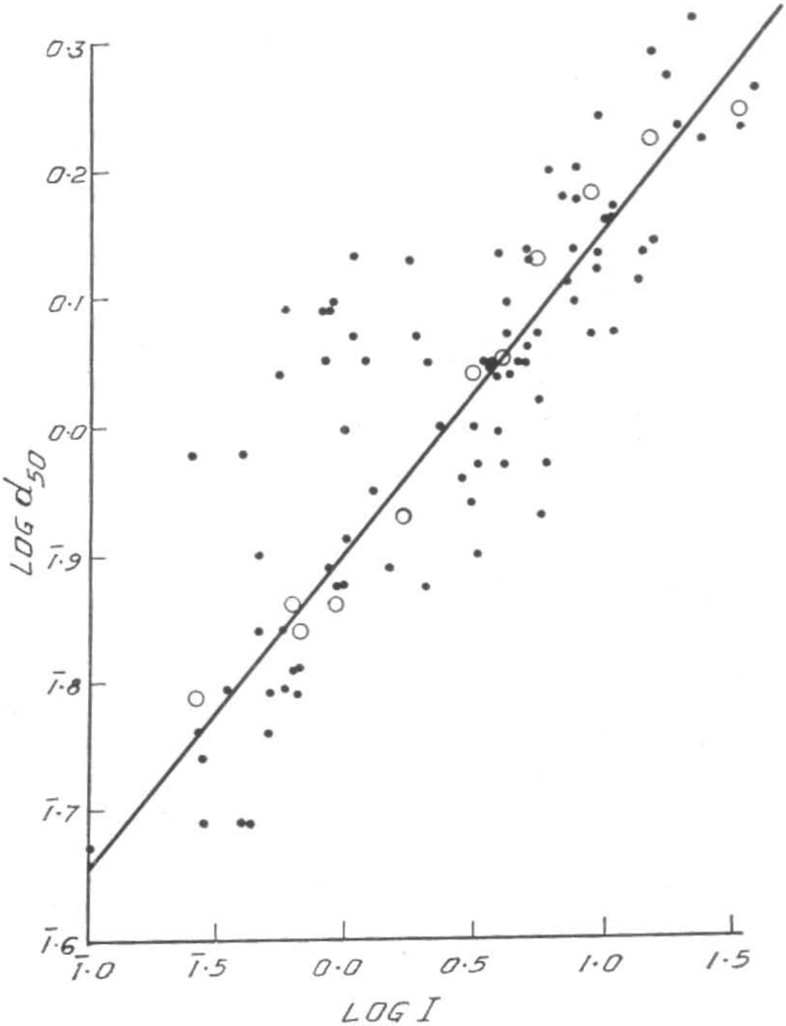

Fig. 4. Variation of median volume diameter with intensity of precipitation

intensities, a second higher mode is present, the distribution becoming bimodal.

(c) *The mean volume diameter d_v, **i.e.**, the diameter of drop whose volume is equal to the average volume of drop*—The average volume $\bar{v}$ is given by

$$\bar{v} = 0 \cdot 25\ I^{0 \cdot 64}\ \text{mm}^3$$

and the mean volume diameter d_v, is given by

$$d_v = 0 \cdot 79\ I^{0 \cdot 21}\ \text{mm}.$$

(d) *The predominant diameter d_p, i.e., the diameter corresponding to the maximum volume of water*—The variation of the predominant diameter with the intensity of precipitation is best expressed in the form of a table (Table 3).

(e) *The median volume diameter d_{50}, i.e.,* the diameter of the drop such that half the water is comprised by larger drops, is plotted against intensity of precipitation in Fig. 4.

The median volume diameter d_{50} is given by

$$d_{50} = 0 \cdot 80\ I^{0 \cdot 27}\ \text{mm}.$$

(f) The variation of the average value of the total number of raindrops per m³ of air (n) with intensity of precipitation I as deduced from Fig. 2 (part II, Kelkar 1960) is given by

$$n = 282 + 220 \log_{10} I.$$

(g) The average volume of raindrop for the ground distribution is different from that for the space distribution. The variation of the average volume of raindrop for the ground distribution $\bar{v}_{\text{ground}}$ with intensity of precipitation is given by

$$\bar{v}_{\text{ground}} = 0 \cdot 39\ I^{0 \cdot 55}\ \text{mm}^3.$$

The average volume diameter for the ground distribution is given by

$$\bar{d}_{\text{ground}} = 0 \cdot 91\ I^{0 \cdot 18}\ \text{mm}.$$

TABLE 3

Predominant diameter range (mm)	Intensity of precipitation range (mm/hr)
0·25—0·50	0·00—0·26
0·50—0·75	0·26—0·81
0·75—1·00	0·81—2·9
1·00—1·25	2·9 —4·3
1·25—1·50	4·3 —9·3
1·50—1·75	9·3 —15·5
1·75—2·00	15·5 —34

REFERENCES

Best, A. C.	1950	*Quart. J.R. met. Soc.*, **76**, p. 16.
Kelkar, V. N.	1959	*Indian J. Met. Geophys.*, **10**, p. 125.
	1960	*Ibid.*, **11**, p. 323
Laws, J. O. and Parsons, D. A.	1943	*Trans. Amer. geophys. Un.*, **24**, pp. 452-460.
Marshall, J. S. and Palmer, W. McK.	1948	*J. Met.*, **5**, p. 165.