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Size distribution of Raindrops — Part IV

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ABSTRACT. Diameter spectra of raindrops for identical intensities of precipitation at different epochs of a rain-period are illustrated and discussed. Diameter spectra of raindrops at different altitudes from the ground level to the cloud base level at different epochs of a rain-period are illustrated. The concentration of small drops is found to increase from the cloud base level towards the ground. Evidence for the evaporation of small drops less than 1 mm diameter towards the end of a rain-period has been found.

1. Introduction

As has been remarked earlier in part I (Kelkar 1959) the data collected is also suitable for the study of the time variation of the drop size spectrum. Appendix I gives the number of raindrops per m^3 of air, grouped according to diameters, and the corresponding time from the beginning of the shower for five out of the eight rain-periods for which the time of the beginning and that of the end of the shower were recorded. The relevant information regarding the date, the time of beginning and end of shower, total duration and cloud base level is given in Table 1.

2. Results

One of the points of interest is to examine the variation of the diameter spectrum at different phases of a shower for identical intensity of precipitation. From the intensity-time curve the epochs at which a particular intensity recurred could be determined. By plotting the number of drops per m^3 of air, of different diameter groups against time, it was possible to read off the values of the number of drops at any required time. The results are shown in the form of histograms for two different rain-periods involving very low and high rates of rainfall.

Fig. 1(a) shows the variation of the intensity of precipitation with time from the beginning of the shower, for the rain-period recorded on 19 September 1956. Fig 1(b) shows the diameter spectra at different epochs (in seconds from the beginning of the shower) for three different intensities of 0·4, 0·6 and 0·8 mm/hr. It is seen that for the two lower values of the intensity, the diameter spectrum consists of a few large drops towards the end of the shower, whereas in the earlier stages the smaller drops are more abundant. On account of the linear scale adopted it was occasionally not possible to indicate the very low values of the number of large drops.

Fig. 2(a) shows the intensity-time curve for the rain-period recorded on 2 August 1956. Fig. 2(b) shows the time variation of the diameter spectrum for three different intensities, *viz.*, 16, 25 and 30 mm/hr. Here also the proportion of larger drops increases towards the later parts of the shower.

Another point of interest is to study the variation of the diameter spectrum at different altitudes from the ground level to the cloud base level, on account of the different terminal velocities of drops of different sizes. This difference in the terminal velocities alone produces a dispersion according to sizes as the drops fall towards the ground. A rather simplifying assumption is made that the drops of a particular size move down with a constant terminal velocity. The variation of terminal velocity with height is less than 9 per cent for the heights considered (Best 1950).

TABLE 1

Date	Time of beginning of shower (IST) h	m	s	Time of end of shower (IST) h	m	s	Total duration (sec)	Cloud base level (m)
2-8-1956	12	39	30	13	05	20	1550	—
30-8-1956	15	06	10	15	27	11	1261	670
17-9-1956	12	54	00	12	58	37	277	1060
19-9-1956	13	53	20	14	13	50	1230	1980
8-10-1956	14	32	30	14	49	00	990	770

There may be of course variation on account of the decrease in size of a drop due to evaporation, particularly for the smaller drops. The fact that the diameters are measured in ranges of 0·25 mm will offset to some extent the effect of evaporation on the number of drops of a particular size group. The loss in the number of drops of a particular diameter group due to evaporation will be to some extent compensated by the increase in their number due to evaporation of drops of larger size, except in the case of the drops of the largest size for which the loss due to evaporation will remain uncompensated. Horizontal wind will affect the vertical fall of the drops but it is presumed that it may not affect the vertical component velocity. Vertical wind will more directly affect the terminal velocity, but the rain-periods were quiet ones with no wind at the ground level at least. The disruption of raindrops on collision with smaller ones is a possibility and this will tend to increase the number of smaller drops. The relative contribution to the production of smaller drops due to possible splintering of large drops, which incidentally do not exceed about 2 mm in diameter, cannot be properly assessed and in interpreting the final results this fact will have to be borne in mind. Collision with smaller drops may even lead to coalescence instead of disruption. In thunderstorm rains the author has obtained more definite evidence of the breaking up of large drops, but in these showery rains involving only comparatively small drops, the effect is presumably small. In view of all the possible complications, the assumption that the terminal velocity remains constant is admittedly an over simplification and the results, which are not expected to be quantitatively accurate, must be regarded as a first approximation.

The method of making the calculations is briefly as follows. The concentration of raindrops per m^3 of air near the ground level is plotted against time for each of the different diameter ranges. The concentration of drops at any required height at any instant is the same as the concentration observed at the ground level *after* a time equal to the height divided by the terminal velocity. Suppose for example, it is required to calculate the concentration of drops of diameter 0·25-0·50 mm at a height of 300 m at 100 sec from the start of rain. The average terminal velocity of these drops is 1·5 m/sec. The time taken by these drops to fall through 300 m is 300/1·5=200 sec. The ordinate at 100+200=300 sec is read from the concentration-time curve. This gives the required number of drops at a height of 300 m. In this way the number of

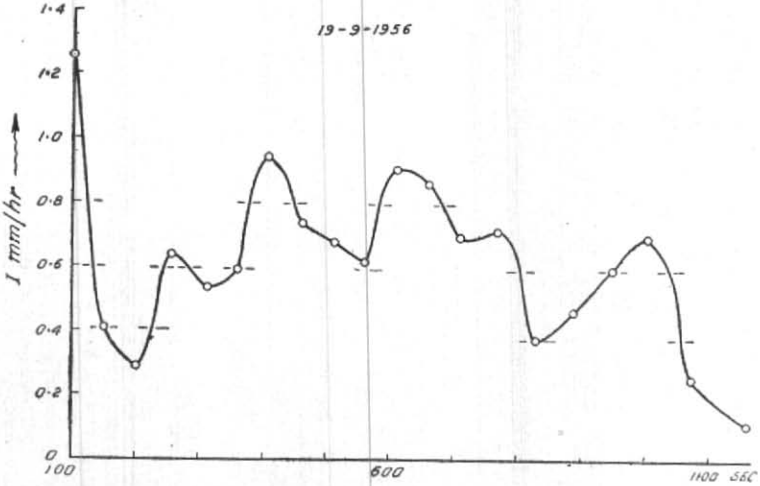

Fig. 1(a). Intensity-time curve for the rain-period recorded on 19 September 1956

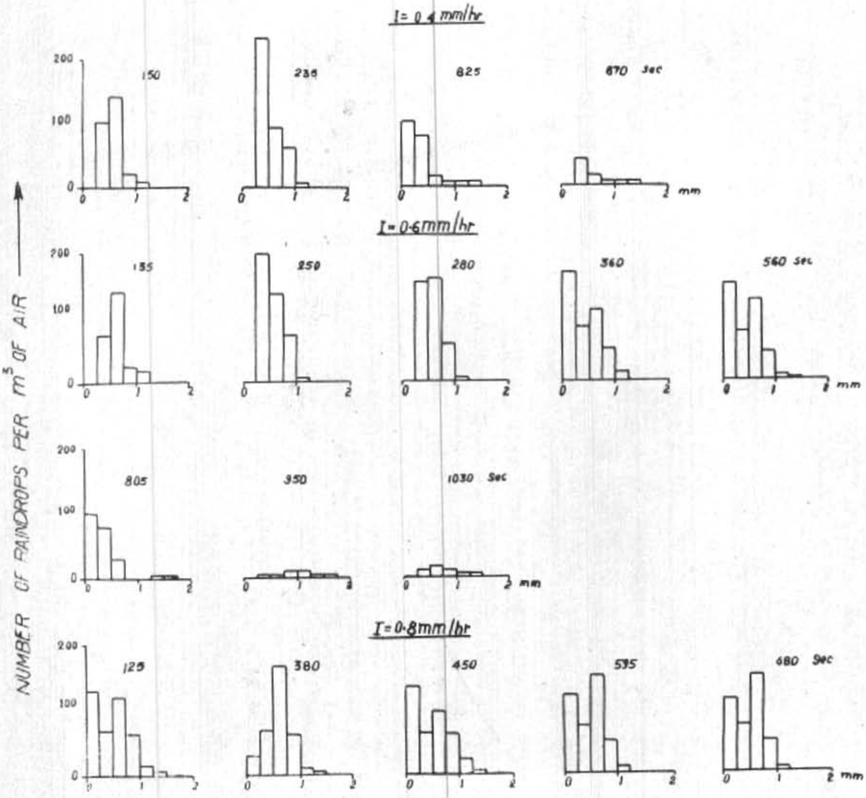

Fig. 1(b). Diameter spectra of raindrops for identical intensities of precipitation at different epochs of the rain-period recorded on 19 September 1956

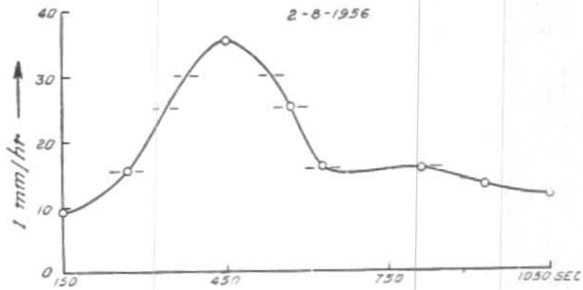

Fig. 2(a). Intensity-time curve for the rain-period recorded on 2 August 1956

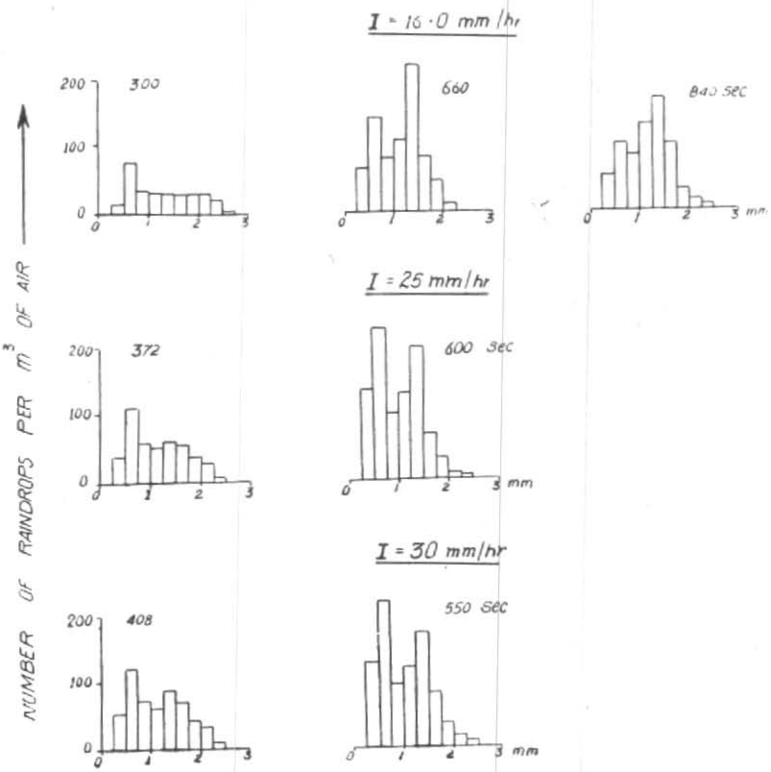

Fig. 2(b).Diameter spectra of raindrops for identical intensities of precipitation at diffrrent epochs of the rain-period recorded on 2 August 1956

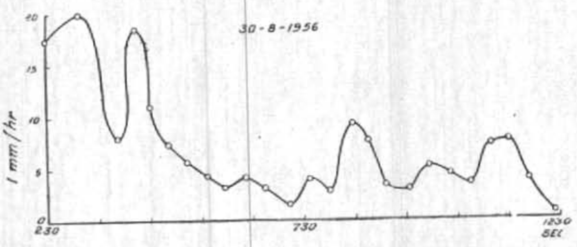

Fig. 3(a). Intensity-time curve for the rain-period recorded on 30 August 1956

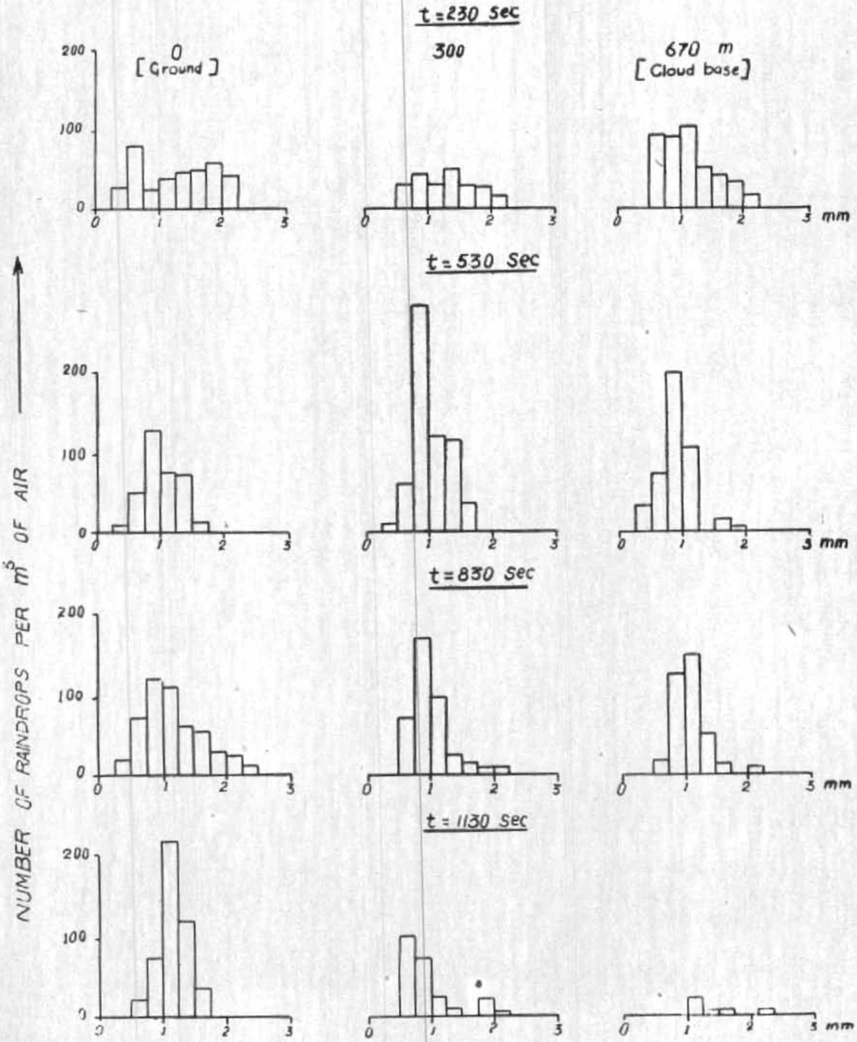

Fig. 3(b). Variation of diameter spectrum with altitude for the rain-period recorded on 30 August 1956

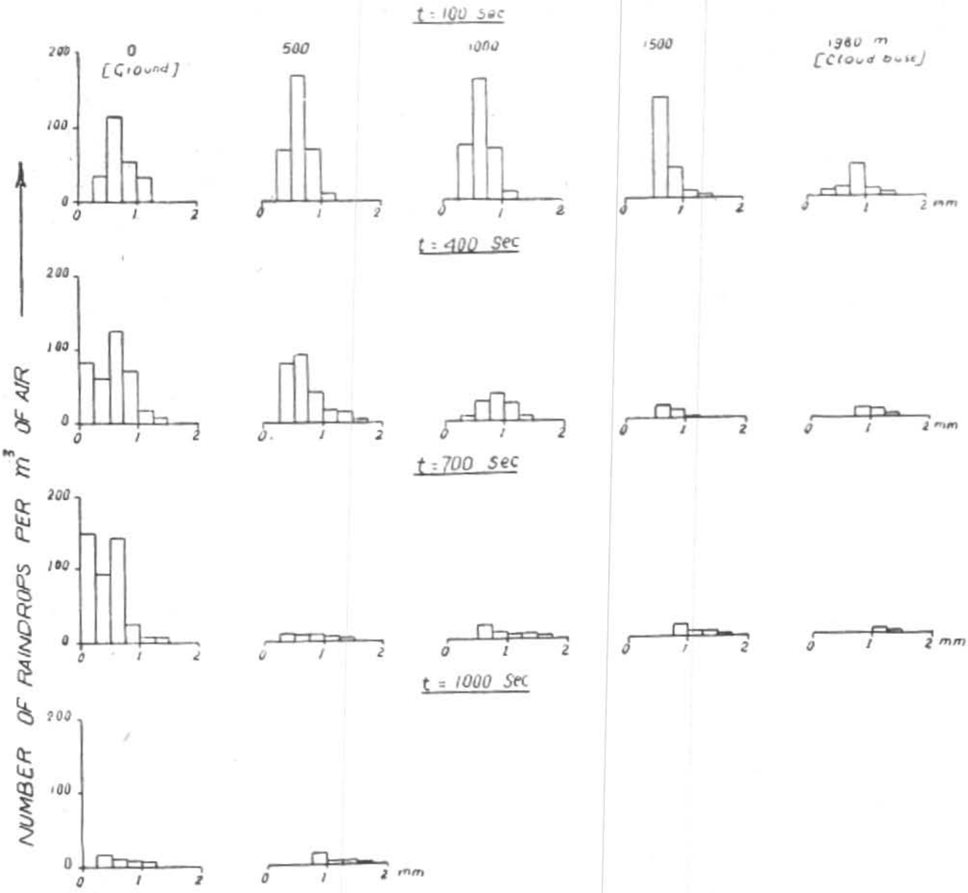

Fig. 4. Variation of diameter spectrum with altitude for the rain-period recorded on 19 September 1956

drops of different diameter groups have been calculated for different altitudes and at different times. The results are illustrated for two different rain-periods in the following.

Fig. 3(a) shows the intensity-time curve for the rain-period recorded on 30 August 1956. Fig. 3(b) shows the variation of the diameter spectrum with altitude at four different epochs. The height of the cloud base as measured at the Meteorological Office, Poona at 1430 hrs by pilot balloon observations was 670 m. It is seen that the concentration of small drops gradually increases from the cloud base towards the ground. The effect however is not so marked as in the next illustration as the height of the cloud base is only 670 m. The dispersion due to the differences of the terminal velocities gets more pronounced as the height of the cloud base increases, the separation between the small and the large drops being also a function of the time of fall. It is also seen that towards the end of the shower, drops less than 1 mm diameter are absent near the cloud base, but a few larger drops are present.

Fig. 4 shows similar variation of the diameter spectrum with altitude from the ground level to the cloud base level at four different epochs for the rain-period recorded on 19 September 1956. The corresponding intensity time curve has already been shown in Fig 1(a). The height of the cloud base was 1980 m at 1430 hrs recorded by pilot balloon observations. The diameter spectrum changes with altitude at any instant and changes in course of time at any altitude. The concentration of small drops is seen to increase from the cloud base towards the ground to a marked extent. Near the cloud base, the smaller drops progressively disappear and only a few larger drops are formed towards the tail end of the shower. This means either that the small drops are not formed at all towards the end of the shower or that they completely evaporate by the time they reach the ground and hence are not recorded. The latter conclusion seems to be more probable. Evaporation of raindrops goes on all the time but its filtering effect on small drops is not detected except towards the end of the shower, since there is no fresh supply of drops from above. The result that towards the end of the shower the diameter spectrum at the ground consists of larger drops is in conformity with this hypothesis of evaporation. At 1000 seconds from the beginning of the shower it is seen that the region above 1000 m has been depleted of all raindrops and no fresh drops are being formed. This of course is bound to happen at some stage when the shower comes to an end.

REFERENCES

Best, A. C.	1950	*Quart. J. R. met. Soc.*, **76**, p. 302.
Kelkar, V. N.	1959	*Indian J. met. Geophys.*, **10**, p. 125.

APPENDIX I

Time variation of the diameter

Spectrum of raindrops per m³ of air

Date	Intensity of precipitation (mm/hr)	Time of record (sec)	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
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2-8 1956	9·55	150	..	70	87	36	20	36	33	25	5·3	11	4·1	0·6	..	..	0·5	0·5
	15·6	270	..	17	85	42	39	37	33	33	31	21	4·5	..	0·6	..	..	..
	35·5	480	..	96	184	92	88	158	138	93	50	35	11	2·7	..	..	..	..
	25·5	570	..	135	235	98	136	184	109	70	31	12	6·5	1·2	..	..	..	..
	16·0	630	..	67	144	79	112	225	86	46	7·6	..	..	..	..	..	..	..
	16·0	810	..	53	105	83	133	176	98	31	13	3·1	1·0	..	..	..	..	..
	12·9	930	..	20	85	71	121	214	66	20	6·1	0·7	0·7	..	..	..	..	..
	11·3	1050	..	15	91	54	104	159	64	13	10	2·4	..	..	..	..	..	..
30-8-1956	17·5	230	..	29	79	25	35	45	49	61	39	13	6	0·8				
	20·1	293	..	11	112	48	31	44	37	23	13	20	15	8	0·7	4·3		
	8·00	357	..	..	16	20	64	46	44	46	2·2	2·3	..	..	..	..		
	18·6	400	..	..	28	41	129	152	82	97	15	..	..	..	..	..		
	11·0	427	..	..	51	93	100	93	68	36	1·5	4·8	..	..	..	..		
	7·32	465	..	2·6	10	74	150	107	50	2·5	0·6	..	..	..	..	..		
	5·58	502	..	..	96	101	93	101	16	3·2	0·6	..	..	..	..	..		
	4·32	738	..	8	23	58	70	67	8	0·8	..	..	..	..	..	..		
	3·30	573	..	116	76	193	106	36	2	0·5	..	..	..	..	..	.		
	4·29	615	..	34	69	285	127	17	5	6	1·5	0·5	..	..	..	..		
	3·16	656	..	100	61	290	45	2·3	12	4	1·8	0·4	..	..	..	..		
	1·55	701	..	8	49	141	9	2	6	4	0·5	..	..	..	..	..		
	3·96	741	..	10	30	258	119	42	5	1·4	..	..	..	..	..	..		
	2·83	778	..	10	49	218	115	20	3·5	0·5	..	..	..	..	..	..		
	9·38	824	..	19	78	190	117	62	47	28	8	0·7	..	..	..	..		
	7·82	854	..	..	13	36	76	56	61	20	4	1·3	..	0·6				
	3·34	889	..	..	33	122	94	26	14	3	0·7	..	..	..				

APPENDIX I (*contd*)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
30-8-1956	3·12	934	..	..	43	180	85	24	7	3·8	..	..	..	..				
	5·23	975	..	32	92	160	148	66	33	10	0·7	..	..	..				
	4·51	1015	..	4	105	146	113	84	5·6	..	..	..	..	..				
	3·66	1055	..	2	18	46	119	51	14	0·5	0·5	..	..	..				
	7·78	1094	..	..	19	38	67	111	63	18	1·4	..	..	..				
	7·83	1132	..	..	20	72	212	121	34	1·3	..	..	..	..				
	3·97	1172	..	..	34	133	41	16	8	22	2·3	..	..	..				
	0·83	1221	..	12	86	75	18	3·6	0·9	0·1	..	..	..	..				
17-9-1956	3·06	0	..	53	238	111	87	45	2	..	..	..	..	..				
	1·53	38	..	50	177	180	39	0·4	..	..	..	..	..					
	1·04	87	..	110	91	129	27	..	..	..	..	..	..					
	0·42	138	..	124	212	30	2	0·3	..	..	..	..	..					
	0·28	188	..	42	116	27	..	..	..	..	..	..	..					
	0·28	237	..	82	122	24	0·2	..	..	..	..	..	..					
19-9-1956	1·25	100	..	38	119	56	32	17	0·9									
	0·39	148	..	98	140	21	8	..	..									
	0·28	202	120	286	26	16	6·3	1·5	..									
	0·63	256	..	172	148	75	4·9	..	..									
	0·53	307	..	124	171	50	3·2	0·6	..									
	0·59	357	168	102	112	53	10	0·8	0·7									
	0·94	405	71	59	128	72	16	6	1	0·7								
	0·73	460	24	75	175	60	9·1	3·1	..	..								
	0·67	510	68	90	162	56	13	1·3	..	..								
	0·61	559	150	77	123	40	12	4	..	..								
	0·90	611	126	63	87	79	24	3·8	0·2	..								
	0·86	657	72	64	146	80	14	1·4	1·9	..								
	0·69	709	166	93	138	14	1·8	0·5	0·4	1	1·5	0·2	0·3					
	0·71	768	98	73	60	3·5	0·3	1·3	4	3·8	0·8	..	..					
	0·37	830	108	80	17	4·4	5·4	3·9	1·7	0·8	0·7	..	..					

APPENDIX I (*contd*)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
19-9-1956	0·46	893	..	13	13	10	6·6	5·6	2·7	0·5	0·8	..	..					
	0·59	948	..	2 8	6·3	8·5	9·3	7·1	3·1	0·8	0·3	..	..					
	0·69	1006	..	17	12	8·5	4·5	4·7	2·9	2·5	1·0							
	0·25	1074	..	6·8	19	13	4·5	4·1	0·1	..	..	..						
	0·11	1160	9·5	15	28	8·2	0·7	0·1	..	..	..	..						
8-10-1956	40·8	150	..	565	335	165	123	170	101	78	66	29	22	1·7	1·6			
	35·1	210	2370	1450	799	119	73	113	120	161	59	17	1·8	..	..			
	14·3	255	..	37	210	110	60	97	115	35	9·6	..	..	..	..			
	4·25	294	..	58	87	60	39	76	24	0·6	0·6	..	..	..	..			
	4·56	330	96	272	382	116	44	72	10	3·9	0·8	..	..	..	..			
	9·96	368	26	212	242	51	29	89	107	11	2	..	..	..	..			
	3·52	412	..	79	198	40	71	47	9	3·7	0·6	..	..	..	..			
	5·79	439	..	198	402	315	62	44	28	1·8	..	..	..					
	1·07	481	14	35	119	59	20	9	1·6	0·3	..	..	..					
	0·24	536	158	41	16	1·4	2·0	1·2	..	..	..	..	..					
	2·13	582	..	28	308	198	45	2·4	1·0	..	..	..	..					
	0·49	623	..	39	176	42	1·5	..	..	..	..	..	..					
	0·84	670	..	37	83	133	4	..	..	..	..	..	..					
	0·47	724	..	21	104	63	1·3	..	..	..	..	..	..					
	0·61	776	..	48	172	56	7·2	..	..	..	..	..	..					
	0·10	840	111	218	38	..	..	..	..	..	..	..	..					