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A study of major rainstorms of Assam

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ABSTRACT. More than 100 rainstorms of durations ranging from 2 to 7-day during the period 1901-1960 over the Brahmaputra catchment in Assam plains have been studied by the Isohyetal Method. Enveloping curves of maximam depths for various durations are presented and discussed in this paper. The synoptic situations associated with some of the heavy storms are also discussed.

1. ntroduction

The southwest monsoon is responsible for a large bulk (about 70 per cent) of the annual rainfall of India. In the case of Assam the normal monsoon rainfall (June to September) is 164 cm and forms 66 per cent of the annual rainfall. It is also interesting to note that Assam is one of the regions in India with low variability of the seasonal rainfall, being 10 per cent. If we consider the individual months of the monsoon season the variability is 19·3 in June, 18·4 in July, 18·2 in August and 24·4 per cent in September (Parthasarathy 1960). One of the interesting features of the monsoon rainfall in Assam, as well as in other parts of the country is that the rainfall during each month is made up of a few spells of above normal rainfall with normal or even below normal rainfall during the rest of the month. This type of distribution of the monsoon rainfall causes floods in certain periods of the month even when the total monthly rainfall itself is just normal or even below normal.

The purpose of this study is to examine the characteristics of some of the heavy rainstorms that occurred over this area during the 60-year period 1901-1960. Attention has been given to the Brahmaputra catchment lying within Assam and its neighbourhood, since we are primarily interested in rainstorms that are likely to cause floods in the *Brahmaputra*.

2. Area selected and data used for storm study

The present study is confined to the Assam plains. The area considered is marked in all the relevant figures and is about 37,000 sq. miles.

The *Daily Rainfall Volumes* for the period 1901 to 1960, compiled by the India Meteorological Department, have been taken as the main source of the data for this study. The data of the raingauge stations in the neighbourhood of the area under study have also been utilized for preparing isohyetal maps.

3. Normal features of rainfall over Assam

Monsoon sets in over Assam in the first week of June and withdraws in the second week of October. The rainfall during the month of June is highest for the season and it gradually decreases thereafter. Another interesting feature is that even before the monsoon sets in there is considerable thunderstorm activity in this region in the month of May and the rainfall caused by these thunderstorms (33·8 cm) is comparable in magnitude to the rainfall of any of the monsoon months. Hence, for purposes of storm selection and study, May is equally important.

The normal annual isohyetal pattern for Brahmaputra catchment in Assam is shown in Fig. 1. The monthly isohyetal maps from May to October have also been examined in conjunction with the Normal Annual Isohyetal Maps and one significant feature found to be that the patterns in all of them have strong resemblance to each other and the regions of high and low rainfall are more or less the same. This is mainly because the rainfall in Assam is largerly determined by orographic features and the direction of monsoon winds with respect to these features. Further, about 70 per cent of the annual rainfall is made up by the monsoon rainfall itself. Also the maxima of rainfall occur around Mawsynram, Tamenglong and the northwestern and northeastern parts of Assam with marked minimum between Lanka and Dimapur (Fig. 1).

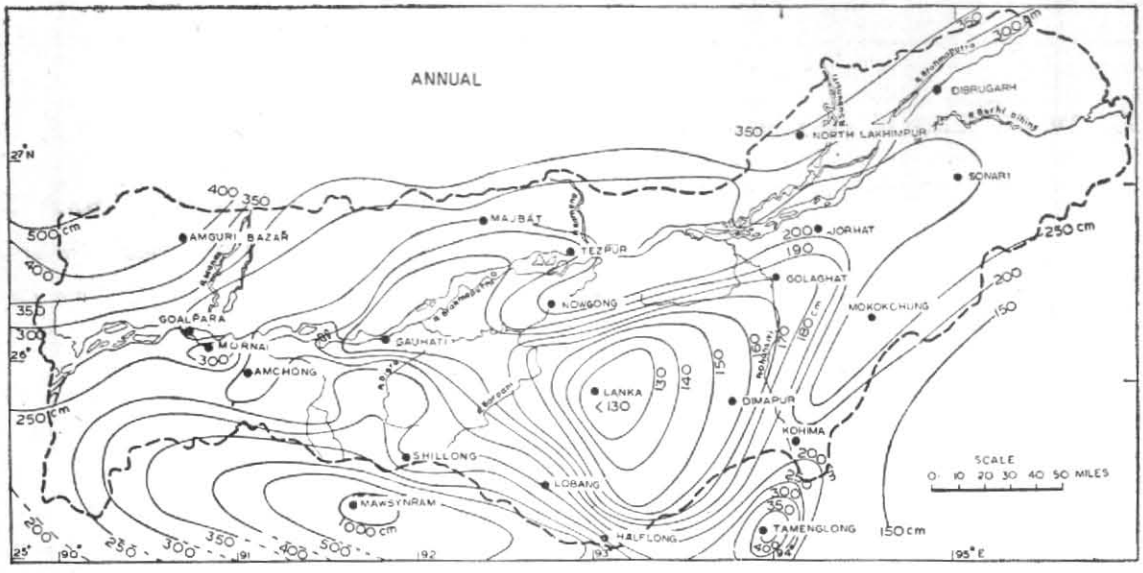

Fig. 1. Normal isohyetal map of Brahmaputra Catchment in Assam

TABLE 1

Storm duration	May	Jun	Jul	Aug	Sep	Oct	Total
2-day	5	10	7	9	2	1	34
3-day	8	15	5	4	2	—	34
4-day	1	8	8	2	4	—	23
5-day	1	5	1	—	—	—	7
6-day	—	2	—	—	1	—	3
7-day	—	1	1	—	—	—	2
Total	15	41	22	15	9	1	103

TABLE 2

	Synoptic situations					Total
	Pre-monsoon thunder-showers	Eastern end of monsoon trough extends over Assam	Break monsoon conditions	Low pressure system*		
				Over Assam	West of Assam	
May	11	—	—	3	1	15
June	3	26	5	2	5	41
July	—	11	8	1	2	22
August	—	6	7	—	2	15
September	—	2	1	3	3	9
October	—	—	—	—	1	1
Total	14	45	21	9	14	103

*Including depressions and cyclonic storms

4. Storm studies

In order to limit our study to relatively heavy rainstorms only such storms which gave an average depth of at least 2·5 cm per day over the area under study and extended at least over 2-day have been considered. According to this criterion, during the period 1901 to 1960 there were 103 storms. A list of these storms together with the average depth of precipitation and the synoptic situations associated with the storms are given in Appendix.

5. Frequencies of rainstorms

The distribution of the rainstorms according to their duration and the month of occurrence is given in Table 1. It will be seen that rainstorms are most frequent in this area in the month of June (41 out of 103) with next highest frequency (22) in July. They are equally frequent (15) in the month of May and August. In the month of September and October they are infrequent. There are equal number of 2 and 3-day storms whereas storms of 4-day duration are relatively less (23 out of 103). Storms of duration of more than 4 days are rare. Also rainstorms are rare in the month of October over Assam. The number of rainy days in this month are 7 and only one storm of 2-day duration occurred during the entire 60-year period under study.

It will also be interesting to examine the different types of meteorological situations that are responsible for these rainstorms in different months. In order to study this, the bivariate frequency distribution of the 103 storms considered here, according to the month of occurrence and associated meteorological situations, is presented in Table 2.

The significant feature of this distribution is that, considering the period May to October as a whole, the one synoptic situation which most frequently causes rainstorms in Assam is the extension of the eastern end of the monsoon trough over Assam.

It may, in this connection, be mentioned that normally the monsoon trough dips into the head Bay of Bengal and it is pulled up towards Assam either under general 'break monsoon' conditions over the country or under the influence of disturbances in the westerlies which affect the northern portions of Assam. It is noticed that the well-known break monsoon conditions occur after monsoon has established over the country as a whole whereas the changes in position of the eastern end of the monsoon trough take place as soon as the monsoon sets in over northeast India. It will be seen from Table 2 that maximum number of rainstorms due to the extension of trough over Assam occur

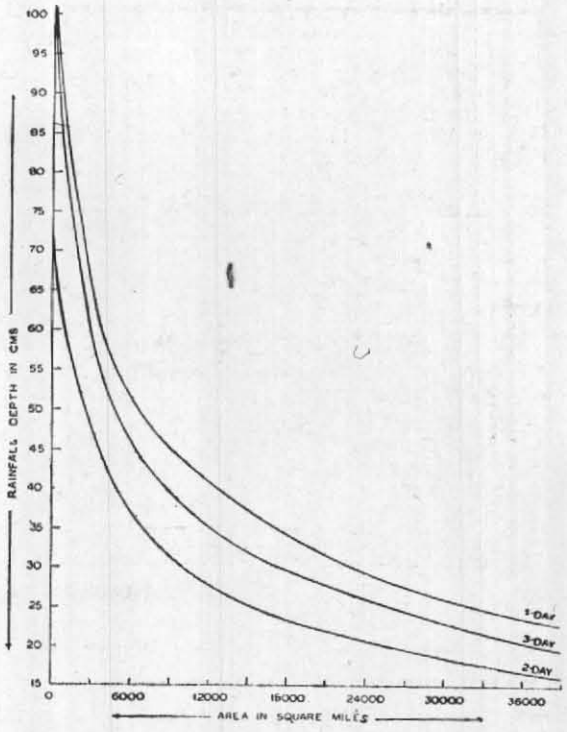

Fig. 8. Enveloping Curves
2 to 4-day duration

in the month of June whereas those associated with the break monsoon conditions occur in the month of July. Next in importance is the pre-monsoon thunderstorm activity over Assam. The pre-monsoon thunderstorm rain in the month of May is comparable in magnitude to the rainfall received during any of the monsoon months. The rainstorms which occur as a result of thunderstorm activity are most frequent in the month of May as should be expected.

Low pressure systems that formed over the Bay of Bengal also cause rainstorms over Assam when they are either directly over Assam or when they have moved westnorthwestwards from the head Bay and lie to the west of Assam. It will be seen that the number of low pressure systems which lie directly over Assam and cause rainstorms are relatively less than those which move westnorthwestwards and cause rainstorms over Assam when they are located west of Assam.

Table 3 shows whether rainstorms of particular duration have a tendency to occur more frequently in association with a particular synoptic situation.

It is seen that most of the storms are of 4-day duration or less. It is also seen that with each synoptic situation storms of different durations have occurred thereby indicating that there does not

TABLE 3

Rainstorms duration	Synotpic situations					Total
	Pre-monsoon thunder-showers	Eastern end of monsoon trough extends over Assam	Break-monsoon conditions	Low pressure systems*		
				Over Assam	West of Assam	
2-day	4	11	10	2	7	34
3-day	6	13	5	6	4	34
4-day	1	14	5	1	2	23
5-day	3	3	—	—	1	7
6-day	—	3	—	—	—	3
7-day	—	1	1	—	—	2
Total	14	45	21	9	14	103

*Including depressions and cyclonic storms

TABLE 4

Return period (yr)	Storm rainfall magnitude (cm)
5	5·7
10	6·8
25	7·8
50	8·8
75	9·6
100	10.2

seem to be any apparent relation between the synoptic situation and the duration of the storm.

Another characteristic of the rainstorms that will be of utility is the relation between the depth of precipitation and duration of storms. The study reveals that only 25 per cent of the 3-day storm cause average depth of precipitation greater than the depths caused by 2-day storm and only 14 per cent of the 4-day storm cause depth greater than that yielded by 2 and 3-day storms.

6. Design storms

The design storm rainfall for a basin can be worked out by different methods — (1) Depth-duration study of rainfall over the basin; (2) Derivating enveloping curves of all major storms; (3) Storm transposition; (4) Estimation of storm rainfall magnitude from probability considerations; and (5) Moisture adjustment technique of maximisation (Raman and Dhar 1966). Here storm magnitudes have been worked out from probability considerations. Considering also that it may be useful for the design engineers to have some idea of the rainfall depths experienced during major rainstorms, a brief description of selected rainstorms of various durations has been included and their isohyetal patterns given.

7. Storm rainfall magnitudes

The maximum 1-day isohyetal averages contributed by each of the 103 rainstorms included in the study were arranged in a series and analysed statistically by Duration Curve Technique for storm rainfall magnitudes corresponding to different return periods. Storm rainfall magnitudes for various standard return periods are given in Table 4.

8. Analysis of the heaviest rainstorm for each duration

For each one of the durations (2 to 7-day) isohyetal patterns associated with the heaviest storm on record together with the depth-area curves of these storms are presented in Figs. 3 to 16. While drawing the isohyets, the relief characteristics *vis-a-vis* normal rainfall distribution of this rugged terrain (area under sudy) have been taken into consideration.

(*i*) *2-day rainstorm* — Considering first the heaviest storm of 2-day duration which was recorded during the period 6-7 October 1916. This rainfall occurred in association with a depression which formed over northwest Bay of Bengal on 2nd, moved over east Madhya Pradesh on 3rd and

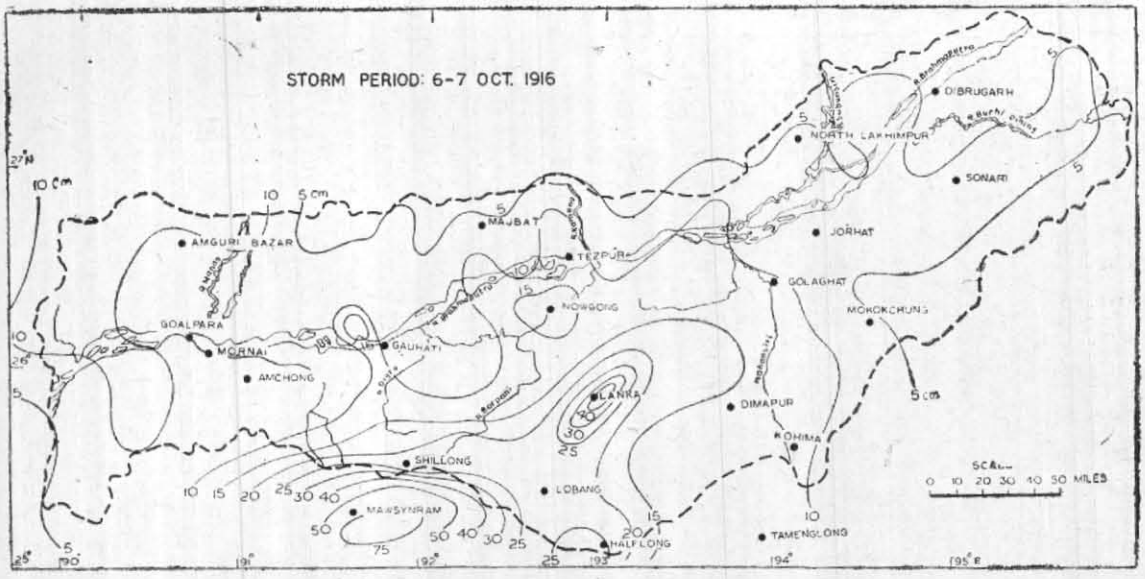

Fig. 3. Isohyetal map of Brahmaputra Catchment in Assam

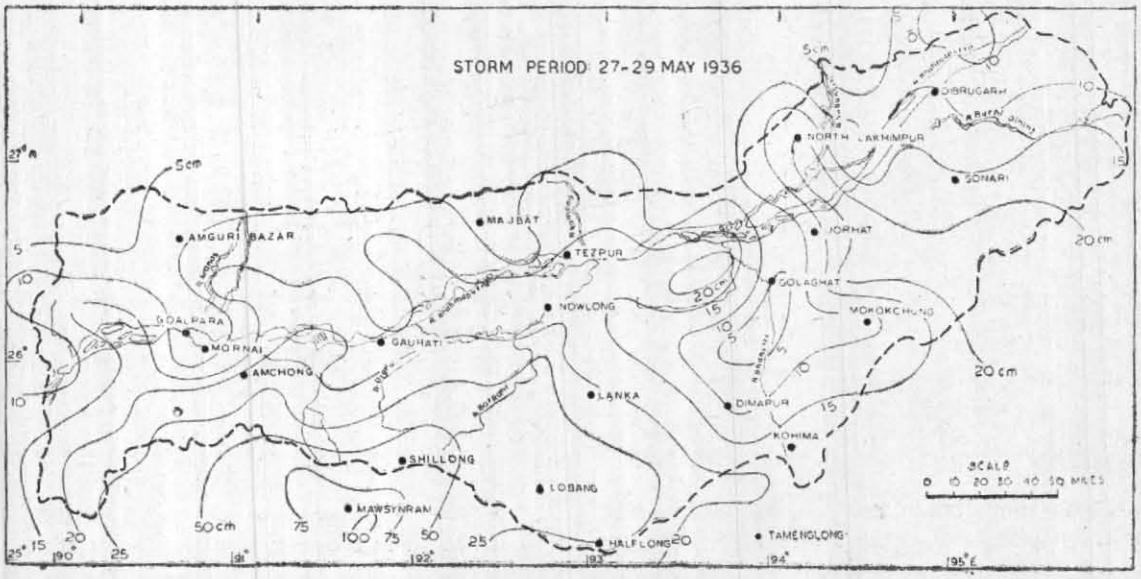

Fig. 4. Isohyetal map of Brahmaputra Catchment in Assam

lay centred near Jabalpur on 4th. It moved east-northeastwards on 5th and was centred near Gaya on 6th. This depression eventually filled up on 7th. In association with this, heavy rainfall was recorded over northeast India on 6 and 7 October. The isohyetal pattern for this storm period shown in Fig. 3 indicates a well distributed rainfall with 2 centres of maxima, one near Mawsynram associated with the orographic features and another near Lanka. The corresponding depth-area-duration curve for this storm is shown in Fig. 5. One interesting feature of the depth-area-duration curve for this storm is that the curves for the storm period rainfall is the usual exponential shape whereas the rainfall for 7 October shows that it is much more uniformly distributed over the catchment.

(*ii*) *3-day rainstorm*—The heaviest 3-day storm was recorded during the period 27-29 May 1936. This rainfall occurred in association with a depression that formed over central Bay of Bengal on 26 May and moved in a northerly direction. It intensified into a severe cyclonic storm near Sandheads on 27th and crossed the coast on 27th evening. It later became deep depression near

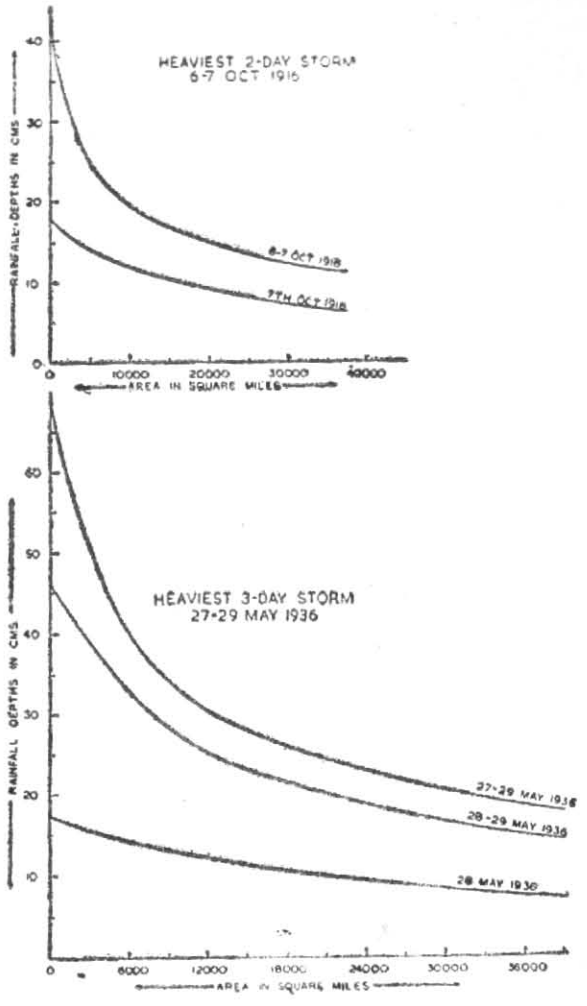

Fig. 5. Depth-area-duration curves of heaviest 2 and 3-day storms

Mymensingh on 28th and eventually filled up on 29th. Very heavy rainfall was recorded over northeast India from 27th to 29th. The isohyetal pattern for this storm is shown in Fig. 4 and the corresponding depth-duration curves are given in Fig. 5. The isohyets in the case of this storm are much more separated up than in the previous case indicating a uniform distribution of the rainfall over the catchment. There is, of course, the usual centre of maximum rainfall near Mawsynram, but there are no other regions of concentrated rainfall. It is interesting to note that the heaviest 2-day storm as well as the heaviest 3-day storm has occurred in the pre- and post-monsoon periods and are associated with low pressure systems.

(*iii*) *4-day rainstorm*—As far as heaviest 4-day rainstorm is concerned, the storm of 18-21 June 1934 has contributed the maximum depth of precipitation over the study area, but if one considers the depths contributed for each day for different areas by rainstorm of 4-day duration, the rainstorm of 9-12 August 1902 is also equally important as the rainstorm of 18-21 June 1934, since both of them contribute to the 2-day and 3-day enveloping curve. The 1902 storm occurred when the monsoon trough extended to northeast Assam with its axis passing through Dinajpur and Gauhati on 9th. It later moved and shifted further northwards and lay close to the foot hills till 11th causing very heavy rainfall in Assam. On 12th the axis shifted southwards with a consequent decrease in rainfall. It is interesting to note that the 1934 storm was also associated with the shift of the eastern end of the monsoon trough northwards on 19th with axis passing through Dinajpur and Dhubri. It shifted further northwards on 20th passing through Jalpaiguri and Tezpur, causing heavy rainfall over upper Assam. The axis shifted back on 21st. The resemblance between the two synoptic situations is striking and so is the similarity between the isohyetal patterns of the two storm-periods

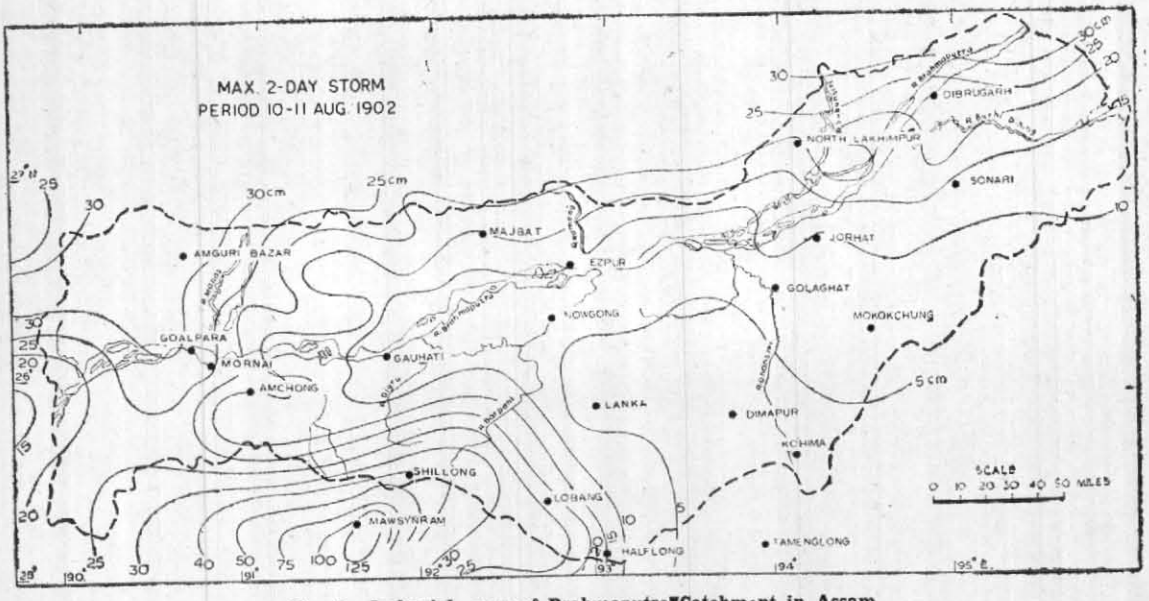

Fig. 6. Isohyetal map of Brahmaputra Catchment in Assam

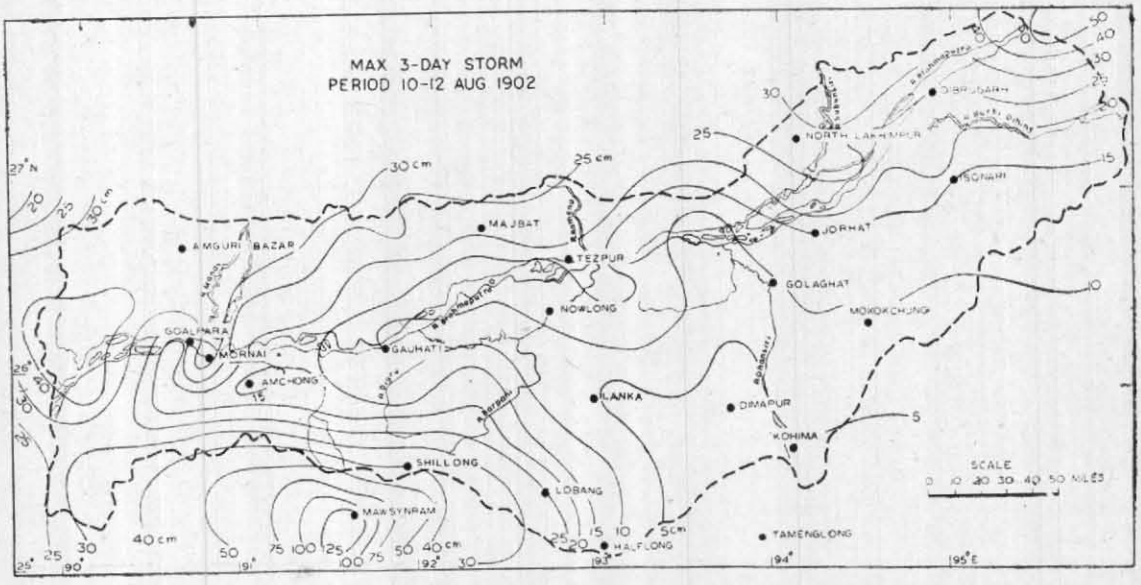

Fig. 7. Isohyetal map of Brahmaputra Catchment in Assam

in so far as the centres of maxima and minima are concerned (Figs. 8 and 11). There are, of course, some differences in magnitude in the maxima recorded at Mawsynram and also some difference in the concentration of isohyets. There is, however one striking feature in the pattern of the storm rainfall of the two storms as revealed by the depth-area-duration curves (Fig. 12). The 1934 storm has given much more concentrated heavy rainfall close to the centre with a rapid decrease as we go away from the centre whereas the 1902 storm has given a more well distributed rainfall. This can also be seen from (Figs. 11 and 8) the greater concentration of the isohyets in the case of 1934 storm as compared to the 1902 storm. Another interesting feature about these 4-day storms is that they made the maximum contribution to the envelope curves presented in Fig. 8 and discussed later.

(*iv*) *5-day rainstorm* — The heaviest 5-day storm was recorded during the period 8 to 12 June 1909. This occurred in association with a depression that formed near Orissa coast on 5th, intensified and moved northwards. It lay near Patna on 9th. Recurving, it moved eastnortheastwards and lay near Purnea on 10th and filled up on 11th. As can be seen from Fig. 13, the heaviest rainfall was concentrated in the western parts of Assam which was

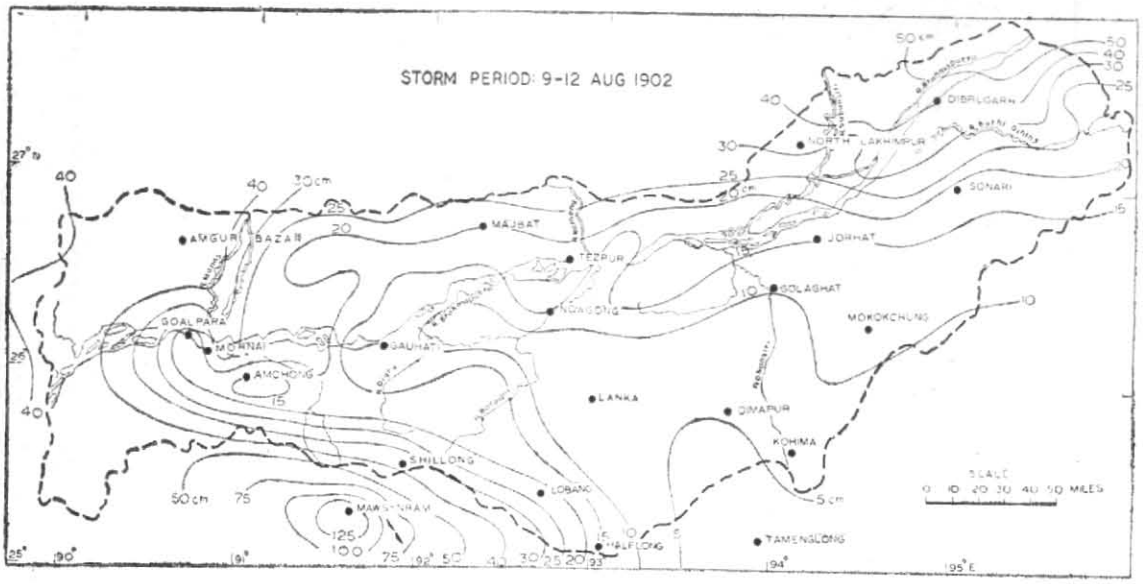

Fig. 8. Isohyetal map of Brahmaputra Catchment in Assam

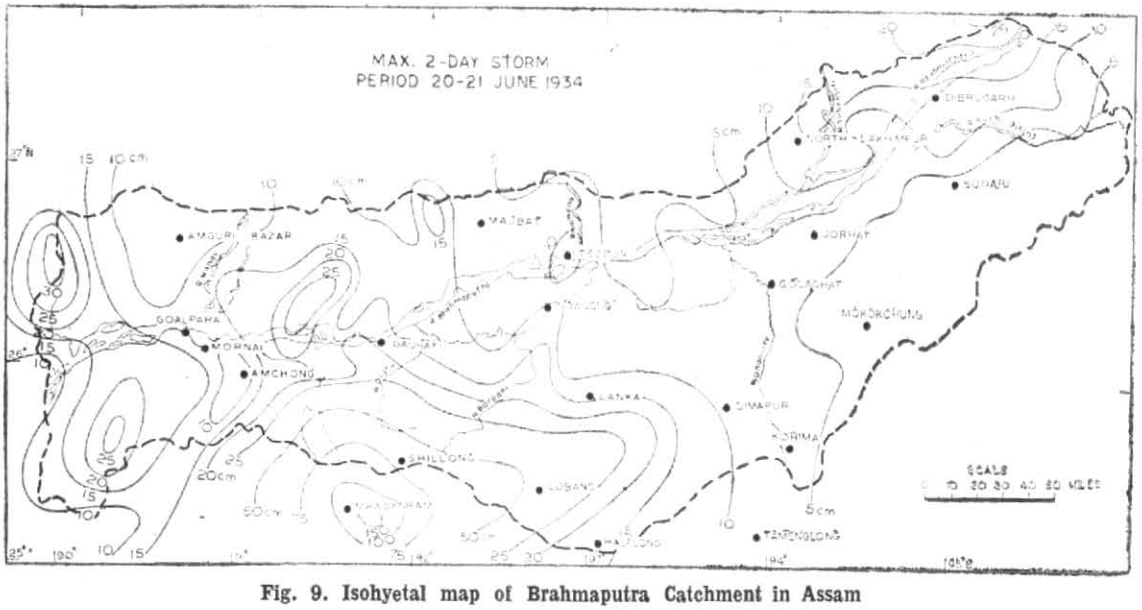

Fig. 9. Isohyetal map of Brahmaputra Catchment in Assam

directly affected by the disturbance. There is the usual secondary maxima over the northeastern parts of the catchment but the magnitudes of the rainfall are much less. The depth-area curve for this storm shown in Fig. 16 indicates that there was no concentrated heavy rainfall in association with this storm.

(*v*) *6-day rainstorm* — The heaviest 6-day storm was also recorded in the month of June 1902 (15th to 20th). The synoptic situation associated with this storm indicates that the depression which was over Gangetic West Bengal on 14th filled up on 15th; but the trough of low pressure associated with it extended over upper Assam with the axis passing through Dumka, Mymensingh and Gauhati. The trough was maintained more or less in the same position throughout the storm period. The isohyetal pattern of this storm (Fig. 14) shows that there were two centres of concentrated rainfall one over extreme northwestern portions of Assam and another near Gauhati. The depth-area curve (Fig. 16) also brings out this fact.

(*vi*) *7-day rainstorm* — The heaviest 7-day storm was recorded during the period 7-13 July 1918. This was associated with the monsoon trough extending over Assam. The axis of the trough shifted northwards on 7th and ran close to the foot hills on 8th where it persisted till 13th. As

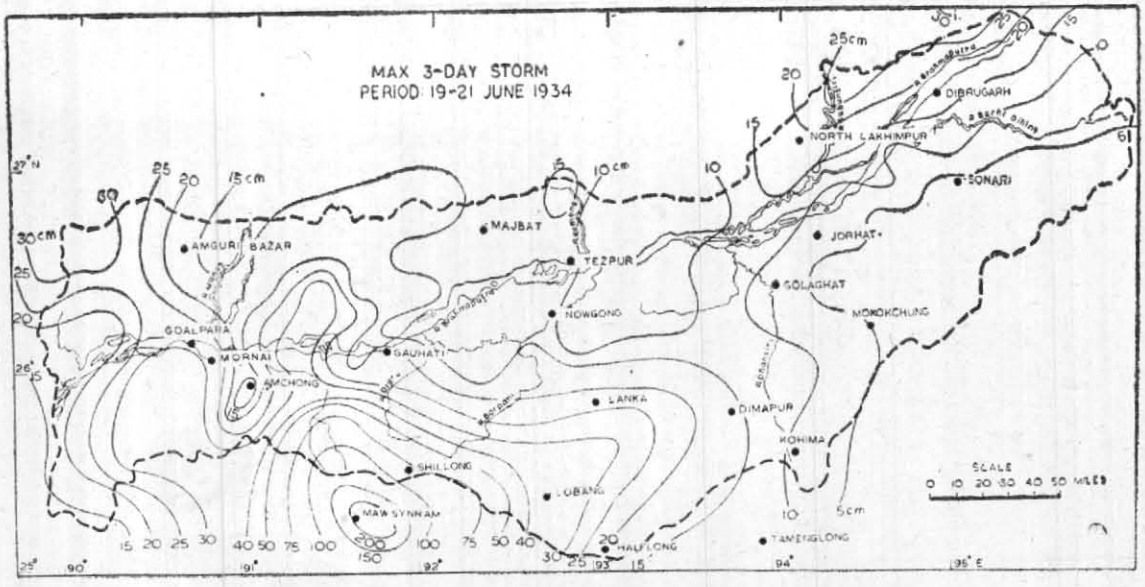

Fig. 10. Isohyetal map of Brahmaputra Catchment in Assam

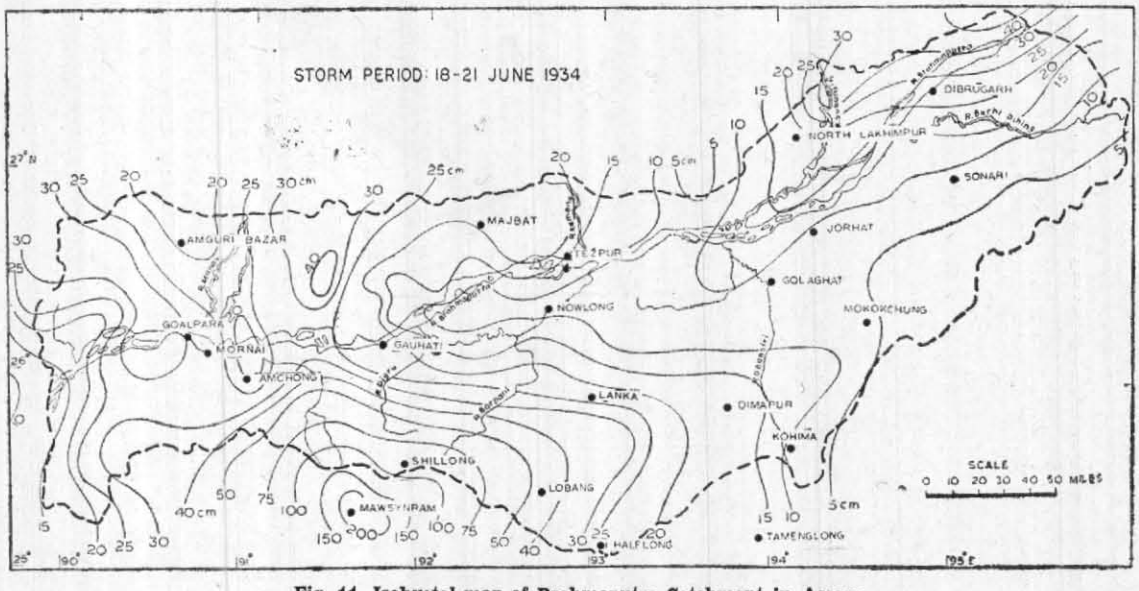

Fig. 11. Isohyetal map of Brahmaputra Catchment in Assam

should be expected with such a synoptic situation the isohyetal pattern for the storm (Fig. 15) clearly shows that the maxima of rainfall are in the northern portions of Assam and minima occur generally over the central parts. The depth-area curve (Fig. 16) for the storm shows that relatively heavy rainfall was confined to very small areas and over a large part of the area, the rainfall is more or less evenly distributed.

9. Enveloping curves

(*i*) *Depth-duration envelope*—Depth-duration curves have been drawn in Fig. 17 for rainstorms including major ones for each duration from 2 to 7 days. Each curve has been labelled by the serial number of the rainstorm and the storm duration as given in Appendix. For example, the curve bearing number 8(4) is for the rainstorm at serial number 8 amongst 4-day rainstorm.

It may be seen that maximum depth for 1 and 2-day durations has been contributed by the first rainstorm amongst 4-day rainstorm (9-12 August 1902); for 3 and 4-day durations by the eighth rainstorm amongst 4-day rainstorm (18-21 June 1934); for 5-day durations by the first rainstorm amongst rainstorm of 5-day duration (8-12 June 1908) and for 6 and 7-day durations by the first

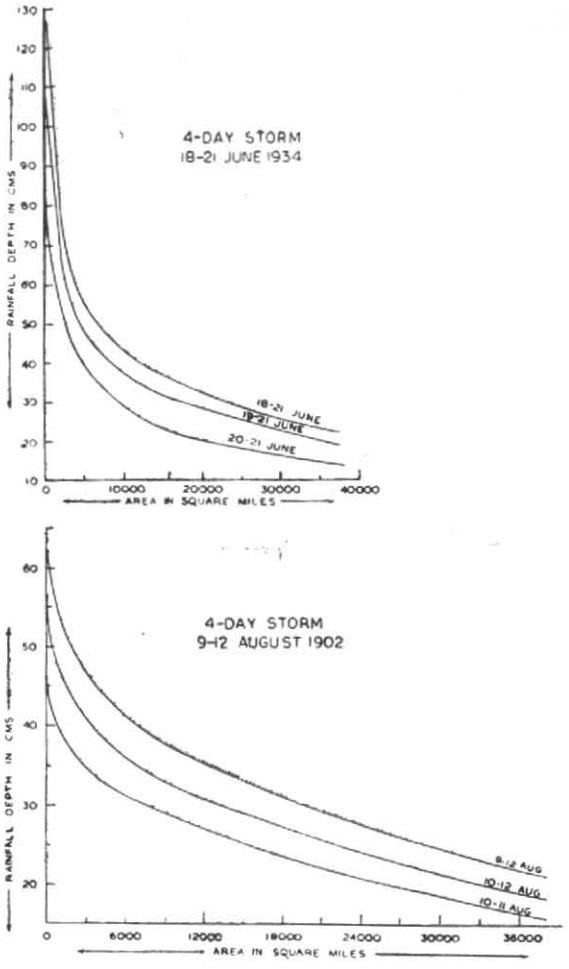

Fig. 12. Depth-area-duration curves for two heaviest 4-day storm

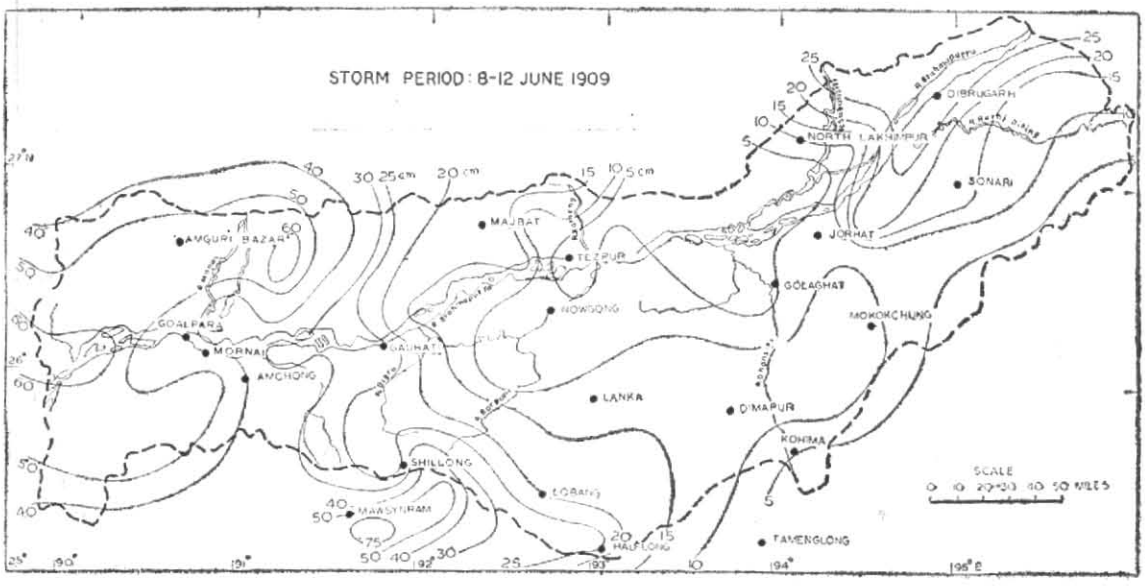

Fig. 13. Isohyetal map of Brahmaputra Catchment in Assam

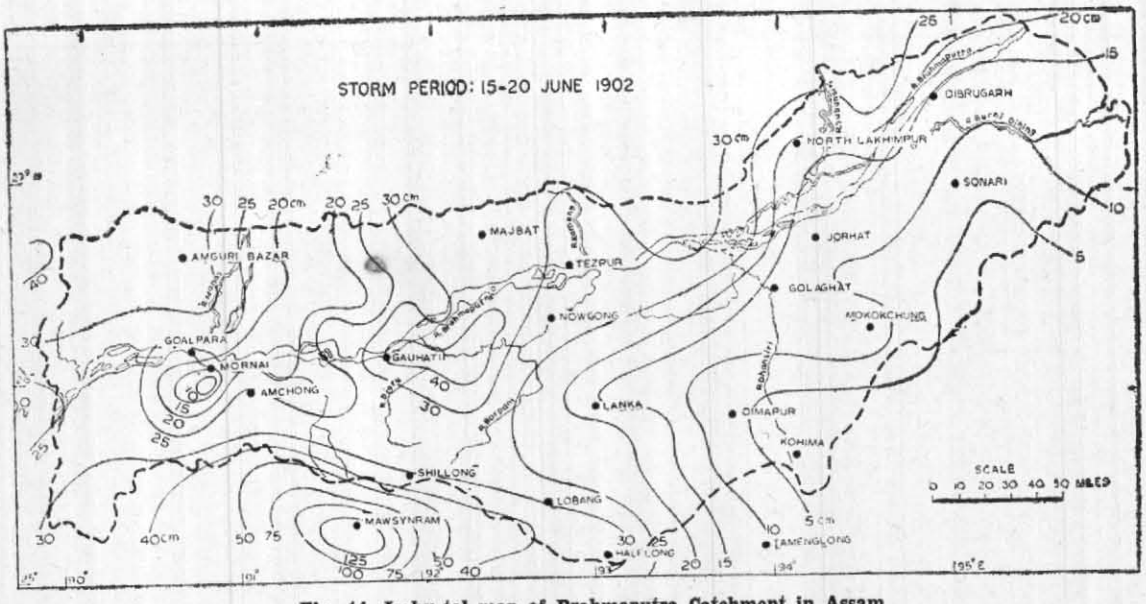

Fig. 14. Isohyetal map of Brahmaputra Catchment in Assam

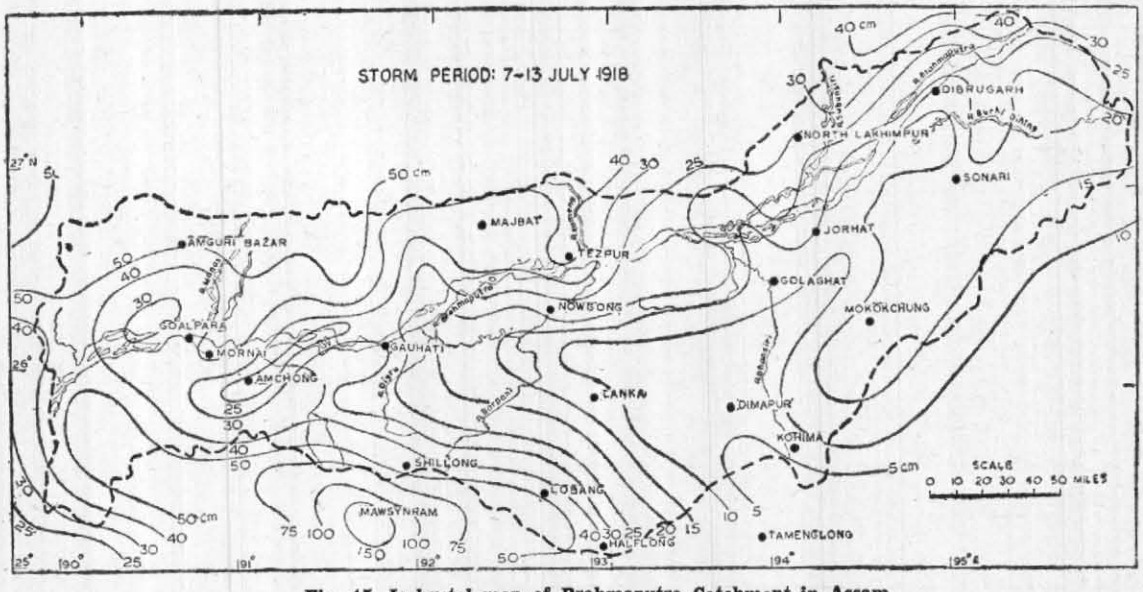

Fig. 15. Isohyetal map of Brahmaputra Catchment in Assam

rainstorm amongst 7-day rainstorms (7-13 July 1918). The enveloping curve has been drawn by broken line. A double curvature has been given to the enveloping curve to bring out the fact that rainstorm of durations longer than 5-day are not single entity but are a combination of two rainstorms occurring in succession.

(*ii*) *Depth-area-duration envelope* — Enveloping or maximum depth-area curves for different durations (Fig. 2) have been drawn by considering all the rainstorms. It is, however, observed that only two rainstorms, *viz.*, 18-21 June 1934 and 9-12 August 1902 contribute to the enveloping curves upto 4-day duration.

The 2-day enveloping curve is formed only by the depth-area curves of 1902 and 1934 storms, the isohyetal patterns of which are given in Figs. 6 and 9 respectively. The corresponding depth-area curves are given in Fig. 12. The 1934 storm contributed highest depths for areas upto 12,000 sq. miles and the 1902 storm contributed highest depths for larger areas. The 1934 storm contributed highest 3-day rainfall depths for all areas. Therefore, the depth-area curve for this storm (Fig. 12) is also the 3-day enveloping curve. The isohyetal pattern for this storm is given in Fig. 10.

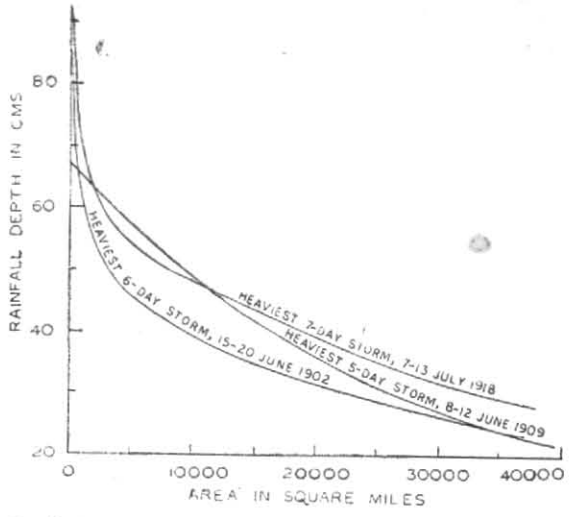

Fig. 16. Depth-duration curves of heaviest 5-day, 6-day and 7-day storms

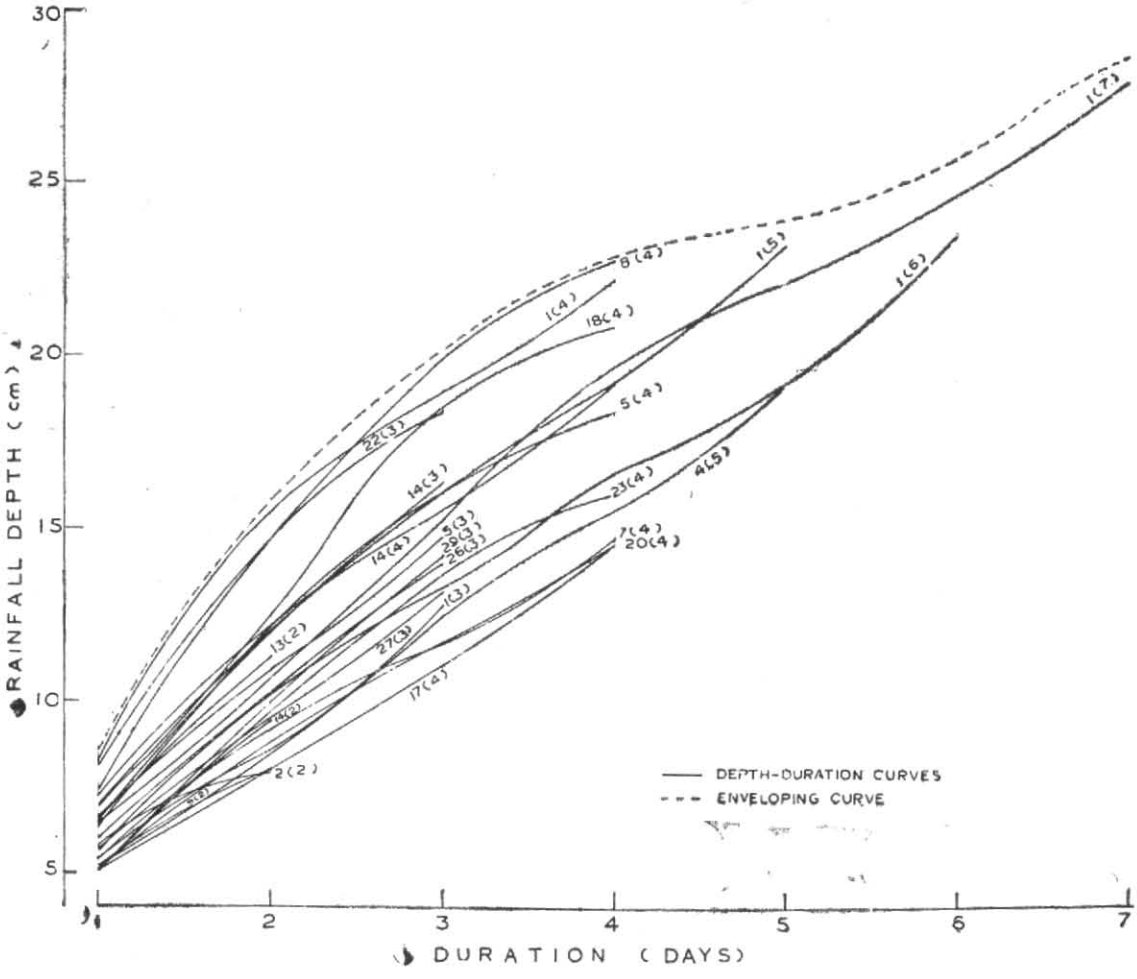

Fig. 17. Depth-duration curves and enveloping curve

Also the 4-day enveloping curve is the same as the depth-area curve of 18-21 June 1934 storm as it has contributed the highest 4-day depths for all areas.

10. Conclusions

Rainstorms are most frequent in the month of June in the Brahmaputra catchment lying largely in Assam. Most of the storms are of duration 2-4 days.

2. The synoptic situation which is associated with maximum number of rainstorms is the extension of the eastern end of the monsoon trough over Assam either in association with a general break in the monsoon or otherwise.

3. Storms of duration greater than 4-day are not only rare but do not contribute substantially more to the depth of precipitation than those of 4-day duration.

4. The storms of 18-21 June 1934 and 9-12 August 1902 are the heaviest on record and have made maximum contribution to the enveloping curves for durations 2 to 4 days. It is interesting to note that both these heavy storms occurred in association with shift of the eastern end of the monsoon trough over upper Assam.

11. Acknowledgements

We have great pleasure in acknowledging the assistance rendered by S/Shri I. D. Sharma and P. K. Datta Roy. We are grateful to Dr. L.S. Mathur, Director General of Observatories for the keen interest he has shown in this hydrometeorological studies.

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APPENDIX

List of rainstorms studied together with the maximum averages for various durations of the storm period and the associated synoptic situations

Storm dates	Average depth (cm)		Associated synoptic situations
	Max. 1-day	2-day	
			2-day rainstorms
10-11 Jul 1902	3·3	6·5	The eastern end of the axis of the monsoon trough shifted close to the foot hills
28-29 May 1904	5·8	7·9	Cyclonic storm near Bogra moving in a NE-ly direction filled up on 29th after striking the hills
12-13 Jun 1904	4·3	8·3	Cyclonic storm which lay near Mymensingh on 12th filled up on 13th after striking the hills
24-25 Jun 1905	4·6	7·1	Eastern end of the axis of the monsoon trough moved northward passing through Dumka and Narayanganj
30 Sep–1 Oct 1906	3·9	6·9	Low pressure area over NE India on 30th, deepened into a depression on 1 Oct with centre near Bogra
12-13 Jul 1906	3·1	6·0	Axis of the monsoon trough shifted close to the foot hills and persisted till 14th
9-10 Jul 1906	3·4	6·0	Axis of the monsoon trough shifted close to the foot hills on 9th
5-6 Jun 1907	3·9	7·0	Trough of low extending over upper Assam with axis passing through Bogra and Gauhati causing widespread rain and thundershowers
4-5 Jul 1908	5·2	8·0	Trough of low extending over upper Assam with axis passing through Dinajpur and Tezpur
24-25 Aug 1908	2·8	5·0	A trough of low extending over upper Assam with general active monsoon conditions over the country
22-23 Aug 1912	4·3	7·3	The eastern end of the axis of the monsoon trough moved northwards over Assam on 22nd and then shifted southwards on 23rd
2-3 Jul 1913	2·9	5·2	A low pressure area between Darbhanga and Jalpaiguri on 2nd and persisted there on 3rd
6-7 Oct 1916	6·5	11·3	A depression with centre near Gaya on 6th moved ENE and filled up on 7th
24-25 Aug 1918	5·1	9·4	A depression formed over Bihar Plateau on 24th and moved westwards
17-18 May 1921	2·5	5·0	A wind discontinuity over upper Assam with pre-monsoon thundershower activity during storm period
24-25 Sep 1922	3·6	6·5	A depression with centre near Dumka on 24th persisted on 25th and weakened same evening
19-20 Jul 1924	3·1	5·8	A low pressure area over Bihar State persisting on 19th and 20th
17-18 Jun 1930	4·2	8·1	A low pressure area over east Madhya Pradesh on 17th moving in WNW-ly direction
18-19 Jun 1932	4·6	8·1	The eastern end of the axis of the monsoon trough shifted close to the foot hills and persisted till 19th
12-13 Aug 1933	3·5	6·2	The axis of the monsoon trough shifted northward passing through Dhubri and Tezpur on 12th
15-16 Aug 1933	2·8	5·3	The axis of the monsoon trough which shifted northward on 12th passing through Dhubri and Tezpur persisted till 16th
3-4 Jun 1937	2·8	5·1	A low pressure area over Bihar Plateau with trough extending over northeast Assam causing widespread thunderstorm activity over Assam on 3rd and 4th
11-12 Jun 1938	2·8	5·6	Trough of low extending over northeast Assam with axis passing through Dhubri and Tezpur on 11th and 12th
9-10 Aug 1938	3·9	6·5	The axis of the monsoon trough shifted close to the foot hills and persisted on 9th and 10th
3-4 May 1941	3·9	6·2	A low pressure area over Bihar Plateau on 3rd with trough of low extending over northeast Assam causing widespread rain and thunderstorm activity
6-7 May 1941	4·0	7·3	A low pressure area over Bihar Plateau on 3rd with trough of low extending over northeast Assam causing widespread rain and thunderstorm activity, persisted till 7th
25-26 Jun 1942	4·7	9·1	The eastern end of the axis of the monsoon trough shifted close to the foot hills and persisted on 25th and 26th
17-18 Jun 1944	3·6	6·1	A low pressure area over Bihar Plateau with trough of low pressure over northeast Assam causing widespread rain and thunderstorm activity on 17th and 18th
1-2 Aug 1948	4·1	8·1	The axis of the monsoon trough shifted close to the foot hills and persisted from 31 Jul to 2 Aug

APPENDIX (*contd*)

Storm dates	Average depth (cm) Max. 1-day	2-day	Associated synoptic situations
21-22 Jun 1949	2·1	6·0	The eastern end of the axis of the monsoon trough shifted close to the foot hills on 21st
23-24 Aug 1949	3·2	5·7	The axis of the monsoon trough shifted close to the foot hills and persisted on 23rd and 24th
16-17 Aug 1952	3·5	5·6	The trough of low extending over northeast Assam persisted on 16th and 17th
25-26 Jul 1954	3·0	5·7	The axis of the monsoon trough shifted close to the foot hills and persisted on 25th and 26th
5-6 May 1957	3·6	6·2	A trough of low extending over northeast Assam with wind discontinuity causing widespread thunderstorm activity on 5th and 6th

3-day rainstorms

	Average depth (cm) Max. 1-day	Max. 2-day	3-day	
12-14 Aug 1903	5·4	8·6	12·8	Axis of the monsoon trough moved northward close to the foot of the Himalayas
9-11 Aug 1905	4·4	7·0	11·9	Axis of the monsoon trough passed through Assam Plains while shifting northwards and then shifted back on 11th
10-12 Jul 1912	4·9	8·1	12·0	The eastern end of the axis of the monsoon trough moved northwards over Assam on 10th and shifted back southwards on 12th
28-30 Jun 1913	4·7	8·1	11·3	A low pressure area over Bihar Plateau on 28th filled up on 29th
15-17 Jun 1914	6·6	10·9	14·8	The eastern end of the axis of the mosoon trough passing through Dinajpur and Gauhati on 15th and persisting on 16th. On 17th a low pressure area developed over upper Assam
8-10 Jun 1921	3·1	5·6	9·2	A trough of low-extending over northeast Assam with eastern end of the axis shifted northwards throughout the period
9-11 Jul 1921	4·2	7·6	11·5	A low pressure area over extreme northeast Assam on 8th persitsing till 10th
25-27 Jun 1922	3·2	6·3	8·9	A low pressure area over sub-Himalayan West Bengal and adjoining Assam on 25th persisting till 26th
10-12 Jun 1923	3·1	5·9	9·0	A trough of low extending over northeast Assam with eastern end of the axis shifted northward on 10th
14-16 Jun 1923	4·2	7·7	11·1	A trough of low extending over northeast Assam with eastern end of the axis shifted northwards and persisting till 16th
18-20 May 1923	3·0	6·0	8·8	A low pressure area over northeast Assam on 18th and another depression which formed over Orissa coast on 18th entering Assam on 20th and filling up on 21st
29 Jun-1 Jul 1926	4·4	8·1	11·3	Trough of low extending over northeast Assam with eastern end of the axis shifted northwards throughout the storm period
10-12 Aug 1928	3·2	6·3	8·5	The axis of the monsoon trough moved northwards on 10th and shifted close to the foot hills on 11th and 12th
10-12 Jun 1929	6·5	12·0	16·3	The eastern end of the axis of the monsoon trough shifted north passing through Bogra and Tezpur, persisting there till 12th
10-12 Jun 1930	3·7	7·4	10·1	The eastern end of the axis of the monsoon trough shifted north passing through Bogra and Tezpur and pesisting there till 12th
24-26 Jun 1931	4·6	8·9	13·0	The eastern end of the axis of the monsoon trough passing through Dinajpur and Tezpur on 24th and persisting till 26th
25-27 May 1932	4·8	7·7	10·3	A deep depression lying near Mymensingh on 25th filled up on 26th
14-16 Jun 1932	3·6	6·3	8·9	A low pressure area over Gaya with trough extending over upper Assam and its axis passing through Mymensingh to Dibrugarh on 14th and persisted till 16th
4-6 Jul 1932	3·6	6·4	9·2	The eastern end of the axis of the monsoon trough passing through Bogra and Gauhati on 4th and persisting till 6th
5-7 Jun 1933	3·1	5·8	7·9	Wind discontinuity over upper Assam causing widespread thunderstorm activity persisting from 5th till 7th

APPENDIX (*contd*)

Storm dates	Average depth (cm) Max. 1-day	Max. 2-day	3-day	Associated synoptic situations
3-day rainstorms (*contd*)				
11-13 Jul 1934	3·9	6·5	8·8	A depression over Bihar and sub-Himalayan West Bengal filled up on 11th but the monsoon trough with its axis close to the foot hills persisted on 12th and 13th
27-29 May 1936	7·4	14·8	18·4	A cyclonic storm near Sandheads on 27th crossed coast and lay as a deep depression near Mymensingh on 28th and filled up on 29th
30 Aug–1 Sep 1936	3·9	6·5	9·0	A depression over east Madhya Pradesh on 30 August moved northwards and weakened on 1 Sep
30 May–1 Jun 1937	3·2	6·1	8·8	Wind discontinuity over Assam causing widespread thunderstorm activity from 30 May to 1 Jun
13-15 Jun 1940	3·4	6·7	8·9	A trough of low extending over northeast Assam with wind discontinuity over the region causing widespread rain and thunderstorm activity from 13th to 15th
3-5 Jun 1941	6·0	10·2	14·0	A low pressure area over Orissa on 3rd and another low forming over head Bay on 4th intensifying into a cyclonic storm on 5th
21-23 Sep 1942	5·7	9·5	13·1	A depression over sub-Himalayan West Bengal on 21st moved to over Assam on 22nd and became unimportant on 23rd
26-28 Sep 1943	4·6	9·2	11·6	A depression moved to over Bihar Plateau on 26th, Bihar Plains on 27th and was centred near Dhubri on 28th
25-27 May 1944	5·0	9·9	14·2	A low pressure area over Bihar Plateau with trough of low over northeast Assam causing widespread rain and thunderstorm activity from 25th to 27th
28-30 May 1948	4·0	6·7	9·6	A low pressure area over Madhya Pradesh with trough extending over northeast Assam caused widespread thunderstorm activity from 28th to 30th
24-26 Jun 1949	2·9	4·9	7·1	The eastern end of the axis of the monsoon trough shifted close to the foot hills and persisted till 26th
28-30 May 1953	3·4	6·0	8·3	A trough of low extending over northeast Assam with wind discontinuity passing through Mymensingh causing widespread rain and thunderstorm activity over Assam
24-26 Jul 1955	4·8	9·3	13·2	The axis of the monsoon trough lay close to the foot hills from 24 to 26 Jul
14-16 May 1956	2·8	5·5	8·4	A trough of low extending over northeast Assam with wind discontinuity causing widespread thunderstorm activity from 14th to 16th

4-day rainstorms

	Average depth (cm) Max. 1-day	Max. 2-day	Max. 3-day	4-day	
9-12 Aug 1902	8·2	15·6	18·9	22·1	Axis of the monsoon trough passed through Assam on 9th and shifted close to the foot hills on 10th and 11th. It then moved southwards on 12th
14-17 Sep 1920	3·9	6·8	9·2	11·0	A low pressure area with centre near Burdwan on 14th shifted northeastwards was centred near Berhampore on 15th and then moved rapidly to lie between Gauhati and Tezpur on 16th and then disappeared on 17th
2-5 Jun 1921	3·8	6·5	10·7	15·9	A trough of low extending over northeast Assam with eastern end of the axis shifted northwards throughout the storm period
6-9 Jul 1927	4·1	7·9	10·7	14·2	A low pressure area over extreme northeast Assam on 6th persisted till 7th. The trough of low with axis passing through Dhubri and Tezpur remained there till 9th
5-8 Sep 1927	6·3	12·2	16·1	18·4	The axis of the monsoon trough close to the foot of the Himalayas on 5th and 6th, the axis shifted southwards on 7th with conditions becoming favourable for a depression over head Bay on 8th

APPENDIX (*contd*)

Storm dates	Average depth (cm) Max. 1-day	Max. 2-day	Max. 3-day	4-day	Associated synoptic situations
4-day rainstorms (*contd*)					
24-27 May 1928	3·5	6·4	9·1	11·3	A sharp wind discontinuity over upper Assam with widespread pre-monsoon thundershower activity over Assam on 25th to 27th
21-25 Jul 1931	5·4	9·1	11·6	14·7	The eastern end of the axis of the monsoon trough shifted northwards passing through Bogra to Dibrugarh on 21st and persisted till 24th
18-21 Jun 1934	8·1	14·7	19·9	22·7	The axis of the monsoon trough shifted northwards on 18th, shifted further north on 20th and then back south on 21st
8-11 Aug 1935	4·4	7·7	10·3	13·7	The axis of the monsoon trough close to the foot hills persisting on 8th and 9th. On 10th a low pressure area formed over sub-Himalayan West Bengal and Bihar Plains persisting till 11th
13-16 Jul 1938	2·9	5·4	8·1	11·0	A low pressure area over east Uttar Pradesh on 13th with trough of low extending over northeast Assam and persisting there till 16th
17-20 Sep 1938	4·1	7·7	11·3	13·4	Trough of low extending over northeast Assam with sharp wind discontinuity over the region causing widespread thunderstorm activity from 17th to 20th
28 Jun–1 Jul 1939	4·8	8·7	12·6	15.3	The eastern end of the axis of the monsoon trough shifted close to the foot hills on 28th Jun and persisted there till 1 Jul
30 Jul–2 Aug 1945	3·7	5·8	8·0	11·5	The axis of the monsoon trough shifted close to the foot hills on 30th and persisted till 2 Aug
7-10 Jul 1946	7·2	12·2	15·5	19·1	The eastern end of the axis of the monsoon trough moved northwards with axis passing through Bogra, Gauhati and persisted from 7th till 10th
5-8 Jul 1947	4·8	9·3	14·4	17·1	The eastern end of the axis of the monsoon trough shifted northwards passing through Bogra and Tezpur persisting from 5th to 8th
7-10 Jun 1951	4·2	8·3	11·6	14·5	The trough of low extending over northeast Assam with eastern end of the axis shifted northwards causing widespread rain and thunder showers during 7th to 10th
11-14 Jul 1954	5·0	8·0	11·0	14·5	The eastern end of the axis of the monsoon trough shifted northwards passing through Bogra and Gauhati and persisted from 11th to 14th
10-13 Jul 1952	6·9	12·5	18·5	20·8	The eastern end of the axis of the monsoon trough shifted northwards over Assam on 9th and moved back southwards on 13th
13-16 Jun 1956	4·4	8·2	10·5	12·9	A trough of low extending over extreme northeast Assam and persisting from 13th to 16th
13-16 Jun 1959	5·1	8·8	11·7	14·5	A low pressure area over sub-Himalayan West Bengal on 13th moved northeastwards and became unimportant on 15th
22-25 Jun 1959	3·3	5·3	8·1	10·7	A low pressure area over Uttar Pradesh with trough extending over northeast Assam caused widespread rain and thundershower activity from 22nd to 25th
12-15 Jun 1960	4·2	7·6	10·5	13·8	A trough of low extending over northeast Assam with eastern end of the axis passing through Mymensingh and Dibrugarh and persisting from 12th to 15th
12-15 Sep 1960	5·0	9·7	13·7	16·0	A low pressure area over Uttar Pradesh on 11th broke up over Nepal on 13th with wind discontinuity extending from northeast Assam causing widespread rain and thunderstorm activity from 12th to 15th

APPENDIX (*contd*)

Storm dates	Average depth (cm) Max. 1-day	Max. 2-day	Max. 3-day	Max. 4-day	5-day	Associated synoptic situations
5-day rainstorms						
8-12 Jun 1909	7·0	12·1	16·0	19·2	23·2	A depression formed near Orissa, moved northwards and lay near Patna on 9th. It then moved east-northeastwards and was centred near Purnea on 10th and disappeared on 11th
15-19 May 1915	3·7	6·2	9·9	12·7	15·6	A sharp wind discontinuity over upper Assam caused widespread pre-monsoon thundershowers
7-11 Jul 1915	4·7	8·9	13·2	16·5	19·5	The eastern end of the axis of the monsoon trough shifted northwards passing through Purnea and Gauhati on 7th. It persisted there till 10th and moved back south on 11th
3-7 Jun 1918	5·2	8·5	12·5	15·5	19·1	Trough of low extending over upper Assam with axis shifting northwards on 3rd and persisting till 7th
6-10 Jun 1927	4·9	9·5	12·2	16·0	19·0	A depression with centre near Purnea on 6th moved northwards and disappeared on 7th, but trough of low persisted over upper Assam till 10th
1-5 Jun 1936	3·0	5·1	7·9	10·2	12·6	Wind discontinuity over upper Assam persisting from 1st to 5th causing widespread pre-monsoon thunderstorm activity
30 May-3 Jun 1947	3·5	6·7	9·7	12·4	14·7	The wind discontinuity extending over northeast Assam on 30 May and a low pressure area over Bihar Plateau on 1 Jun with trough extending over northeast Assam caused widespread rain and thunderstorm activity during the storm period

6-day rainstorms

	Average depth (cm) Max. 1-day	Max. 2-day	Max. 3-day	Max. 4-day	Max. 5-day	6-day	
15-20 Jun 1902	5·6	10·3	13·3	16·6	19·2	23·4	A depression over Gangetic West Bengal on 14th filled up on 15th but the trough of low extending over northeast Assam persisted. Another low pressure area formed over Bihar Plains on 18th
7-12 Jun 1942	3·7	6·2	9·3	12·2	14·1	17·7	A low pressure area over east Madhya Pradesh with trough extending over northeast Assam on 7th and 8th. Another low pressure area formed over Bihar Plateau on 9th with trough extending over northeast Assam. These situations caused widespread rains and thunderstorm activity over Assam from 7th to 12th
3-13 Sep 1953	3·3	6·3	9·1	12·3	14·7	17·0	The axis of the monsoon trough shifted northwards passing through Mymensingh and Gauhati on 8th and 9th. The axis shifted back south on 10th and a low pressure area formed over Bihar on 11th which weakened on 13th

7-day rainstorms

	Average depth (cm) Max. 1-day	Max. 2-day	Max. 3-day	Max. 4-day	Max. 5-day	Max. 6-day	7-day	
7-13 Jul 1918	6·4	10·8	15·2	19·7	22·1	24·6	27·9	The axis of the monsoon trough shifted northwards on 7th and moved further north close to the foot hills on 8th and persisted there till 13th
3-9 Jun 1935	4·5	7·1	11·4	15·6	18·3	20·3	22·4	A low pressure area over Bihar Plateau on 3rd persisted till 5th with trough of low extending over northeast Assam causing widespread thunderstorm activity till 9th