

## A study of large floods in the Thambraparani river in Tamil Nadu\*

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**ABSTRACT.** The paper contains an analysis of 16 synoptic situations during the period 1891-1960 (70 years) over and near the Gulf of Mannar in which *prima facie*, there could have been very heavy rain and consequent large floods in the *Thambraparani* river in the extreme south of the Indian Peninsula. It was however found that there were only 3 situations, in which 24 hours rainfall exceeding 200 millimetres at any one station in the river catchment was recorded. In all these three cases, there were large floods in that river.

The basic synoptic causes for these 3 occasions of large floods have been investigated in detail. Hydrological data pertaining to these 3 flood-situations were specially obtained from the Government of Tamil Nadu in the proforma prescribed by UNESCO for compiling information about catastrophic floods. Discharge-hydrographs based on the available data were prepared and studied. Isohyetal analysis for a one-day and two-day rainstorms were also carried out. The hydrological characteristics of the floods so far as these could be determined from the available flood-data have been discussed. All the three cases of large floods could be termed as "Flash floods". The factors which led to the very heavy rainfall and flash floods have been discussed from the point of view of issue of heavy rainfall and flood warnings on a quasi-empirical basis.

### 1. Introduction

The river *Thambraparani* is in the Tirunelveli district in Tamil Nadu. It rises on the slopes of Agastiyamalai in the Western Ghats of Peninsular India and flows into the Gulf of Mannar. The catchment of the river may be seen in Fig. 1. It is about 4,500 sq. km in area upto the Srivaikuntam Anicut and should, therefore, be considered as a small catchment.

The monthly and annual normal rainfall over the Tirunelveli district is given in Table 1.

Table 2 shows the normal monthly and annual rainfall and normal monthly and annual potential evapotranspiration (PE) at Palayamkottai (08° 44'N, 77° 45'E) in the Tirunelveli district where the India Meteorological Department is maintaining an observatory.

The normal rainfall figures given in Table 2 have been taken from the India Meteorological Department publication (1962). The normal PE values have been taken from a publication by K. N. Rao *et al.* (1971).

It will be seen from these figures that the annual normal rainfall over the catchment of the *Thambraparani* is only about 800 mm and that the PE values are much higher than the corresponding rainfall figures except in the months of October and November. Because of these conditions, the *Thambraparani* is considered to be situated in a semi-arid area in the hydrometeorological sub-zone known as the Sandy-Comorin

Belt (Ramaswamy 1971a). In such a zone, therefore, any unusual floods are of great interest. The present paper is an attempt to investigate into the basic causes of the record floods in that river in December 1923 causing very heavy loss of property. It was also felt desirable to find out whether there were any floods of similar magnitude in the same catchment during periods for which both flood and meteorological data were readily available. It may be added that special emphasis was laid in our study on the large scale synoptic situations which led to the floods, as, in our opinion the synoptic aspect had not received adequate attention in the available published literature on floods. The hydrological aspects have been discussed only to the extent possible with the flood data readily available to the authors and even these have been discussed only on a broad basis.

The following is an account of the damage caused by the floods as given in the *India Weather Review* published by the India Meteorological Department (1923).

"All the tanks in an area about 40 miles in breadth were breached and the river *Thambraparani* rose in high flood, causing serious breaches on the railway line and interrupting all communications. The flood reached its maximum at 9 hours of the 17th, being then 31 feet at Tirunelveli bridge or 4 feet above the previous record of nearly 50 years ago.

\*This paper was presented before the Indian Meteorological Society at New Delhi in July 1975

TABLE 1  
Normal rainfall (mm), Tirunelveli district

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
50.2	30.2	41.3	59.8	38.0	29.6	26.4	23.3	30.2	166.0	208.2	111.6	814.8

TABLE 2  
Normal rainfall and Potential Evapotranspiration (PE) in mm, Palayamkottai

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Normal rainfall	45.0	28.5	30.0	66.5	39.4	10.2	7.9	16.5	29.0	174.0	183.1	112.5	742.6
Normal PE	130.6	136.1	170.6	155.0	175.0	175.5	186.1	194.3	177.4	144.1	107.9	121.2	1,874.4

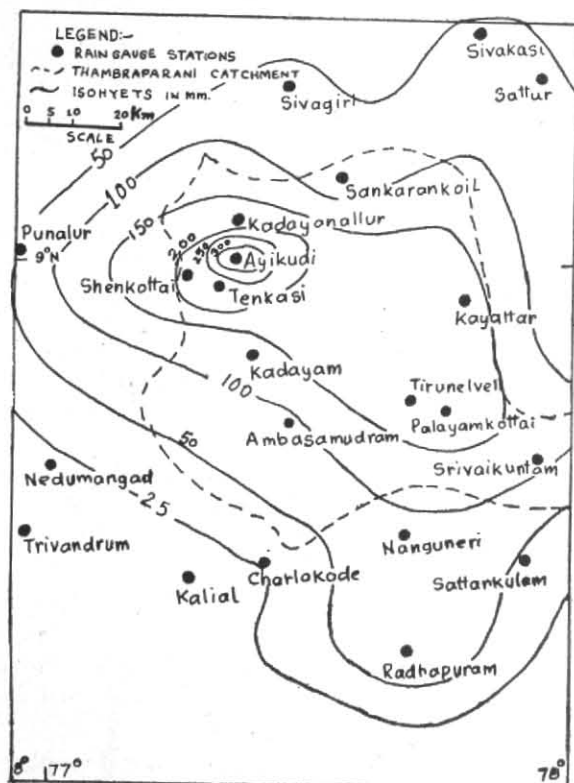


Fig. 1. Isohyetal Map, 16 December 1923

All the villages on the banks of the river were inundated and in Tirunelveli Town, water was running 10 feet deep in some of the streets. There was extensive damage to house properties and movables in all Taluks affected but comparatively little loss of life."

The above account published by the India Meteorological Department is presumably based

on Press reports. It should, however, be pointed out that the flood levels and dates as given in Table 4 in this paper are based on records maintained by the Chief Engineer, Irrigation, Madras.

## 2. Meteorological analysis

### 2.1. Large-scale synoptic situations in association with the floods in December 1923

These record floods in the *Thambraparani* were associated with a low pressure area which developed over the south of the Bay of Bengal on 12 December 1923 and moved westsouthwards across the Gulf of Mannar. According to the India Meteorological Department (1923) the low pressure area probably developed into a depression of small extent over Sri Lanka on 15th December and lay over the Gulf of Mannar on the next day. The disturbance was, however, so feeble that, even after a post mortem examination using available ships logs, the department could not indicate in their publications (1923, 1964) the precise positions of the centre of this disturbance until the morning of 17th December when it was located over the southeast Arabian Sea as a depression with its centre in the position indicated by us in Fig. 2(b) The depression subsequently intensified into a cyclonic storm and moved away westnorthwestwards. This development is however of no interest to us in the present context as the rainfall over the *Thambraparani* catchment considerably decreased after 17th morning and was virtually *nil* after 18th.

Prior to 17th December, the India Meteorological Department have shown in their publications only a broken line upto the west coast of Sri Lanka. We have, however, made a careful

analysis of the situation *de novo* on the basis of available data and indicated in Fig. 2(b), the positions of the centre of this disturbance on 15th and 16th December. Our analysis shows that the disturbance on the 15th and 16th was, at best, a shallow depression. The pressure deficiency at the centre of this shallow depression on the morning of 16th when it lay over the Gulf of Mannar which had caused maximum rainfall over the *Thambraparani* catchment could not have exceeded 5 mb. The pressure deficiency was estimated from the last closed isobar which could be drawn at 1 mb interval at sea level closest to the centre of the cyclonic system. On account of the non-availability of barograph data or frequent eye-observations of pressure either from ships or from land stations along the track of the cyclonic disturbances, the method adopted by us in the present case as well as in the cases listed in Table 3, was the best possible under the circumstances.

As no upper wind data were available for the December 1923 situation, it has not been possible to make a more detailed examination of the synoptic situation which led to these floods.

### 2.2. Depressions and cyclonic storms over the Gulf of Mannar

However, in order to find out the basic causes of these floods the authors have examined all the synoptic situations in which one could *prima facie* expect heavy rainfall and consequent floods over the *Thambraparani* comparable in magnitude to the floods which occurred in December 1923. Figs. 2 (a, b, c) show the tracks of all depressions and cyclonic storms which passed over or close to the Gulf of Mannar. Such disturbances were 16 in number during the 70-year period 1891-1960. They moved from the Bay of Bengal across the Gulf of Mannar or the extreme south of the Indian Peninsula. The tracks were copied out from the Atlas (1964) referred to earlier.

Among these 16 cases, the cyclonic disturbance of November 1945 deserves special mention. The India Meteorological Department Atlas (1964) shows two separate tracks—one upto 9th November and the other from 11th onwards. It is difficult from the available surface and upper wind observations to state categorically that there was a depression over the Gulf of Mannar on 10th with a well defined centre. The disturbance moved through the Gulf of Mannar only as a low pressure wave on 10th November and intensified again into a depression, only after it entered the Arabian Sea on 11th November.

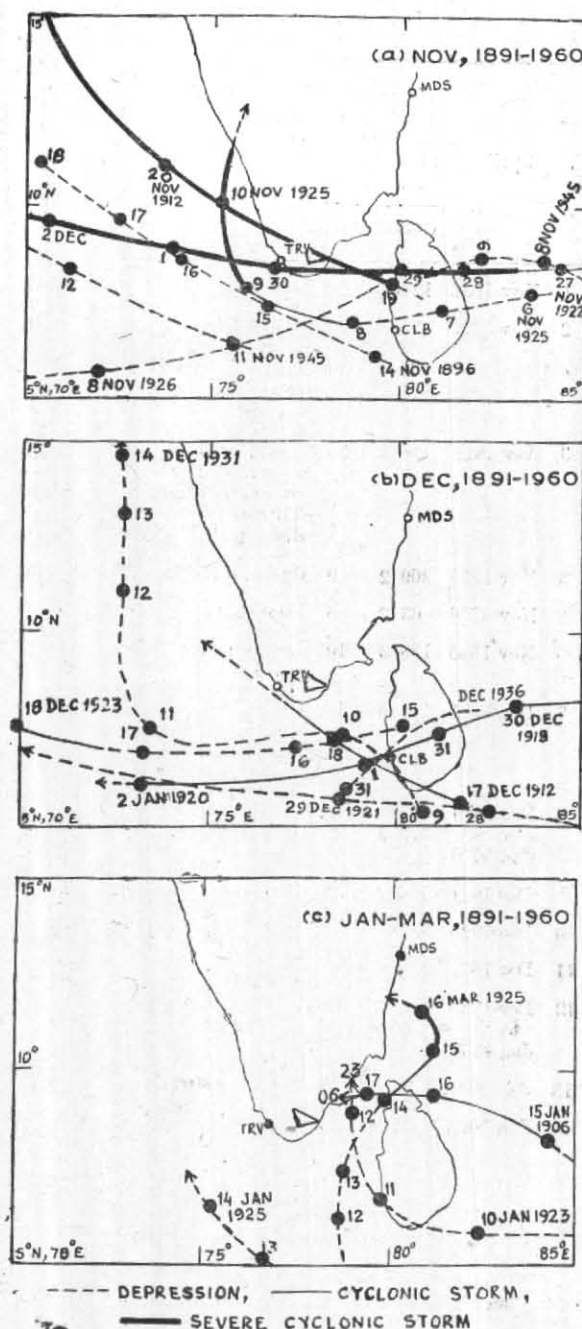


Fig. 2. Cyclonic storms and depressions over and near Gulf of Mannar: (a) November, 1891-1960, (b) December, 1891-1960, (c) Jan-Mar, 1891-1960

Triangle shows the Thambraparani catchment. Shaded circles represent the 8 hours IST positions of the cyclonic systems. The depression moved SWward through the Gulf of Mannar, only as a low pressure wave between 9 and 11 Nov 1945. This system gave the maximum rainfall (138.1 mm in 24 hr ending 8 hr of 10th over Thambraparani catchment. The Nov 1925 depression gave the heaviest rainfall (269.2 mm) between 8 hr of 8th and 8 hr of 9th. The rainfall considerably decreased between 9th and 10th although the disturbance became a severe cyclonic storm by 8 hr of 9th when it was also nearer to the catchment than on the 8th. The depression of Dec 1923 caused heavy rainfall (312.4 mm) over the catchment between 8 hr of 15th and 8 hr of 16th when it was moving WSWwards as a shallow depression through the Gulf of Mannar.

TABLE 3

S. No	Spell	Heaviest rainfall in 24 hours at any one station		Intensity of disturbance over and near Gulf of Mannar	Maximum pressure deficiency at centre of disturbance (Estimated)
		(mm)	Date		
1	Nov 1896	134.1	15	Depression	About 3 mb
2	Nov 1912	38.6	20	Severe cyclonic storm. Centre passed very close to Tirunelveli district	About 7 mb
3	Nov 1922	146.1	30	Severe cyclonic storm. Centre passed through Tirunelveli district	About 5 mb
4	Nov 1925	269.2	9	Cyclonic storm	About 3 mb
5	Nov 1926	63.2	8	Depression	< 2 mb
6	Nov 1945	138.3	10	Low pressure wave	< 1 mb
7	Dec 1912	112.3	19	Cyclonic storm. Centre passed very close to Kanyakumari	< 7 mb
8	Dec 1919 to Jan 1920	179.9	Jan 2	Cyclonic storm	About 5 mb
9	Dec 1921	109.2	30	Depression	< 5 mb
10	Dec 1923	312.4	16	Depression	< 5 mb
11	Dec 1931	248.6	10	Depression	About 5 mb
12	Dec 1936 to Jan 1937	5.6	Jan 1	Depression	< 4 mb
13	Jan 1906	30.5	18	Cyclonic storm	5 mb
14	Jan 1923	83.8	15	Depression	< 5 mb in the depression stage < 2 mb in the low pressure area stage (see text)
15	Jan 1925	74.9	14	Depression	4 mb
16	Mar 1925	State rain-gauge data as printed in the rainfall tables are not reliable.		Depression	3.4 mb

### 2.3. Synoptic situations in association with heavy rainfall over the Thambraparani catchment

Table 3 sets out the heaviest rainfall in 24 hours (ending at 08 hr local time or 03 GMT) at any one station in the catchment of the *Thambraparani* in association with the 16 cyclonic disturbances. The intensities of the disturbances when

they were moving over or near the Gulf of Mannar and the estimated pressure deficiencies at the centres of the disturbances at that stage are given in the last two columns of the table.

The study of the synoptic situations revealed the following —

Conditions were most favourable for heavy rainfall over the catchment of the *Thambraparani* when the centres of the cyclonic systems lay 1 to 2 degrees latitude to the south of Kanyakumari (formerly known as Cape Comorin) and were moving westwards. A slight southerly component of movement was also observed in these cases.

Such systems, even when they were comparatively feeble, produced more heavy rainfall than cyclonic storms moving northwestwards and later recurring to the north. The cases of November 1945 (S. No. 6 in Table 3) and the severe cyclonic storm of November 1912 (S. No. 2 in Table 3) the centre of which passed through the Tirunelveli district serve as good examples. The heaviest rainfall over the catchment caused by the severe cyclonic storm was only 38.6 mm as against 138.3 mm produced by the low pressure wave of November 1945. It is also of interest to mention that the heavy rainfall over the catchment in association with the January 1923 depression (S. No. 14 in Table 3) occurred, not when the depression was moving northwards towards the Tirunelveli district (see Fig. 2c) but later, after it had weakened into a residual low pressure area and the latter had retreated southeastwards\* (Bamford 1923) to a favourable position for the occurrence of heavy rainfall over the *Thambraparani* catchment.

These findings are consistent with our general synoptic experience that, in cyclonic disturbances in the retreating monsoon period (also referred to as northeast monsoon period in Tamil Nadu) heavy rainfall occurs well to the north and northeast of the centre of the disturbance where there is maximum convergence between the easterlies and northerlies in the lower troposphere.

Incidentally, Table 3 brings out the important fact that the pressure deficiency at the centres of the cyclonic disturbances over the Gulf of Mannar in the months November-March as judged from the last closed isobar drawn at 1 mb interval is relatively small. This does not, of course, preclude the existence of a steep gradient of pressure fall very near to the centre.

\*Track of residual low pressure area which moved southward not shown in Fig. 2 (c).

TABLE 4

Large floods in Thambraparani river, Tamil Nadu

Location : Srivaikuntam Anicut (Near Srivaikuntam Town), Tirunelveli District, Lat. 8°37' N, Long. 77°55' E  
 Total catchment area : 4504 sq. km (Hilly catchment area 907 sq. km and Plain catchment area 3597 sq. km)

	Flood elevation above m.s.l.(m)		Max. flood levels ever recorded during flood (m)	Period of flood/Period of Inundation	Base flow (m <sup>3</sup> /s)	Q <sub>max</sub> (m <sup>3</sup> /s)	q <sub>max</sub> (cusecs)	Characteristics of flood			Type	Flood damage
	Damage (danger) level (m)	Max. recorded during flood (m)						h (mm)	T <sub>B</sub> (hr) T (hr) p	P% Type of probability curve used		
Dec 1923	12.02	16.04*	16.04 on 16-12-23	14-12-23 to 24-12-23	10	4993 on 16-12-23	1.11	180	240/48	—	Rainfall	Details are not available
Nov 1925	..	15.88	..	8-11-25 to 15-11-25	47	4796 on 9-11-25	1.06	165	168/36	—	Rainfall	Details are not available
Dec 1931	..	15.97	..	9-12-31 to 19-12-31	46	4913 on 10-12-31	1.09	173	240/42	—	Rainfall	Details are not available

\*Max flood level was observed at 22.00 hr on 16-12-1923 and the water level stood at 52.59 ft (16.04 m). On 17-12-1923, the water level came down by 0.50 ft (0.15m) and the then floods gradually receded.

It will also be seen from Table 3 that there were only three synoptic situations during the period of 70 years (1891-1960) in which heavy rainfall in 24 hours at one station exceeded 200 mm. These occurred in December 1923 (the one already studied by us), in November 1925 and December 1931. The tracks of the cyclonic systems which caused the spells of heavy rain in November 1925 and December 1931 may be seen in Figs. 2 (a and b). The catchment of the *Thambraparani* has been marked as triangle in Figs. 2(a, band c) to show its position relative to the moving cyclonic disturbances concerned.

It may be of general interest to mention at this stage that in December 1964\* the famous Rameswaram cyclone which was one of the most severe cyclones, occurred in the Indian Seas and moved westnorthwestwards across the Palk Strait. A storm wave associated with it swept away an entire passenger train off the railway track near Dhanushkodi, an island in the northeastern boundary of the Gulf of Mannar. This severe cyclone which struck the Indian coast on 23rd December caused little or no rain in the *Thambraparani* catchment. Palayamkottai, the Headquarters of the Tirunelveli district and where the India Meteorological Department is maintaining an observatory, lies inside the *Thambraparani* catchment. It recorded 1 mm rain on 24 December and no rain on 20, 21, 23 and 25 December. No data are available for 22nd.

This is perfectly consistent with our synoptic analysis and our conclusions regarding situations which caused heavy rainfall and floods in the *Thambraparani*. For the track of the Rameswaram cyclone and a detailed description of the cyclone, the paper by Bhaskara Rao and Mazumdar (1966) may be seen.

3. Hydrological analysis of the floods

3.1. Flood data

Table 4 contains the relevant data in respect of the floods which occurred in association with the 3 synoptic situations (December 1923, November 1925 and December 1931) referred to in the preceding paragraph. The flood data were supplied by the Chief Engineer, Irrigation, Government of Tamil Nadu at our request in the proforma supplied by us. The proforma is the same as the one suggested by UNESCO (1970) for compiling information on catastrophic floods. The data, however, have been regrouped into one table to save space. The explanations for some of the terms and symbols used in the proforma are given below. These have been taken from the UNESCO circular referred to above.

Term	Explanation
Period of flood	Total period of flood rise and recession in the river, in days.

\*Although this cyclone did not occur within the period 1891-1960 selected by us for study, we are referring to it here as this cyclone made history in India and is, therefore, of great public interest.

Term	Explanation
Period of inundation	Of the countryside, in days.
Base-flow	In the river just prior to the actual flood rise.
$Q_{\max}$	Peak flood discharges in cubic metres per second.
$q_{\max}$ (cusecs/km <sup>2</sup> )	The "specific" peak discharge, <i>i.e.</i> , peak discharge rate, per unit area of catchment, in cubic metres per second per sq. km.
$h$ (mm)	Average run-off (volume) depth in millimetres over the active catchment, <i>i.e.</i> , total run-off volume divided by the free or "active" catchment area.
$T_B$ (hours)	Total duration of the flood, <i>i.e.</i> , time base of direct surface run-off of the flood hydrograph.
$T_p$ (hours)	Time to peak or time of rise.

### 3.2. Discharge hydrographs for the floods

The discharge hydrographs prepared from the data contained in Table 4 are shown in Fig. 3. As these are based only on the data of base-flow,  $Q_{\max}$  and  $T_B$  and  $T_p$  hours, they do not bring out the details of the rise and recession during the floods. They are, however, good enough to bring out the fundamental point that, in all the three cases of floods, the base-flow was at the low values of 10 to 47 m<sup>3</sup>/sec prior to the floods while the peak, flow reached high figures ranging from about 4800 to 4990 m<sup>3</sup>/sec within 36 to 48 hours from the time of commencement of rise. The duration of the flood did not also exceed 240 hours in any of the three occasions. All the three cases could, therefore, be classed in the category of flash floods. We are, therefore, of the opinion that the antecedent rainfall prior to 48 hours from the time of the peak flow could not have contributed significantly to the development of the floods. Hence, we have not reproduced in the paper, the figures we had worked out of antecedent rainfall in 10 days and 30 days from the date of peak flow. It is also of interest to note that the  $Q_{\max}$  values in all the three cases would justify our declaring them as cases of "Large Floods" in the Terminology of UNESCO (1970) and in conformity with the criteria adopted by the Central Water and Power Commission of the Government of India in their Catalogue of Large Floods in India (1971).

Fig. 3 and Table 4 also show the following :

- The maximum flood elevation of 16.04 metres occurred in December 1923 flood and constituted a record for the *Thambraparami*. However, the flood elevations in the other two cases, 15.97 metres in December 1931 floods and 15.88 metres in November 1925 floods, were quite comparable in magnitude to the flood elevation in December 1923 flood.
- The period of inundation of the surrounding country-side varied between 7 and 10 days in all the three cases.
- The value of  $q_{\max}$ , *i.e.*, the peak discharge rates per unit area of catchment was highest in December 1923 floods and lowest in November 1925 floods (*vide*, Table 4). The variation in the  $Q_{\max}$  (peak flood discharge) values also showed the same trend.

### 3.3. Isohyetal analysis

Figures 1 and 4 show the isohyetal patterns respectively for the rain storms on 16 December 1923 and on 16 and 17 December 1923, combined. While studying these patterns, it is to be remembered that rainfall was recorded at the observatories only once in 24 hours ending at 8 hours local time daily (Data of self-recording raingauges were not available for the cases studied by us). An examination of the rainfall figures shows that the isohyetal average of rainfall reported on 17th morning was higher than that reported on 16th morning and that, on the 17th, it occurred further down in the catchment. This is also clearly seen in the isohyetal patterns in Figs. 1 and 4. We have, however, to remember that much of the rainfall reported on 17th morning might have occurred during the course of the 16th itself after the 8 hr observations were recorded on that day. In view of this and also of the fact that the rainstorm centre lay between Kadayam and Tirunelveli on 16th and 17th combined (*i.e.*, much nearer the Srivaikuntam Anicut where the discharge measurements were taken), there is nothing inconsistent in the observation that the highest flood level was reached at the gauging site at Srivaikuntam at 22 hr on 16th (*vide*, the note with asterisk in Table 4). We have also to remember that, in all the three cases of floods discussed in this paper, we are dealing with a small catchment and therefore the interval between the time of occurrence of rainfall and the time of occurrence of  $Q_{\max}$  will necessarily be small.

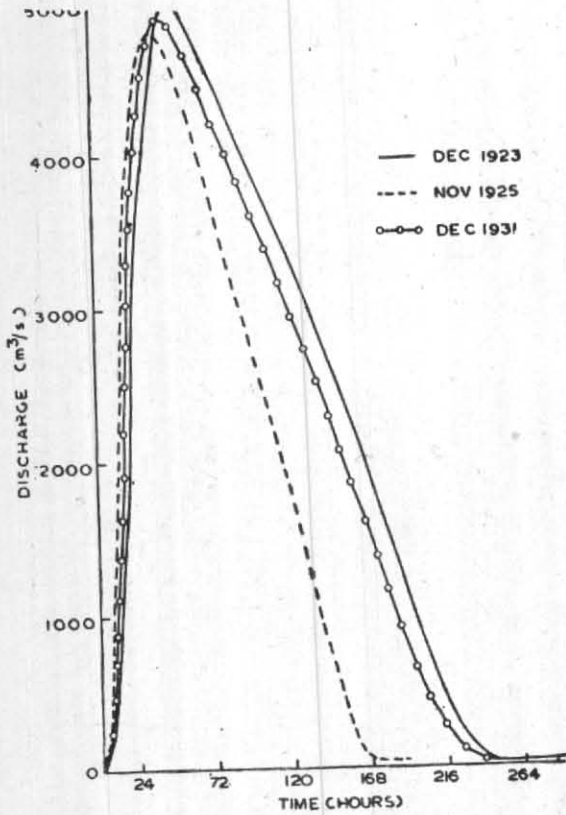


Fig. 3. Discharge hydrographs of floods in December 1923, November 1925 and December 1931

Note that the total duration of the floods was significantly less in November 1925 floods than in the December 1923 and December 1931 floods.

Figs. 5, 6, 7 and 8 show the isohyetal patterns of the rainfall in association with the November 1925 and December 1931 floods. In both these cases, the isohyetal average rainfall was higher on the first day (9th November in the 1925 floods and 10th December in the 1931 floods) than on the corresponding second day. These are also fairly obvious from isohyetal values shown in Figs. 5 to 8. It may further be noted that the  $Q_{max}$  was also recorded on the first day itself in both these cases of floods. Hence, unlike the December 1923 case, there is no difficulty in explaining in these cases, the times of occurrence of  $Q_{max}$  with reference to the times of occurrence of rainfall.

Table 5 shows the mean depth of rainfall and the volume of water released over the catchment in one day and two days of the rainstorms in the three cases of floods. The data clearly show that in the 2-day periods, the December 1923

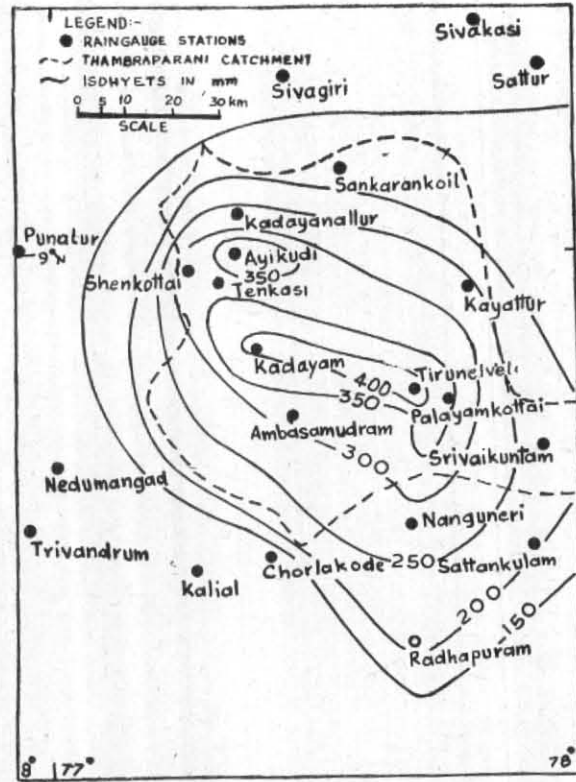


Fig. 4. Isohyetal Map, 16 and 17 December 1923

Compare with Figure 1 and note that the rainstorm centre has considerably shifted southeastwards, i.e., much nearer to the gauging site at Srivaikuntam.

TABLE 5

Spell	Mean depth of rainfall over catchment (mm)	Volume of water released over catchment (cubic metres)
16 Dec 1923	139.8	$630 \times 10^6$
16 & 17 Dec 1923	294.2	$1325 \times 10^6$
9 Nov 1925	183.0	$824 \times 10^6$
9 & 10 Nov 1925	247.8	$1116 \times 10^6$
10 Dec 1931	123.8	$558 \times 10^6$
10 & 11 Dec 1931	235.8	$1062 \times 10^6$

flood was most pronounced among the three cases, the November 1925 case ranking next and the December 1931 ranking still lower. These values are of the same order of magnitude as those computed for the floods in the Luni river in West Rajasthan (Ramaswamy 1971 b).

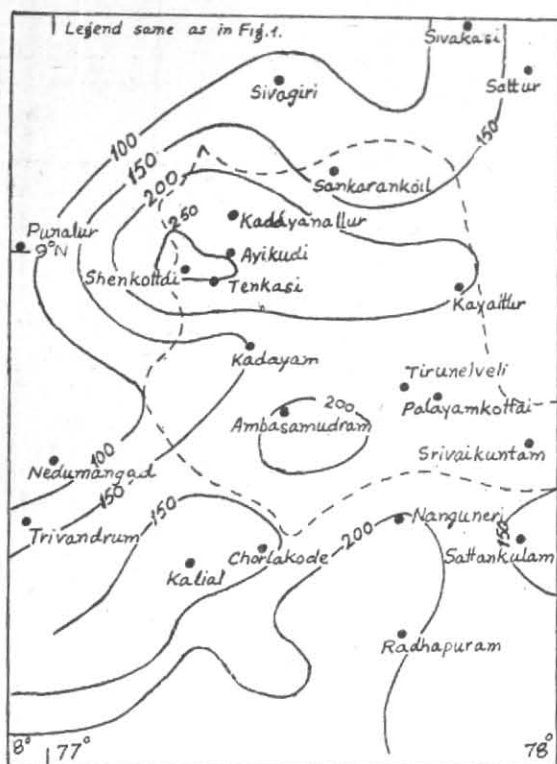


Fig. 5. Isohyetal Map, 9 November 1925

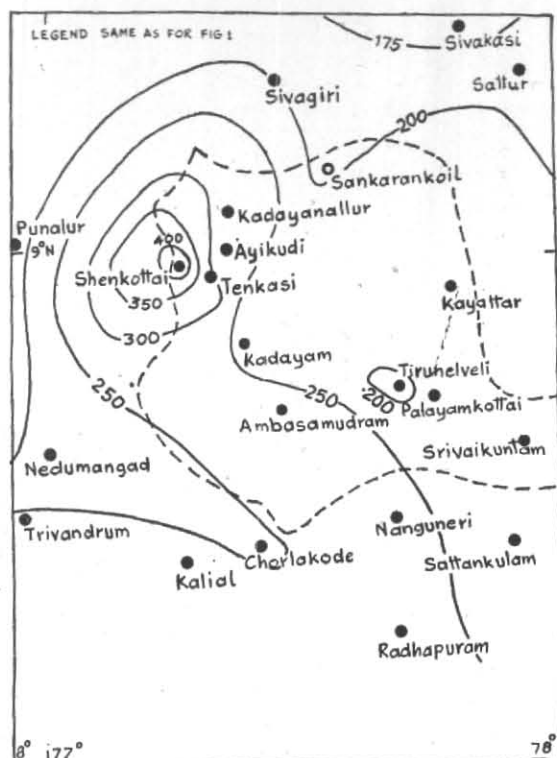


Fig. 6. Isohyetal Map, 9 and 10 November 1925

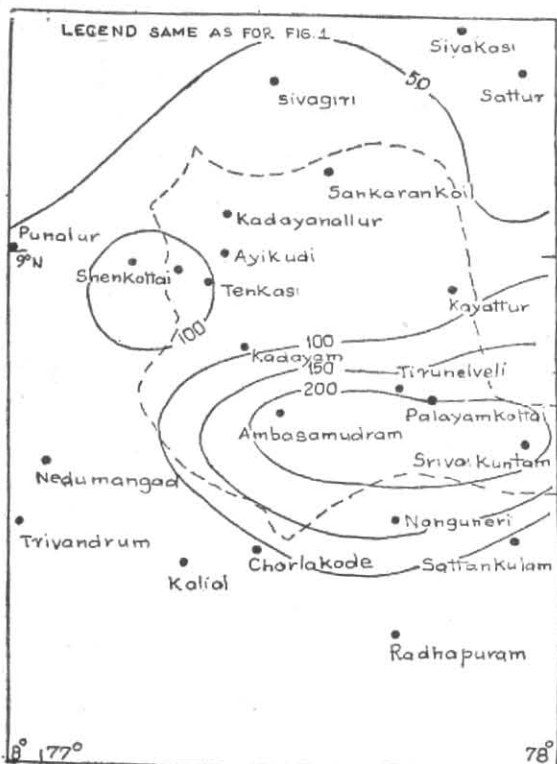


Fig. 7. Isohyetal Map, 10 December 1931

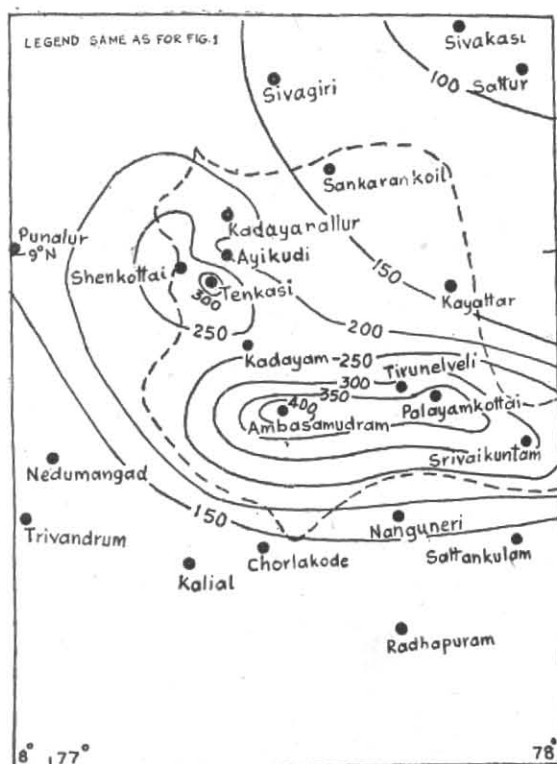


Fig. 8. Isohyetal Map, 10 and 11 December 1931



### 3.4. Mean depth of rainfall in the other spells in 1891-1960

We have so far discussed only 3 out of the 16 situations listed in Table 3 and shown that they led to large floods in the *Thambraparani*. Our study would however be incomplete if we do not include in the paper at least the mean depth of rainfall we had computed for the remaining 13 spells listed in that table. The figures of mean depth of rainfall over the catchment on two consecutive days, one of which was the day of heaviest rainfall, ranged in these 13 cases from 179 mm, in the December 1919 situation to 5.6 mm in December 1936 situation. We have however no information whether even floods of moderate intensity occurred in some of these cases.

### 3.5. Heavy rainfall and flood warnings

The very rarity of the occurrence of heavy rainfall and consequent floods in this catchment, make it very difficult for a forecaster to anticipate these developments and issue timely warnings against them. There is also a great probability of "crying wolf too often" when cyclonic storms are moving towards the Tamil Nadu to the south of latitude 12°N. We have, therefore, thought it worthwhile to make the following suggestions, based on our present investigation for the issue of warnings against heavy rainfall and floods in the Tirunelveli district in general and in the *Thambraparani* catchment in particular.

(a) When a low pressure wave begins to move westwards or westsouthwestwards across Sri Lanka, the forecaster should become alert. He should not wait for a depression to develop at sea level. Nor should he underestimate the consequences of a relatively small pressure deficiency observed near the centre of the system.

(b) He should watch the progress of actual rainfall over the north of Sri Lanka with westward moving low pressure waves approaching Sri Lanka.

(c) The forecaster should keep track of the movement of the region of maximum convergence between the easterlies and northerlies in the lower troposphere to find out whether this region has a tendency to shift into the Tirunelveli district. He can do this from the development of hydrometeors over that district, the sea level pressure changes in the south of the Peninsula besides the upper winds below 2 km asl. Any detectable high-level divergence over the same area should also be taken note of.

(d) Any tendency for a depression "to slip" southwestwards into the Gulf of Mannar is a very favourable condition for the development of heavy rainfall over the Tirunelveli district in general and over the *Thambraparani* catchment in particular.

(e) If a low pressure wave or a depression is expected to move into the Gulf of Mannar with its centre 1 to 2 degrees latitude to the south of Kanyakumari, the situation would well warrant the issue of warnings.

(f) Other conditions being the same, antecedent rainfall over the river catchment will make conditions more favourable for the development of floods. It is, however, important to remember that this is not an essential condition for the development of flash floods in the Tirunelveli district.

### 4. Summary of conclusions

The conclusions have been given in each of the different sections. However, a summary of the same is given below for the convenience of the reader.

(a) During a period of 70 years, there were only 16 synoptic situations which could possibly have caused large scale heavy rainfall and consequent floods over the *Thambraparani* catchment. Out of these 16 situations, there were only 3 in which heavy rainfall in 24 hours at any one station in the catchment, exceeded 200 mm. On all these 3 occasions, there were "Large Floods" in that river.

(b) For causing heavy rainfall above 200 mm in 24 hours in the catchment, it is not necessary that the large scale synoptic system need be a deep depression or a cyclonic storm. Even a low pressure wave or a depression with a pressure deficiency of 5 mb or less at the centre is sufficient, provided the centre of the system lies 1 to 2 degrees latitude to the south of the extreme tip of the Indian Peninsula and provided the system is moving westwards. It is in such situations that there is maximum lower tropospheric convergence in the moist stream in the field of the cyclonic system.

(c) All the three cases of large floods could be termed as flash floods. The peak discharges ( $Q_{max}$ ) were recorded within 36 to 48 hours of the times of commencement of rise in the water level in the river. The total duration of the floods did not exceed 240 hours in any of these 3 cases. In December 1923 floods, the peak discharge reached a value of 4993 cubic metres per second (176320 cusecs) in 48 hours of the time of commencement of the rise.

(d) In two (November 1925 and December 1931) out of the three cases, the greater part of the heavy rainfall which led to the floods occurred on the first day. In the third case (December 1923) the second day of heavy rainfall also contributed an important share to the flood situation.

(e) The volume of rainfall released over the catchment in a 2-day (consecutive days) period of rainstorms was 1326, 1116 and 1062 million cubic metres respectively in the December 1923, November 1925 and December 1931 floods. The flood elevation also reached a record value of

16.04 metres in the December 1923 floods.

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#### REFERENCES

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|---|-------|---|
| Bamford   | 1923  | Report on the Colombo Observatory for 1923, pp. 11-12.  |
| Bhaskara Rao, N. S. and Mazumdar, S.                | 1966  | <i>Indian J. Met. Geophys.</i> , <b>17</b> , 2, pp. 171-178.                                    |
| Central Water and Power Commission (Govt. of India) | 1971  | <i>Catalogue of Large Floods in India.</i>  |
| India Met. Dep.                                     | 1923  | <i>India Weather Review</i> , p. 106.   |
|   | 1962  | <i>Memoir XXXI</i> , III, p. 172.   |
|   | 1964  | <i>Atlas of Tracks of cyclonic storms and depressions in the Bay of Bengal and Arabian Sea.</i> |
| Ramaswamy, C.                                       | 1971a | <i>Vayu Mandal</i> , <b>1</b> , 4, p. 181.  |
|   | 1971b | <i>Ibid.</i> , <b>1</b> , 3, p. 139.  |
| Rao, K. N., George, C. J. and Ramasastri, K. S.     | 1971  | India. Met. Dep. Pre-published Sci. Report No. 136  |
| UNESCO  | 1970  | IHD-Report of Working Group on Floods and their computations—Annex. II.                         |