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SPACE-TIME DISTRIBUTION OF RAINFALL IN THE CATCHMENT OF YELERU RIVER DOWNSTREAM OF YELESWARAM

आपो हि ष्ठा मयोभुव

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ABSTRACT

Tropical cyclones affect India's coast during October-December and April-May seasons and a majority of these hit Andhra Pradesh coast. Cyclones cause damage due to storm surges, high winds and extensive rainfall. As most of the regions in the East Coast are low lying flat areas, flooding is the natural disaster occurring in these areas. Although floods do not claim as many lives as do storm surges, they affect the residential areas, transportation, telecommunication and agricultural areas to a very large extent. Floods created by tropical cyclones can reach catastrophic proportions when aggravated by wind induced surges along the coastline.

The magnitude of peak flood and shape of the flood hydrograph depends not only on the magnitude of the total storm rainfall but also on its distribution in space and time. Improvements of the accuracy and timeliness of hydrological forecasting would thus largely depend on the prediction of rainfall distribution in space and time. As the rainstorms associated with the cyclonic storms are likely to produce a somewhat different picture, which generally exceeds 24-hr. and covering vast areas, it was found necessary to study this aspect in the study area, which is prone to regular cyclonic storms. An attempt has been made to study the space and time distribution of rainstorms associated with the tropical cyclones in the Bay of Bengal over a period of 20 years from 1976 - 96.

<u>The study broadly indicated that</u>

- From the Spatial variation analysis of the selected heavy rainstorms occurred over the study area during 1976-96, it reveal that the rainstorms of 23 July, 1989 (1- day), 9-11 May 1990 (2-day and 3-day), have contributed the highest average rainfall depths of 254.8 mm, 483.8 mm and 682.6 mm for 1,2,3 day duration respectively.
- From the Temporal variation analysis of the selected rain storms occurred over the study area, it has been observed that 50 percentage of the rainfall in a storm spell occurred in the 25 percentage of the storm duration and the remaining 50 percentage of the rainfall occurred in the remaining 75 percentage of the storm duration.
- From the Isohyetal maps it has been observed that rainfall is concentrated in lower part of the study area and decreasing towards the land, i.e., towards the upstream of the river catchment.

- The flood/inundation problem is coupled with the favorable antecedent soil moisture condition, as most of the storms occurred in post-monsoon season.
- The heavy storms of duration more than 24 hours concentrated over the study area are very conducive for causing floods and consequent inundation.
- The study area experienced heavy rainfall after the cyclonic storm crosses the coast.

1.0 INTRODUCTION

In India, large parts of the country receive most of the annual rainfall during June to September constituting the summer monsoon or southwest monsoon season. It is of common knowledge that the tropical disturbances, popularly known as storms or cyclones originate in the Bay of Bengal and Arabian sea prior to, during and after the monsoon season and move in a north-northwest or westerly direction.

The total coastline of Andhra Pradesh is about 700 km. Coastal Andhra Pradesh receives monsoon rainfall of 58 cm, which is about 58% of its mean annual rainfall and receives 32 % of its mean annual rainfall during the post-monsoon season. On average four cyclones develop over the Bay of Bengal in a year and generally one hits the coast of A.P.

Floods and consequent inundation, which is a recurring phenomenon, has been well known to mankind since the dawn of civilization. Losses due to these unprecedented events have continued to grow with the increasing influence of man's activities like encroachment of the natural drainage space thereby influencing the hydrologic cycle. Precisely in the coastal districts of Andhra Pradesh it has been observed from the past records that these flood and subsequent inundation disasters are associated with the tropical cyclones / depressions originating from the Bay of Bengal. The monsoon depressions/cyclonic storms have attracted notice from early times because of high precipitation potential with very heavy to exceptionally heavy falls and wide spread distribution and consequent floods and inundation disasters in coastal plains. Rainfall of 200 mm or more in a 24-hr duration are not uncommon during these depressions which cause heavy floods and inundation of the low lying areas.

Cyclones in association with torrential rains, hurricane winds and tidal waves cause considerable damage like most other natural disasters. The worst damage occurs while the storm crosses the coast, especially on low relief areas. Deltas being the zones of large concentration of population are affected to a great extent.

Unlike the storm water resulting from rainstorms during monsoon season, these cyclonic storms produce runoff almost instantaneously, due to the prevailing wet antecedent soil moisture conditions. It is well known that the runoff hydrograph from a catchment due to a rainstorm depends not only on the total storm rainfall but its distribution in the space and with time. The influence of rainfall movement on the magnitude of peak flood and the shape of the hydrograph has come to be recognized for quite some time now. The direction of storm movement has considerable effect on an elongated catchment and more so if the area is large also. It has been seen that the same amount of rain over the same period, produces a much greater peak when the storm is moving down the valley than when it is moving up the valley, since the rainfall becomes runoff long before the storm reaches the top of the catchment.

To arrive at the magnitude of flood occurrence in streams and the maximum discharge from the drainage area, both the factors namely intensity of the storm, its duration and area are the important factors and therefore the engineer must again have recourse to the rainfall records.

The rate and space distribution of rainfall from a watershed is the result of the combined effect of physiographic and climatic factors. The main physiographic factors are, geometric properties of the watershed, land-use characteristics, soil type, geologic structure and the characteristics of drainage channels (geometry, slope, roughness, and storage capacity). Important climatic factors include: the form, type, time distribution of precipitation, the characteristics of the regional vegetal cover, prevailing evapotranspiration characteristics, and the status of the soil moisture reservoir.

The main source of moisture for precipitation is evaporation from the surface of large bodies of water. Therefore precipitation tends to be heavier near the coastlines. Normally, with winds prevailing from the shore, the precipitation will decrease slowly towards the interior, except at places where the topography is steep. Precipitation also varies with respect to time. The information on spatial variation of rainfall and temporal variation of rainfall intensity is extremely important in determining the stream flow from precipitation, for the design of various water resources projects.

Many engineering projects, such as flood protection works, size of spillways, flood gates in dams etc. which are often affected by the possible maximum flow in streams are often dependent on the knowledge of the intensity and distribution of the maximum rainfall which is expected and the flood flows that will result there from. While the flood flow volume in all such cases depends on many factors, the most important one is the amount of rainfall that may occur on the area under consideration within a given period of time.

The designing of hydrologic structure depends on the intensity, duration and sequence of rainstorms and their distribution over the catchment area in successive time intervals. The peak flood hydrograph determines the time lag between the occurrence of rainfall and peak flood discharge. The successive spells of rainfall play an additive role in the peak discharge if they occur during the period of time lag. Therefore, for a given time lag for the peak flood discharge, designers are most concerned on the time distribution of rainfall that can provide accumulated effect on the hydrograph. This factor is most vital for designing of all types of hydrologic structures in a catchment.

The actual maximum runoff from a given area is always the best information to be used as a basis for the solution of such problems. Nevertheless, such knowledge is seldom collected until a need for such information arises. However, the precipitation statistics for a considerable period at stations where the conditions are sufficiently similar may be referred to warrant conclusions based on the same. A study of such records often becomes essential for the solution of some problems where runoff data is not available.

2.0 REVIEW

Individual rainstorms contribute widely differing amounts of rain. The variation of precipitation in space and time is largely determined by spatial and temporal variations in the vertical motion of air. This vertical motion results from processes within the atmosphere and interaction between the atmosphere and the underlying surface of the earth.

In 1954, Central Board of Irrigation and Power (CBIP) passed a comprehensive resolution on rainfall analysis for the development of water resources. Emphasis was specially laid on the analysis of major rainstorms of the country with a main aim to obtain the Depth-Area-Duration (DAD) data for different parts of the country.

Satakopan (1950) was one of the earliest meteorologists of this country who carried out storm analysis using DAD technique. He analyzed major rainstorms of south Bihar and Gangetic West Bengal for the development of water resources of Damodar Valley, where a chain of dams was being planned. Parthsarathy(1959), using rainfall data of the country up to 1955, selected 5 severe rainstorms in different parts of the country and analyzed them and prepared their DAD curves. Raman and Dhas (1966), after analysing nearly 200 rainstorms of M.P. and Bihar found that rainstorms of August 1917 and September 1926 were the most severe rainstorms, on consideration of DAD analysis. For the first time, Dhar and Bhattacharya, (1975) prepared comprehensive DAD data of all the major rainstorms of North India. In recent years, rainstorms of A.P. and Maharastra were also analyzed and their results where published (Dhar et al 1989, 1990).

Several researchers have studied rainfall associated with cyclonic storms and depressions. Results of the most of the earlier works are based on case studies (Pisharoty and Asnani 1957, Mukherjee et al. 1982 etc.,). C.M. Mohile and D.A. Mooley (1984), have studied maximum rainfall in the different zones along the coast on either side of the point (p) were the storm struck normally. Rainfall associated with post-monsoon cyclonic storms during the period 1877 - 1980 striking two sections (10.5 N to 15.5 N and 15.5 N to 20.4 N) of the coast on the day of crossing as well as one and two days prior to the day of crossing were analyzed. The regions of maximum rainfall extend for longer distances north of 'p' than to the south.

Ramasastri. K.S. , analyzed some hydrometeorological aspects of October 1983 storms over Andhra Pradesh. Dhar et al (1989), using Depth-area-duration (DAD) analysis, analyzed severe rainstorms of Andhra Pradesh and found that, for one-day duration rainstorms of May ,1952; July, 1965 and

August, 1986 contributed highest rain depths over different size areas upto 15,000 sq. miles but for 2 and 3-day duration, the rainstorm of August, 1986 yielded the highest rain depths from point value to 15,000 sq. miles of area. This study has shown that rainstorm of August, 1986 was the most severe rainstorm over Andhra Pradesh and as such DAD data of this rainstorm can be utilised for the PMP estimation of river basins in Andhra Pradesh.

Dhar et al (1966), made a study of rainfall cver the Teesta basin based on 5 year of rainfall data. A detailed rainfall study of rainstorm of North Bengal as a whole has been carried out by Abbi et al. (1970),. Gupta and Abbi (1972), have further studied in detail, the rainfall depth in various river catchments of North Bengal including the estimation of average catchment precipitation and computations of rainfall of different magnitudes for different return periods. Biswas and Bhadram (1984), have studied rainfall distribution of major rainstorms and their associated synoptic conditions over the entire Teesta basin from its origin in Sikkim up to Indo-Bangladesh border.

In recent papers (Dhar and Nandagiri 1993), (A & A), it has been shown that using the severe rainstorms data of the period 1880 to 1990, severe rainstorms occurred in certain preferred zones of areas. They have also worked out envelope DAD rain depths for these zones in order to know the distributions of average area rain depth magnitudes of these severe rainstorms. It has been observed that practically all the past severe rainstorms in this country are associated with cyclonic disturbance either from the Bay of Bengal or Arabian Sea.

3.0 PROBLEM DEFINITION

All the coastal areas and deltas face many hydrological problems of engineering importance. Poor drainage and extensive flood damage, submergence to a depth of about 5 m during hurricanes or cyclones is not uncommon in deltas. To mitigate these problems it is necessary to understand the rainfall distribution in space and time in the concerned area. Cyclones are amongst the frequent and devastating natural disasters affecting the coastal belts of A.P.

Cyclonic storms affecting India originate either in the Bay of Bengal as low pressure systems in the pre-existing seasonal trough of low pressure or enter into Bay of Bengal from the South China sea. It depends on the season and latitude of their formation. The low pressure areas originating in the Bay of Bengal intensify and move towards the coastal areas of the Indian sub-continent following typical tracks. Nearly 70 percent of the cyclonic storm over Indian seas are of the size whose diameter is between 600 and 1200 km. Most of these storms occur in the post-monsoon season, i.e., from October to December. The pre-monsoon storms occurring in the months of April and May are generally smaller with diameter varying between 400 to 800 km. The rainfall resulting from these storms also exhibits variability, not only in distribution in time and space but also in the number of rain spells at a station and the duration between these spells.

Briefly the causes of flood and inundation in the study area can be summarized in the following points :

1. Yeleru river discharge from reservoir
2. Wide speared rainfall associated with cyclonic storms
3. Combination of both the above factors

Under irrigated conditions, the farmers adopt uncontrolled irrigation due to which excess water, more than the capacity is added to the ground water table. Sometimes water-logging occurs in low lying areas due to seepage taking place from the irrigated uplands and from the canal system. Also the obstruction of natural drainage by roads, railways and other structures with poor or choked cross-drainage facilities causes the pounding of monsoon runoff thereby creating water logging in the fields. This is due to the negligence shown towards the surface hydrology aspect. Although irrigation and drainage should go hand in hand for proper utilization of water , the drainage aspect has not been given the due attention in the study area.

In the study area open head irrigation practice exist ,they also plays an important role in causing flood. The tanks are age old tanks with old surplus weirs that are mostly broad crested or narrow crested . When there is very heavy intensity of rainfall , if the weirs are found inadequate the bounds breaches. And in case of system tanks and tanks in a chain , the breaching of upper tanks lead to breaching of lower down tanks also, resulting in floods in the area. The problem of inundation and water logging is also there because of drainage congestion in channels and rather flat slopes of coastal plains.

As the study area is prone to frequent cyclonic storms and heavy rains which results in floods and inundation, it is therefore deemed necessary to study the space and time distribution of rainfall associated with cyclonic storms.

4.0 DESCRIPTION OF STUDY AREA

4.1 YELERU RIVER CATCHMENT

The Yeleru river originating in Sanbara Konda hills of Chintapalli Taluq of Srikakulam District, after traversing nearly 120 kms. east, divides into a number of branches. It joins the Bay of Bengal through West Yeleru / Upputeru, while other branches vanish into the delta region or join certain depressions. There are no well defined courses and proper drainage in its delta. The total catchment area of 2941 sq. kms. lies entirely in Andhra Pradesh. A number of open head channels (about 368 nos.) take off from the river, which serves an ayacut of 44,200 ha. (10,931 acres). The Yeleru reservoir is contemplated across Yeleru river near Yeleswaram Village in East Godavari District in Andhra Pradesh. The project serves both irrigation and industrial needs for meeting the requirement of water for Vishakapatnam Steel Plant at Vishakapatnam. The index map of the study area and the map showing the Yeleru river catchment are given as Fig.1 & Fig.2 respectively.

4.2 STUDY AREA

4.2.1 Description:

For the present study, the area chosen is Yeleru River Catchment downstream of Yeleswaram reservoir project, which is physiographically a deltaic plain. The study area is located between latitude $17^0 00'$ to $17^0 15'$N & longitudes $82^0 00'$ to $82^0 15'$E. The total study area is about 745.4 sq. km., which lies entirely in East Godavari district of Andhra Pradesh. The location of the study area is shown in the Fig. 3.

The study area lies in the normal tracks of monsoon depressions and low pressure areas originating over Bay of Bengal. A few selected tracks of cyclonic storms during 1989,1990 and 1995 are shown as Fig. no. 4 to 6. The depressions and low pressure areas constitute the chief synoptic features which cause vigorous monsoon conditions (and hence potential flood producing condition) in the catchment.

The frequent cyclonic storms and heavy monsoon rains occurring in the study area cause extensive damage to the public property. River banks as well as canal embankments are overtopped due to silting of channels. River embankments are eroded and often breached and tanks are silted up or breached.

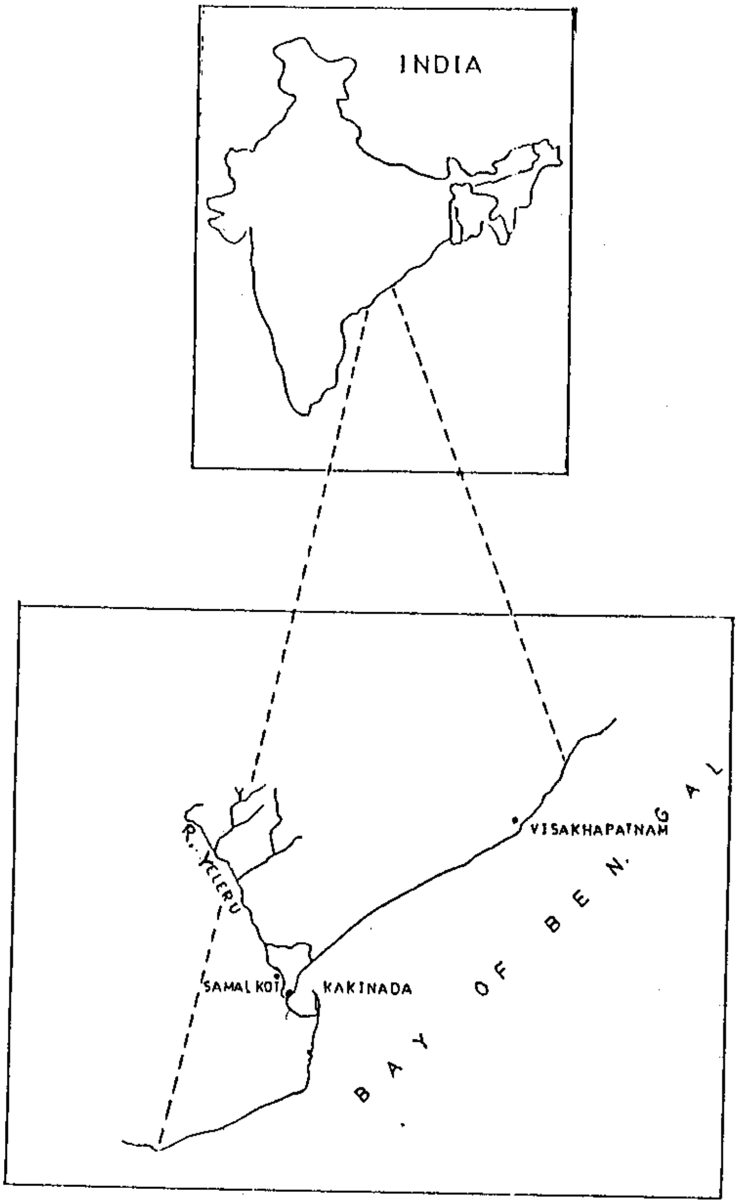


FIGURE 1: INDEX MAP

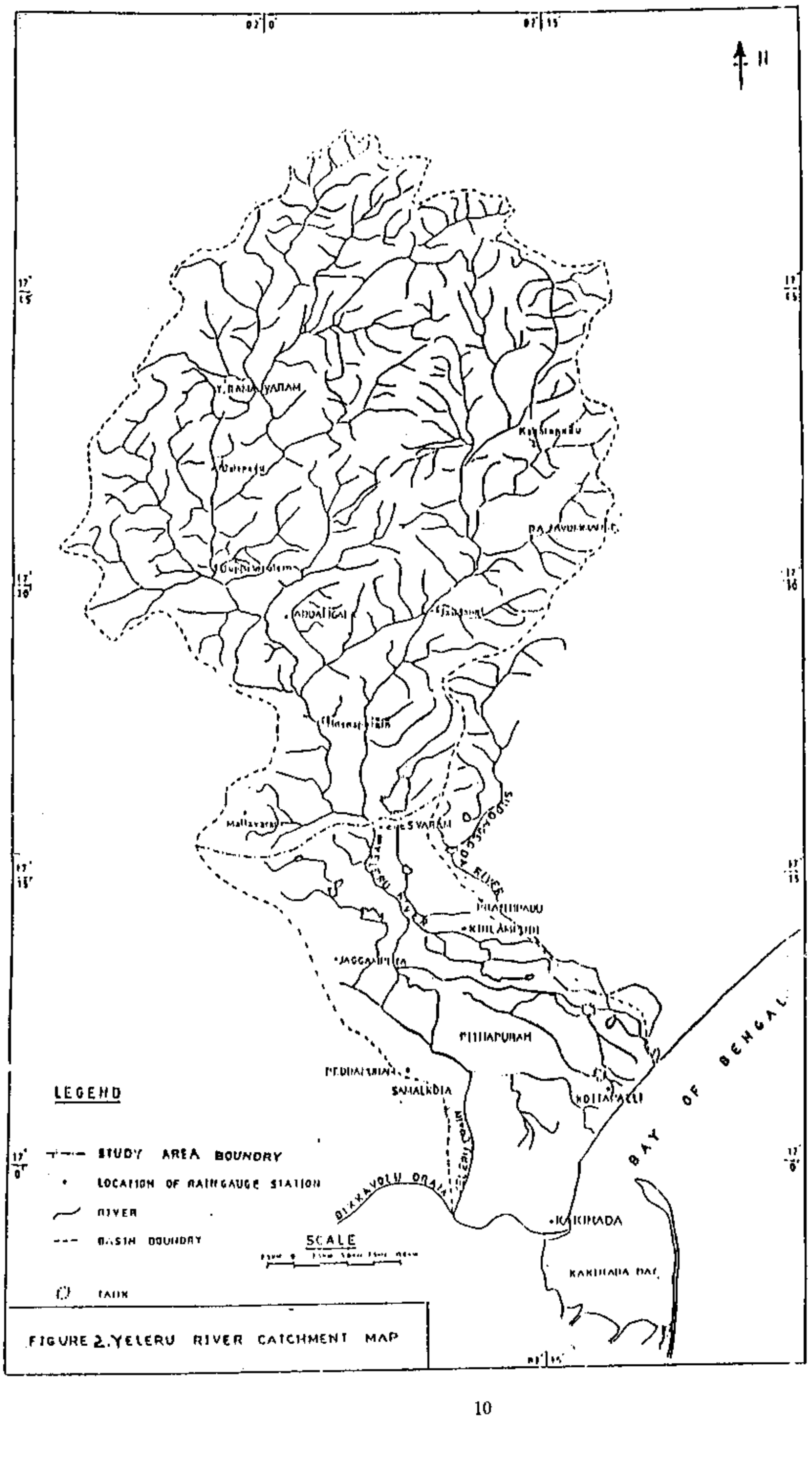


FIGURE 2. YELERU RIVER CATCHMENT MAP

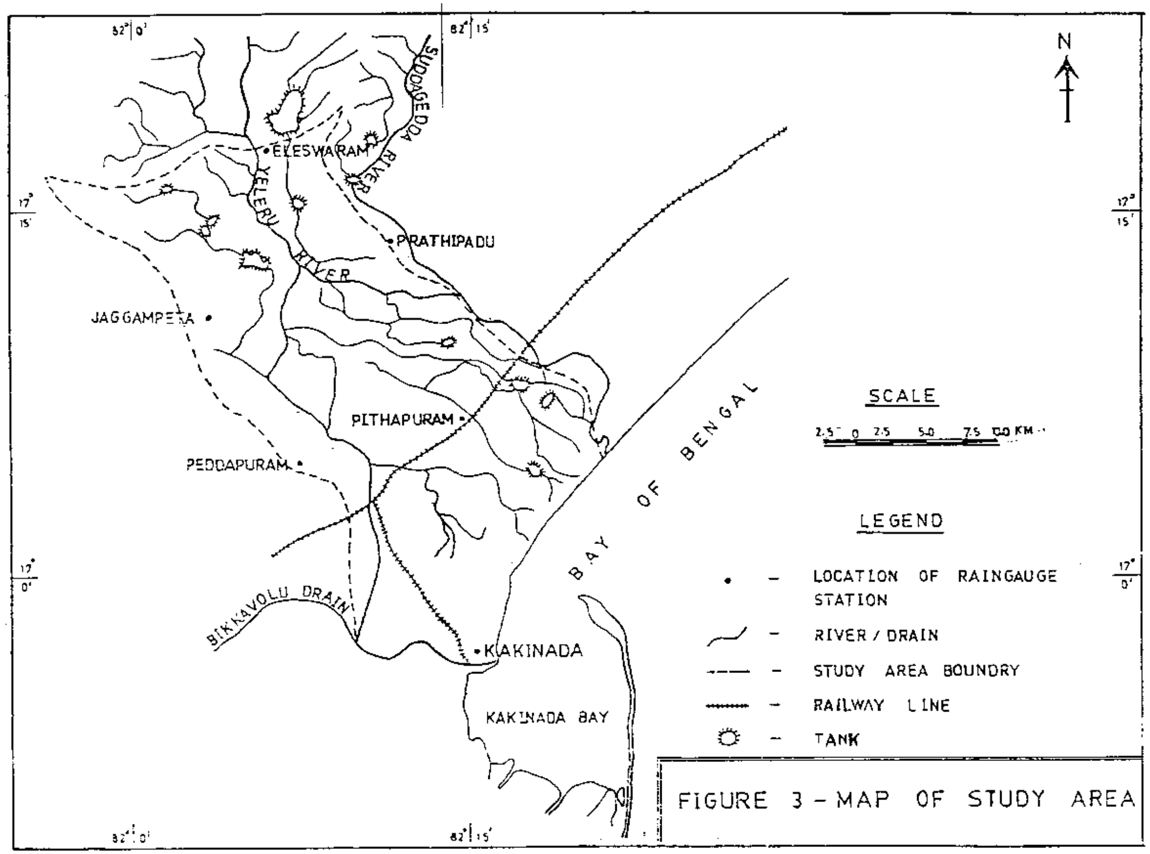


FIGURE 3 - MAP OF STUDY AREA

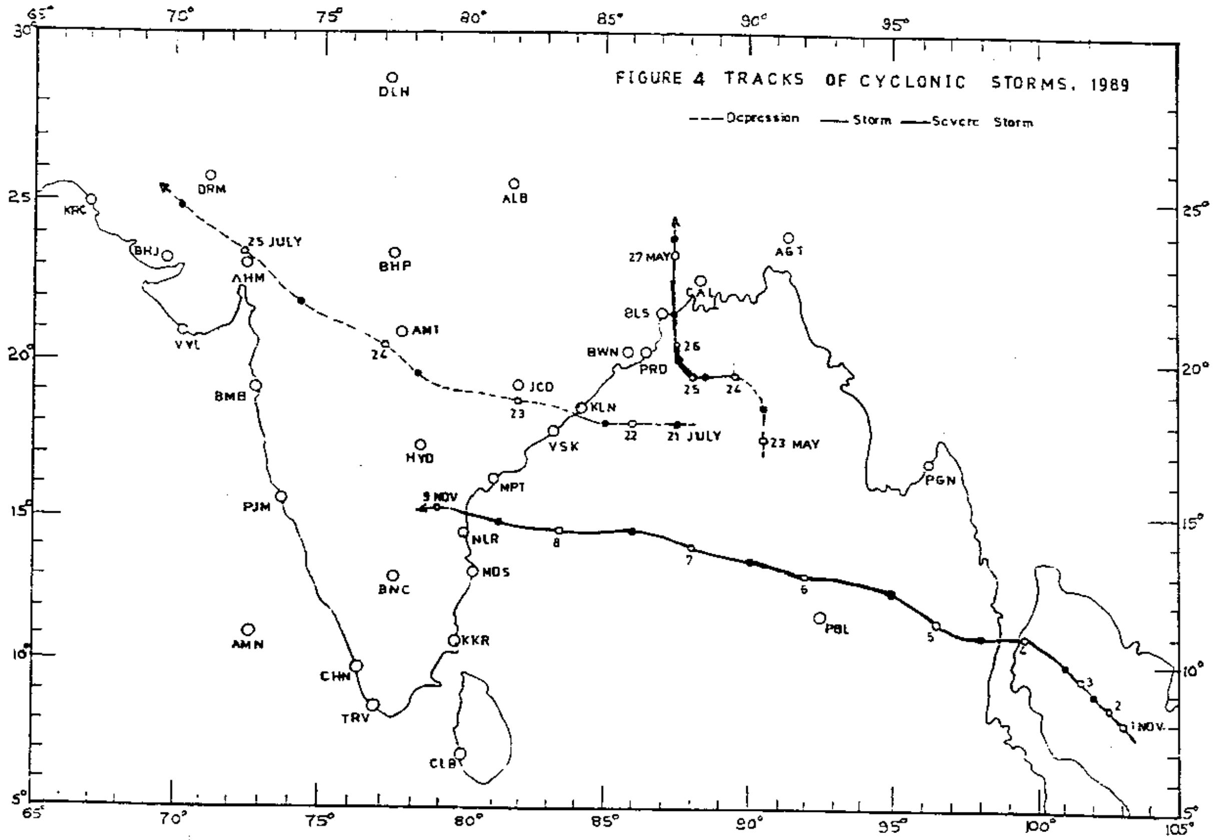


FIGURE 4 TRACKS OF CYCLONIC STORMS, 1989

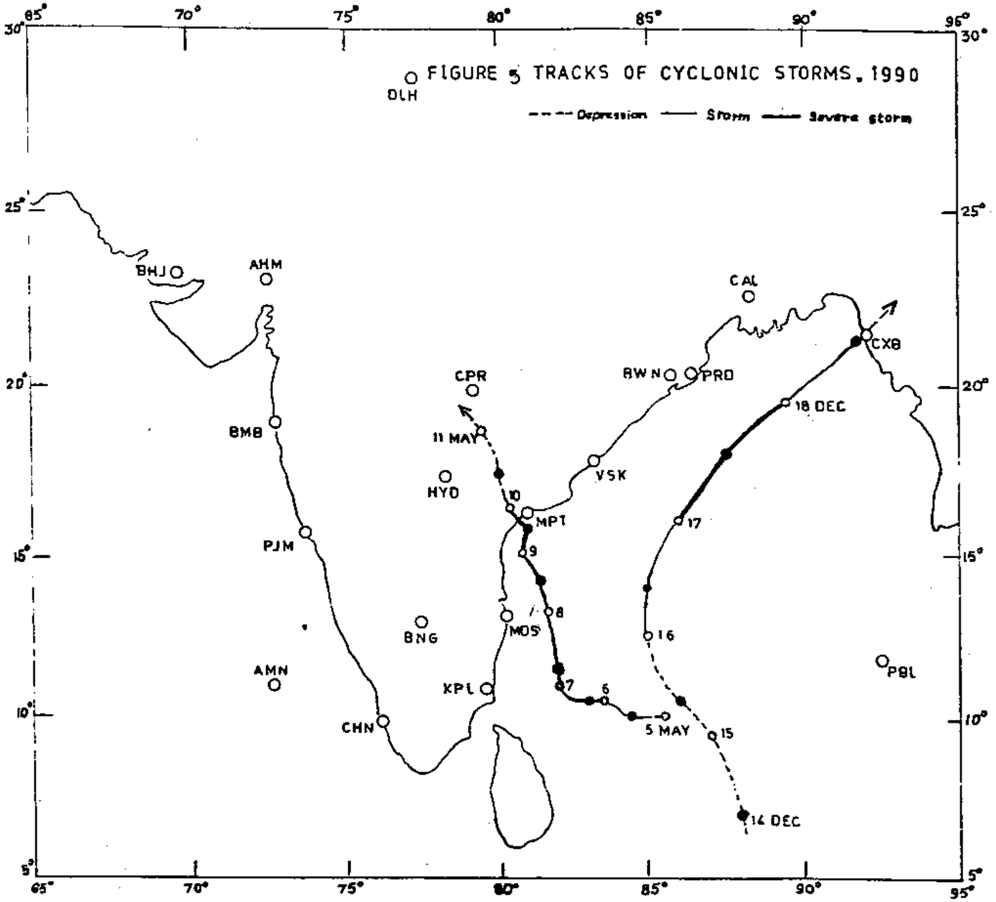


FIGURE 5 TRACKS OF CYCLONIC STORMS, 1990

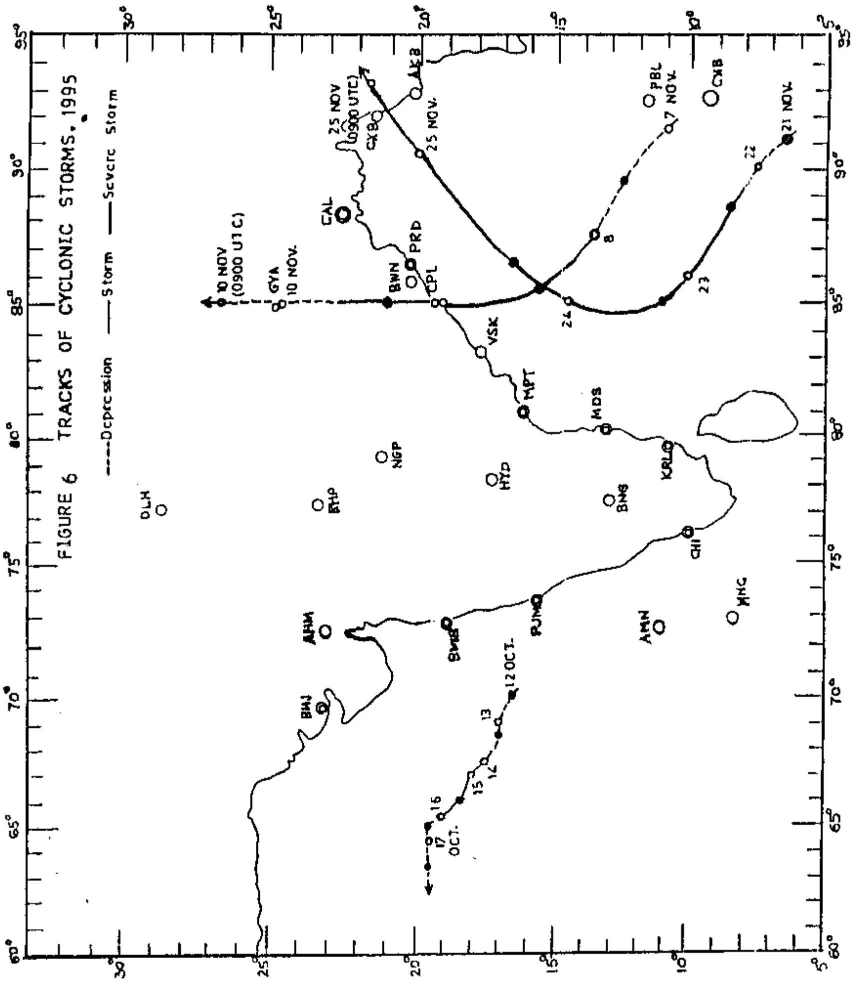


FIGURE 6 TRACKS OF CYCLONIC STORMS, 1995
Depression
Storm
Severe Storm
DLH
BHP
NGP
HYD
BNG
MDS
KRL
CHI
AMN
MNG
AHM
BHJ
BMB
PJM
MPT
VSK
CPL
BWN
PRD
CAL
GYA
10 NOV (0900 UTC)
10 NOV.
25 NOV (0900 UTC)
25 NOV.
CXB
AKB
PBL
CNB
7 NOV.
8
21 NOV.
22
23
24
12 OCT.
13
14
15
16
17 OCT.

4.2.2 Raingauge Network

In the study area ,there are 4 raingauge stations in 1976 and 6 in 1996. The list of the raingauge stations along with the data availability is given in Table no.: 1. Out of these raingauge stations, the station at Kakinada is maintained by the IMD dept., and the remaining are under the control of state government agencies.

4.2.3 Climate

The region has a humid tropical climate with an average rainfall of over 1000 mm . Most of the rains, however occur during the months from July to November from the heavy downpour caused often due to the cyclonic disturbances. The south-west monsoon contributes 58 % of annual rainfall.

In general, high humidity prevails throughout the year in the area. Winds are of moderate strength throughout the year becoming stronger during monsoon season (15 km. per hour) and weaker in October (5-10 km.), except during occurrence of cyclones. From October to **January** winds blow south-west during the summer monsoon.

The temperature starts rising gradually throughout from February onwards but the rise is well marked in March and it continues till the end of May, which records the maximum average temperature. During the post-monsoon season and in the early part of the North-east monsoon, the storms and depressions originating in the Bay of Bengal affect the weather of the region. Some of these depressions intensify into severe cyclonic storms with strong winds and squalls (80-140 km/h) causing heavy rainfall in the region and considerable dislocation to communication and loss of life and property.

The Bay depressions bring in the monsoon by the first week of June. Series of such depressions sweep over the region during June- October and cause heavy to moderate rainfall with July & August emerging as the rainiest months. The withdrawal of the monsoon by mid-October is followed by a short transition between the rainy and the cold season (post-monsoon season). The commencement of the rainy season (June) and the end of the rainy season (September/October) are associated with more thunderstorms than the rainy months of July and August. High relative humidity (70 % and above) along with high and

Table No. 1 : Raingauge network and rainfall data availability in the study area

Sl. No.	Name of the Raingauge station	Data type	From	To
01	Kakinada	Daily	June 1976	May 1996
02	Kakinada	Hourly	During the selected storm spells as given in the table no. 5	
03	Peddapuram	Daily	June 1976	May 1996
04	Pithapuram	Daily	June 1976	May 1996
05	Prathipadu	Daily	June 1976	May 1996
06	Yeleswaram	Daily	June 1982	May 1996
07	Jaggampeta	Daily	June 1990	May 1996

almost uniform temp 35° C and heavy downpour are the characteristics of the season . The climate is often hot humid during rainy season.

In the region maximum rainfall occurs during the south-west monsoon period from June to September. The south-west monsoon normally sets over the region in the first week of June and withdraws in the first week of October. During this period low pressure systems form in the Bay o Bengal which further intensifies into depressions and these cyclonic storms cross the coast and move inland in an westerly or north-westerly direction. When these systems lie over or near the A.P. coast, heavy rainfall occurs particularly in the lower and the adjoining parts of the catchment. After crossing the coast the depressions/cyclonic storms generally weaken but in the course of their movement through A.P. and adjoining regions, widespread rains occur over the catchment whenever the tracks of these depressions/storms lie over the catchment.

5.0 METHODOLOGY & ANALYSIS

5.1 SPATIAL VARIATION OF RAINFALL

5.1.1 Selection of rainstorms

The rainstorms were selected by an inspection of daily rainfall data of all the raingauges in the study area. Rainfall data of stations before 1976 were not readily available and as such the study was confined to the period 1976-1996. The following criteria were adopted for the selection of rainstorms.

1-day: Arithmetic average rainfall of 50 mm and above over the catchment.

2-day: Arithmetic average rainfall of at least 50 mm on one of the days and more than 50 mm on the preceding or succeeding day of the storm.

3-day: Arithmetic average rainfall of at least 150 mm on one of the days, more than 100 mm on preceding or succeeding day and more than 100 mm on the third (any) day in a continuous spell of 3 days.

On the basis of the above criteria, 19 storms of duration ranging from 1-day to 3-day were selected for the analysis with study area as a unit. The average rainfall depths of selected rainstorms experienced over the study area are given as table no.: 2.

5.1.2 Methodology & Analysis

To study the characteristic of the rainstorm namely, areal extent, two methods of analysis normally used are Depth-Duration and Depth-Area-Duration analysis. The Depth-Area-Duration analyses were carried out for the present study, using the daily rainfall data of five stations falling in the study area for the selected rainstorms. The study area centered Depth-Area-Duration analysis for the storms over the study area was carried out.

The isohyethal maps of 1-day, 2-day, and 3-day duration for all the selected storms are drawn, and some of them presented as Fig. No. 7 to Fig. No. 18. Out of these 19 selected storms, 8 are of one day duration, 8 are of two days duration and 3 are of three days duration. The month wise distribution of selected rainstorms of different duration is presented in Table no.: 3. Evidently rainstorms of one day and two days duration are most frequent and no storm of more than three days duration occurred over the study area.

TABLE : 02 THE ARETHEMATIC AVERAGE RAINFALL DEPTHS OF SELECTED RAINSTORMS EXPERIENCED OVER THE STUD AREA

SL. NO.	STORM PERIOD	AVERAGE RAINFALL(mm)		
		1st Day	2nd Day	3rd Day
01	26 NOV 1976	123.7	102.6	
02	20-21 NOV 1977	161.8	100.7	
03	17 JUN 1978	111.8		
04	13 MAY 1979	122.8		
05	25-26 NOV 1979	54.0	154.6	
06	18-19 OCT 1980	87.8	55.5	
07	8-9 AUG 1983	63.6	60.6	
08	4-5 OCT 1983	64.6	68.9	
09	11 SEP 1984	58.2		
10	11 OCT 1985	78.0		
11	12-13 AUG 1986	110.8	105.7	
12	16 OCT 1987	127.7		
13	29 JUL 1988	110.6		
14	23 JUL 1989	244.1		
15	9-11 MAY 1990	194.5	228.9	193.2
16	16 NOV 1992	69.4		
17	1-2 NOV 1994	89.4	70.0	
18	9-11 MAY 1995	134.4	189.5	129.1
19	9-10 OCT 1995	91.8	51.6	

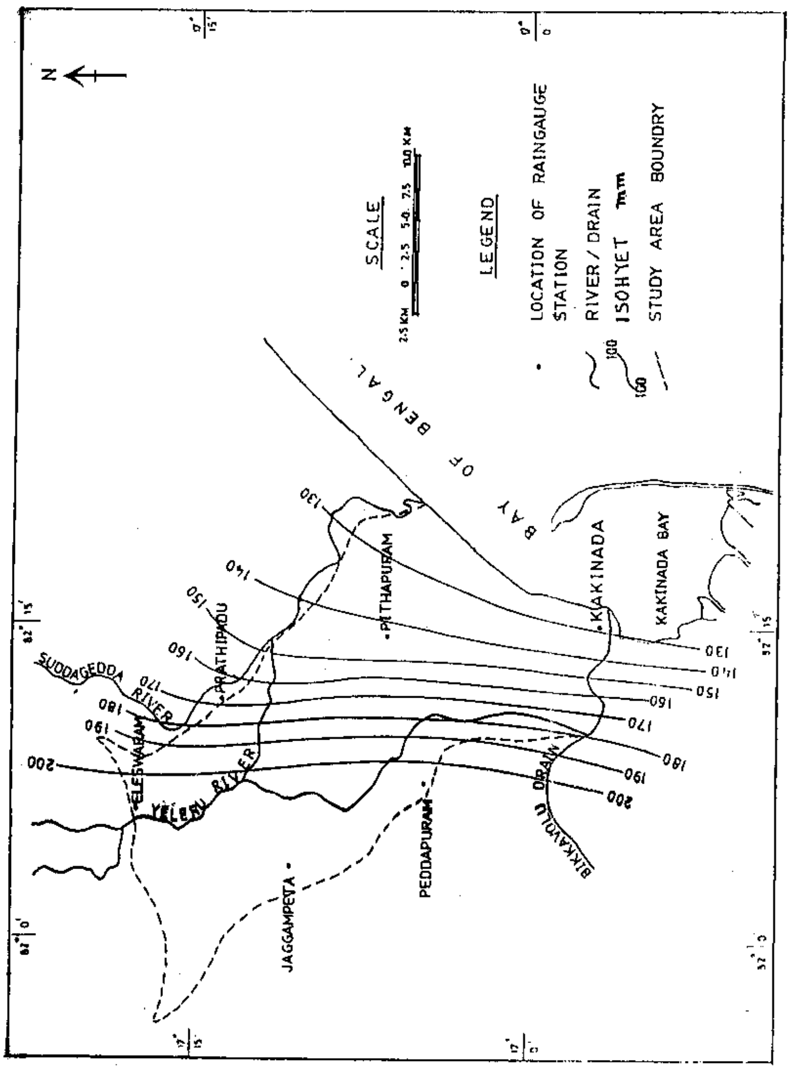


FIGURE 7 - ISOHYETAL MAP OF THE 20 NOVEMBER, 1977 RAINSTORM

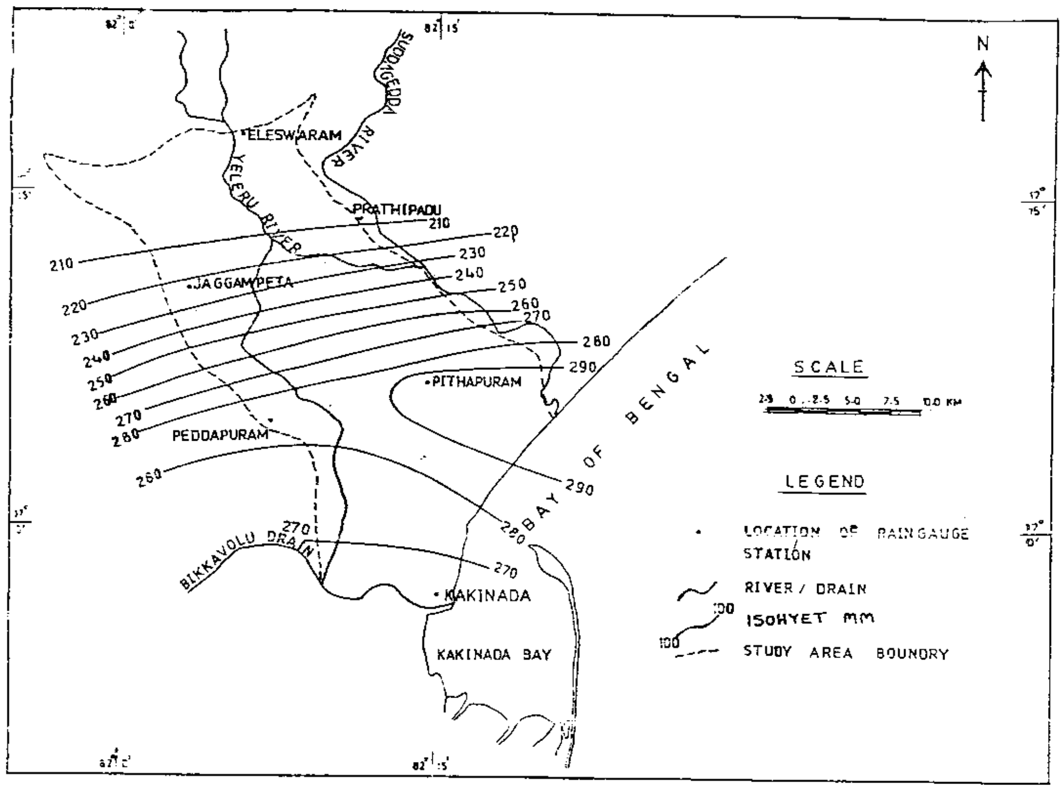


FIGURE 8 - ISOHYETAL MAP OF THE 20-21 NOVEMBER, 1977 RAINSTORM

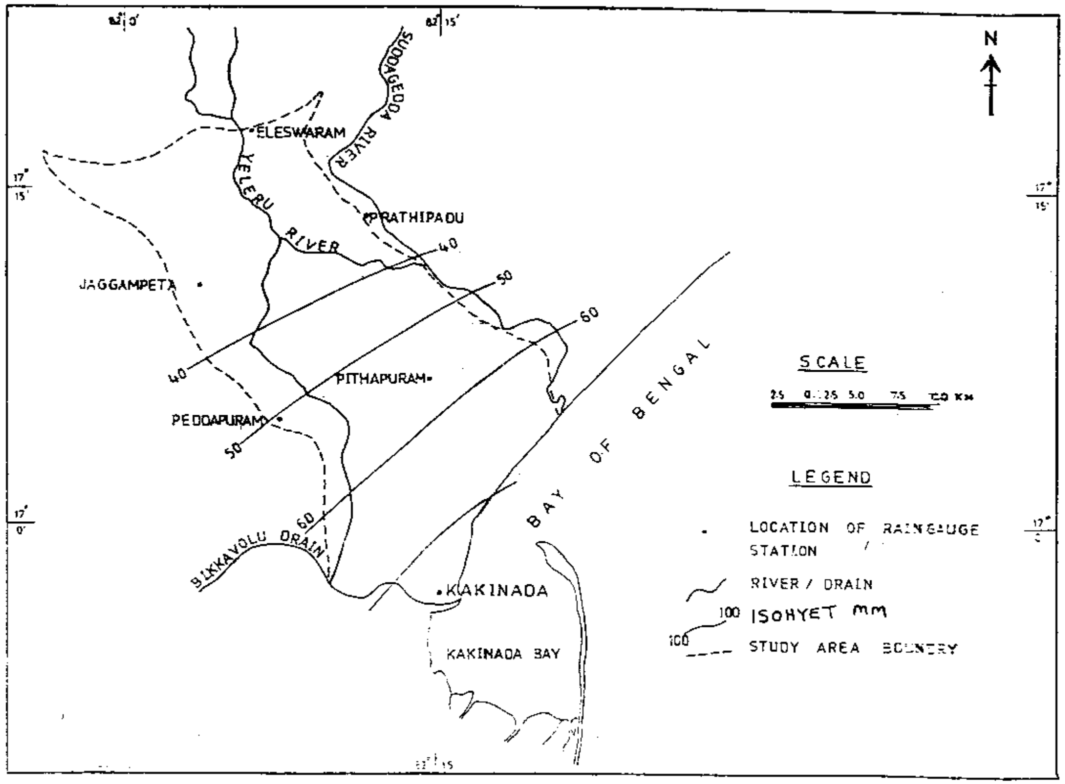


FIGURE 9 -ISOHYETAL MAP OF THE 25 NOVEMBER, 1979 RAINSTORM

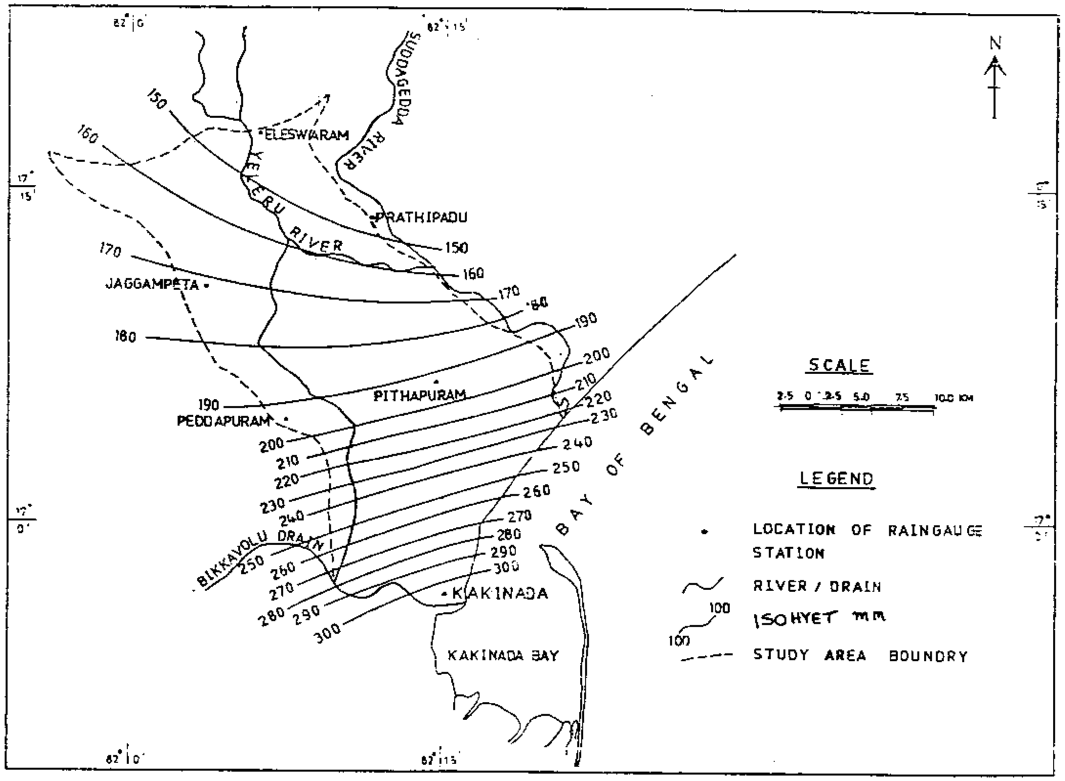


FIGURE 10 - ISOHYETAL MAP OF THE 25-26 NOVEMBER, 1979 RAINSTORM

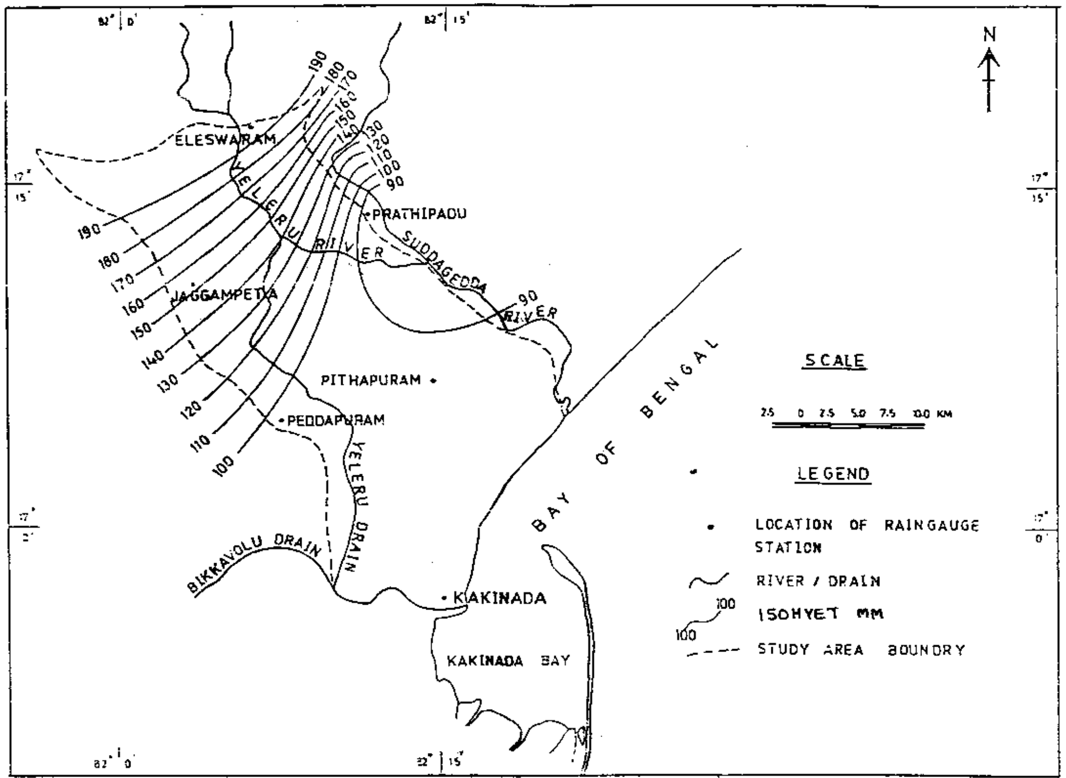


FIGURE 11–ISOHYETAL MAP OF THE 12 AUGUST, 1986 RAINSTORM

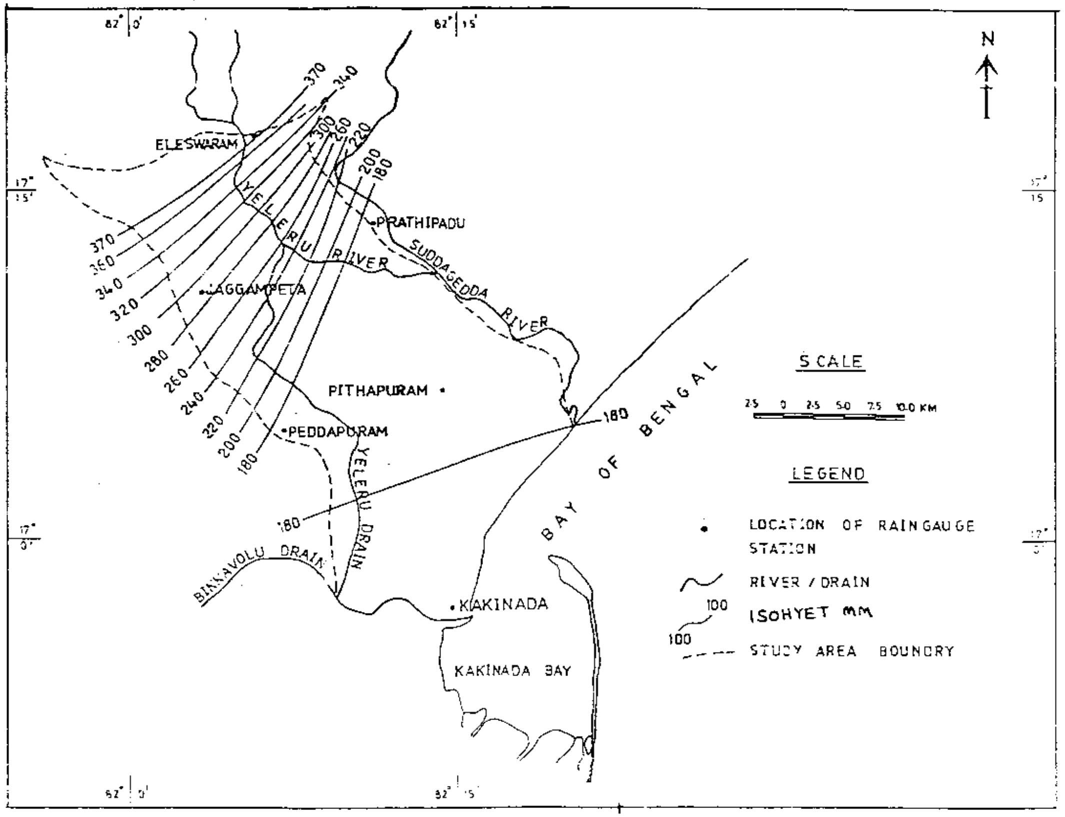


FIGURE 12 - ISOHYETAL MAP OF THE 12-13 AUGUST 1986 RAINSTORM

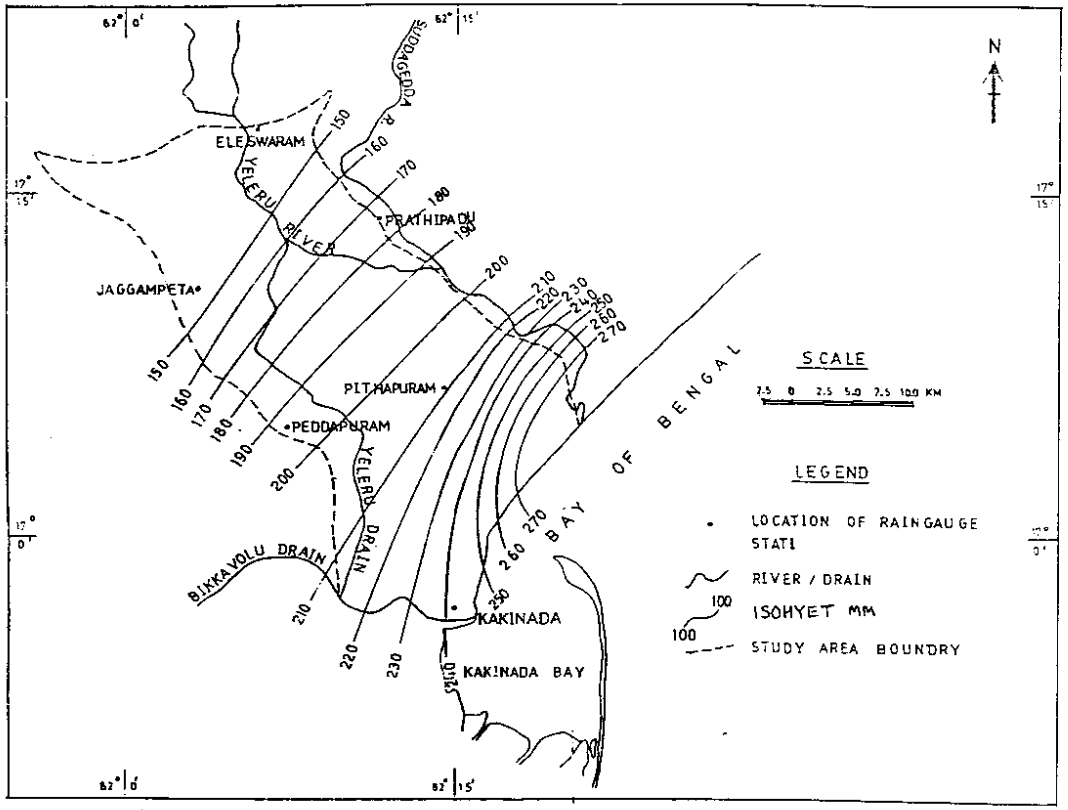


FIGURE 13 - ISOHYETAL MAP OF THE 9 MAY, 1990 RAINSTORM

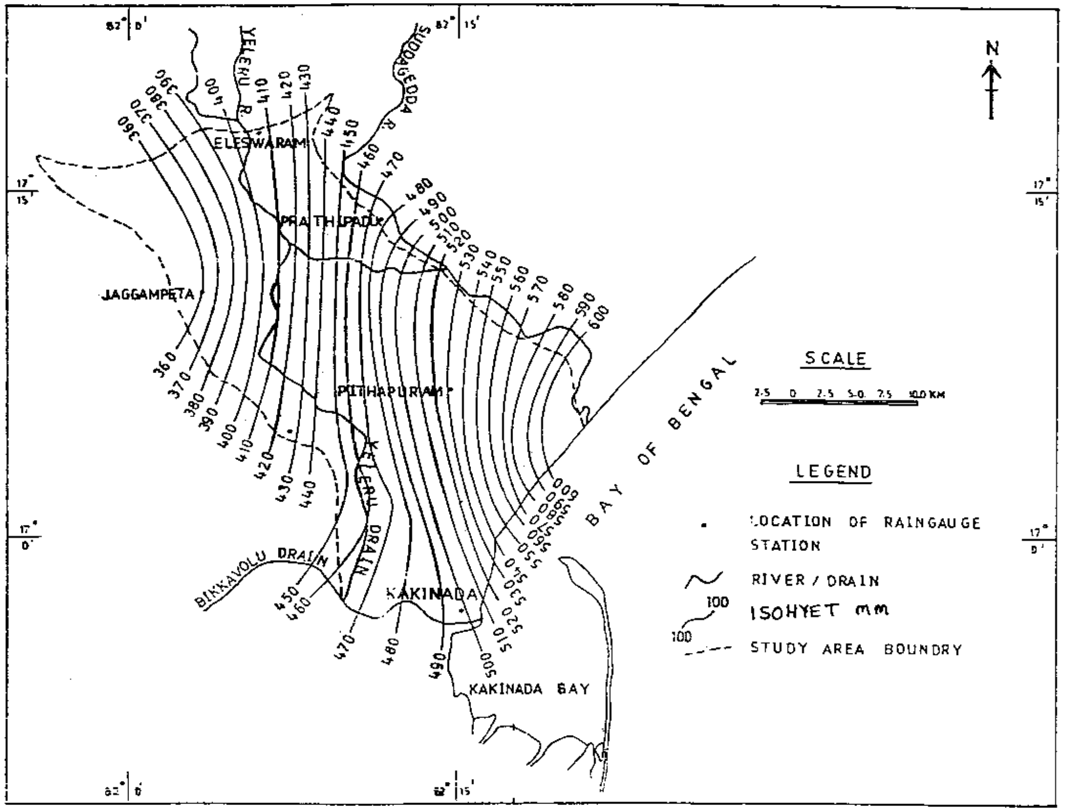


FIGURE 14 - ISOHYETAL MAP OF THE 9-10 MAY, 1990 RAINSTORM

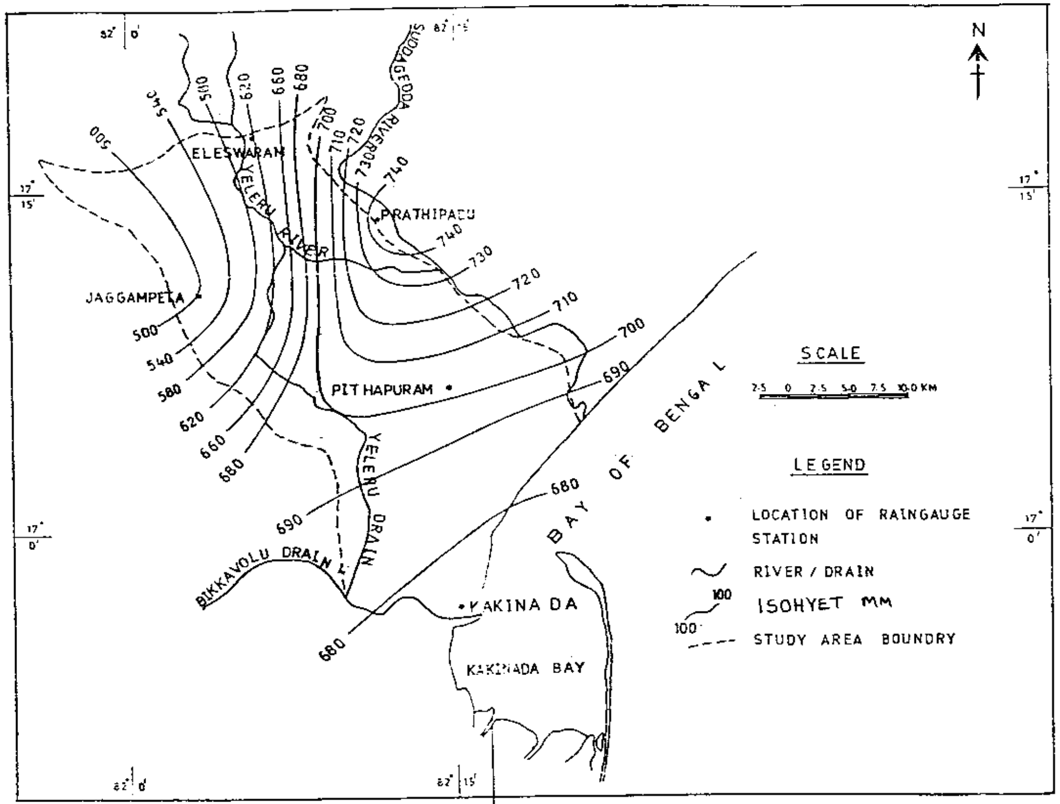


FIGURE 15-ISOHYETAL MAP OF THE 9-11 MAY, 1990 RAINSTORM

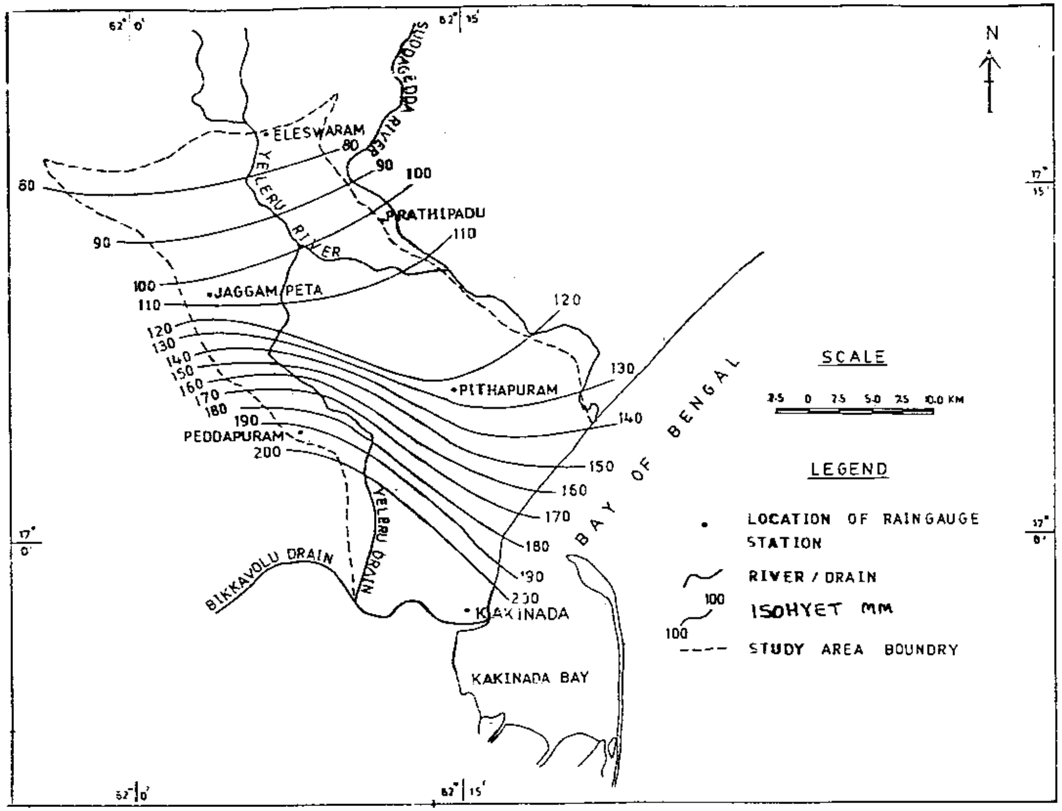


FIGURE 16 -ISOHYETAL MAP OF THE 9 MAY, 1995 RAINSTORM

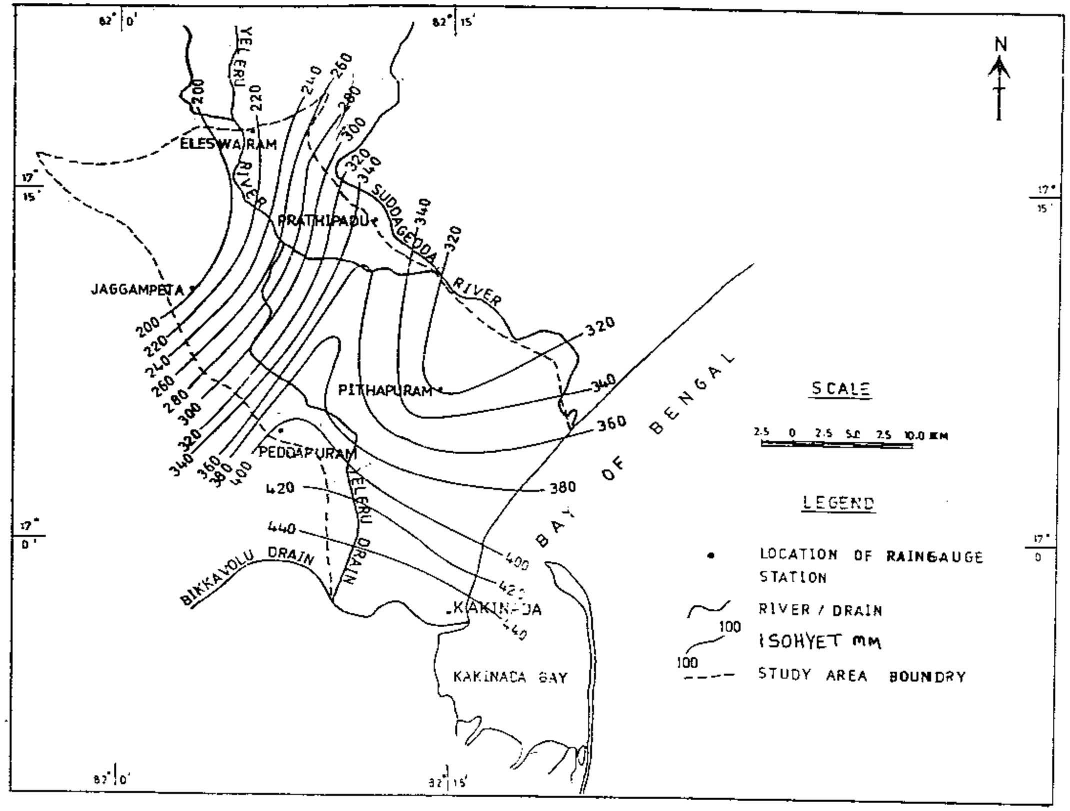


FIGURE 17 - ISOHYETAL MAP OF THE 9-10 MAY 1995 RAINSTORM

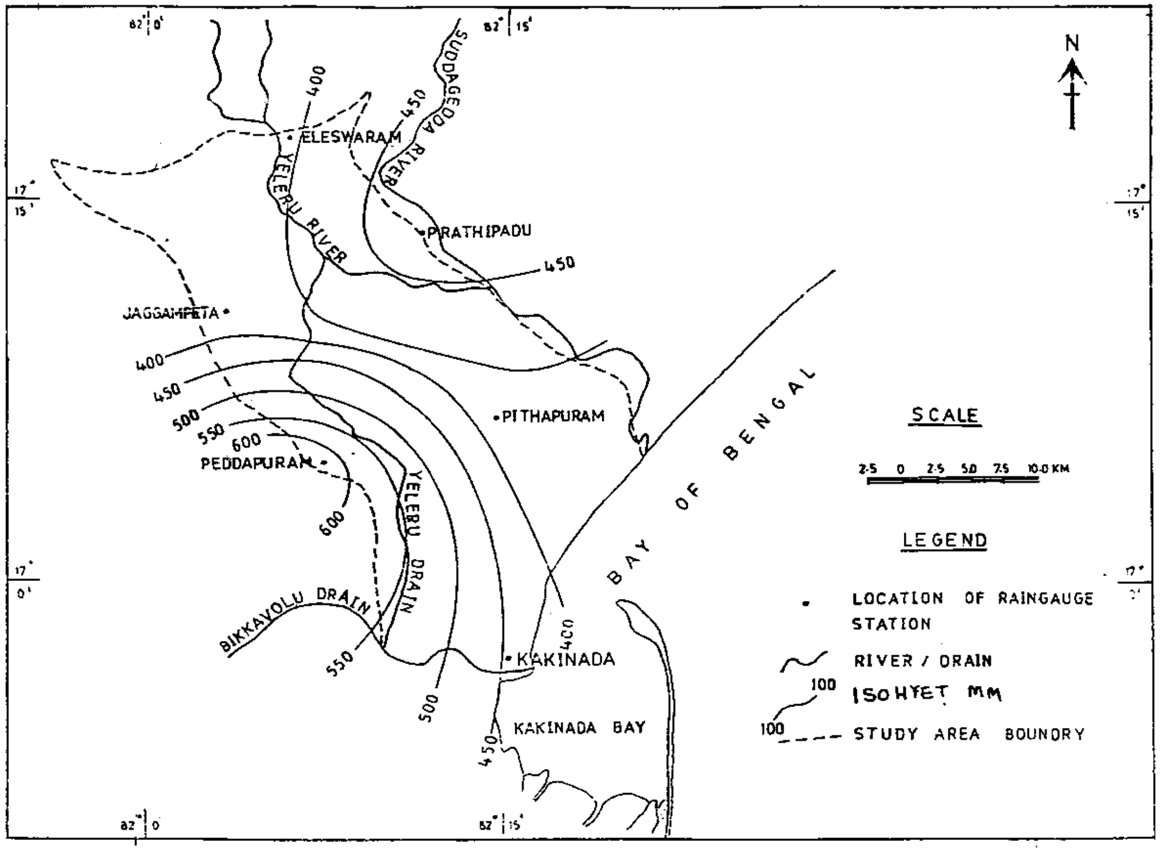


FIGURE 18 - ISOHYETAL MAP OF THE 9-11 MAY, 1995 RAINSTORM

TABLE NO:3

MONTHWISE DISTRIBUTION OF SELECTED RAINSTORMS

MONTH	DUARTION			TOTAL
	ONE-DAY	TWO-DAY	THREE-DAY	
JANUARY	--	--	--	--
FEBRUARY	--	--	--	--
MARCH	--	--	--	--
APRIL	--	--	--	--
MAY	1	--	2	3
JUNE	1	--	--	1
JULY	2	--	--	2
AUGUST	--	2	--	2
SEPTEMBER	1	--	--	1
OCTOBER	2	3	--	5
NOVEMBER	1	4	--	5
DECEMBER	--	--	--	--
TOTAL	8	9	2	19

The Depth-Area-Duration curves for one day, two days and three days duration have been prepared from the selected rain storms and some of them are presented as Fig.no. 19 to 25. Using these DAD curves, the rainfall depths for one day, two days and three days duration for different areas for different rainstorms were obtained and presented in Table no. 4.

From the DAD statistics, it has been observed that maximum average rainfall depths over different areas during the selected rain storms, are from the July, 23, 1989(one day), May 9 - 10, 1990 (two days), and May 9-11, 1990 (three days) storms.

A critical examination of the isohyethal pattern of selected rain storms revel that, in most of the cases, the concentrated rainfall occurred in the lower reaches of the study area. It can also be seen that, in most of the cases the rainfall is decreasing in the north westerly direction , i.e., towards the upstream of the river catchment.

5.2 TEMPORAL VARIATION OF RAINFALL

5.2.1 Selection of storm spells

In order to identify the rainstorms for analysing the temporal variations, looking into the availability of hourly data, all such storm spells whose 24 hour totals have exceeded at least 150 mm and 48 hour totals 200 mm have been selected. Accordingly 8 storms are selected for the analysis. Observed hourly rainfall at Kakinada. The details of selected storms for temporal variation are presented in table no. 5. The hourly rainfall distribution at Kakinada IMD station during the selected rainstorm spells are shown as fig. no. 26 to fig. no. 31.

5.2.2 Methodology & Analysis:

The hourly rainfall data were available for the raingauge station at Kakinada only, where as daily rainfall data is available at the other 4 raingauge stations falling in the study area. Assuming that same hydrometeorological characteristics prevail over the study area, owing to same physiographic and other conditions, the temporal distribution of rainfall at these raingauge stations is assumed to be the same as that at Kakinada. All storm spells whose 24 hour totals have exceeded at least 150mm and 48 hour totals 200mm, during the period 1977 to 1996, were selected for the analysis.
Time distribution curves of Kakinada, for selected storm spells for 24 hrs and 48 hrs duration have been prepared and shown as fig. no. 32 and fig. no. 33. The steps involved in deriving the time distribution are indicated below.

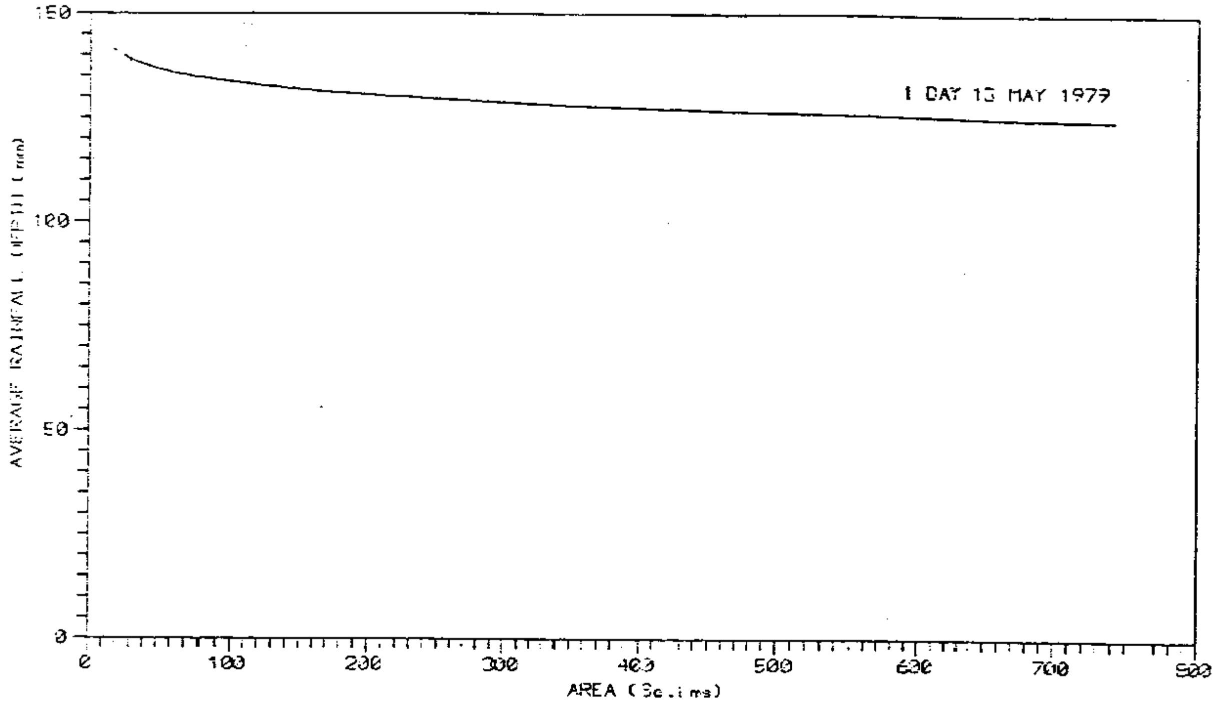


FIGURE 19 DEPTH-AREA-DURATION CURVES, 13 MAY, 1979

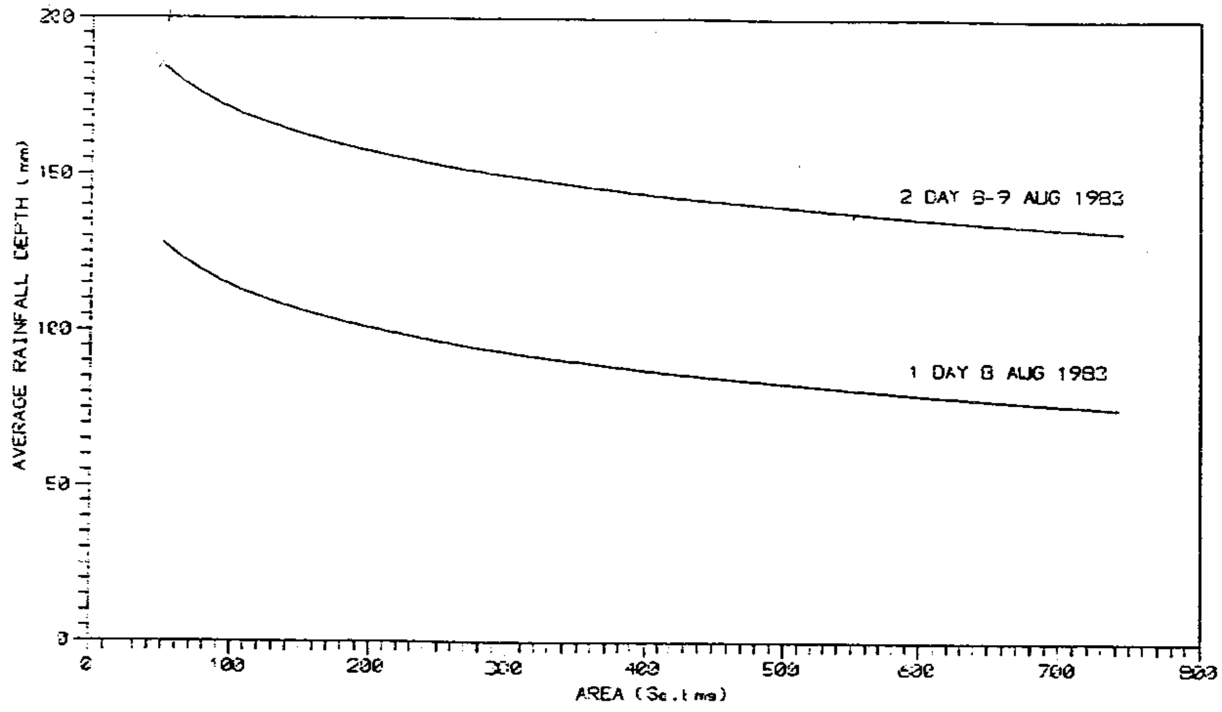


FIGURE 20- DEPTH-AREA-DURATION CURVES, 8-9 AUGUST, 1983

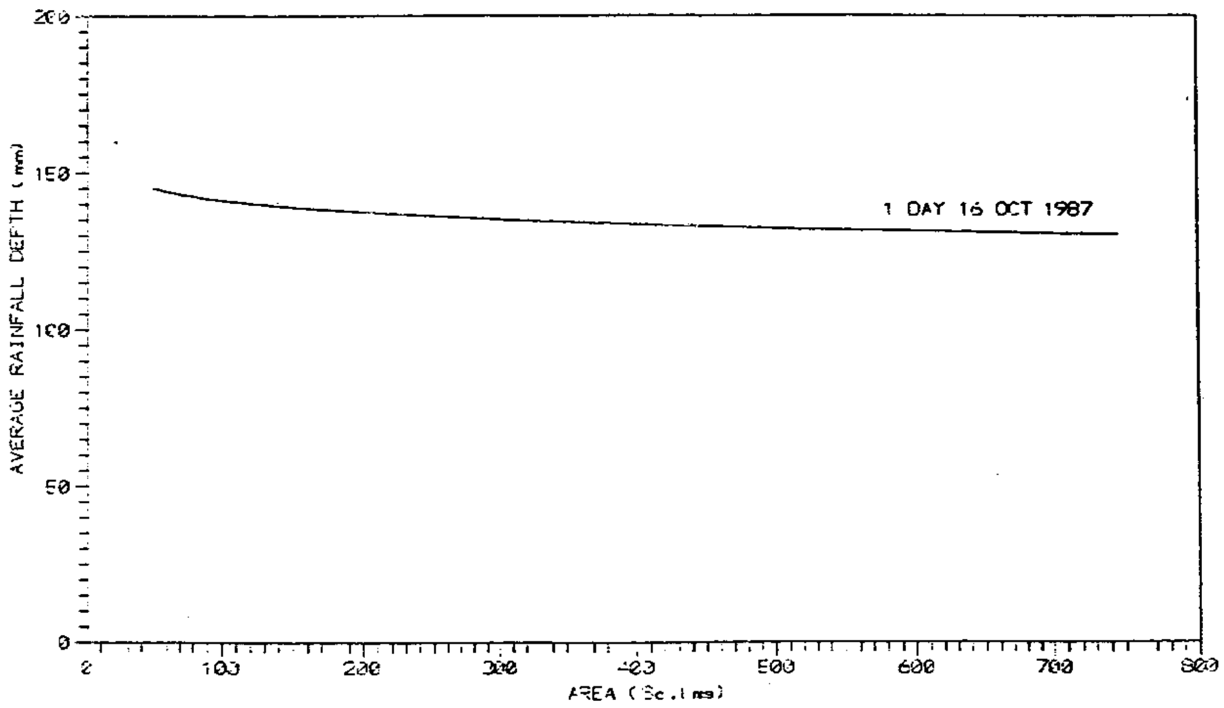


FIGURE 21 DEPTH-AREA-DURATION CURVES, 16 OCTOBER, 1987

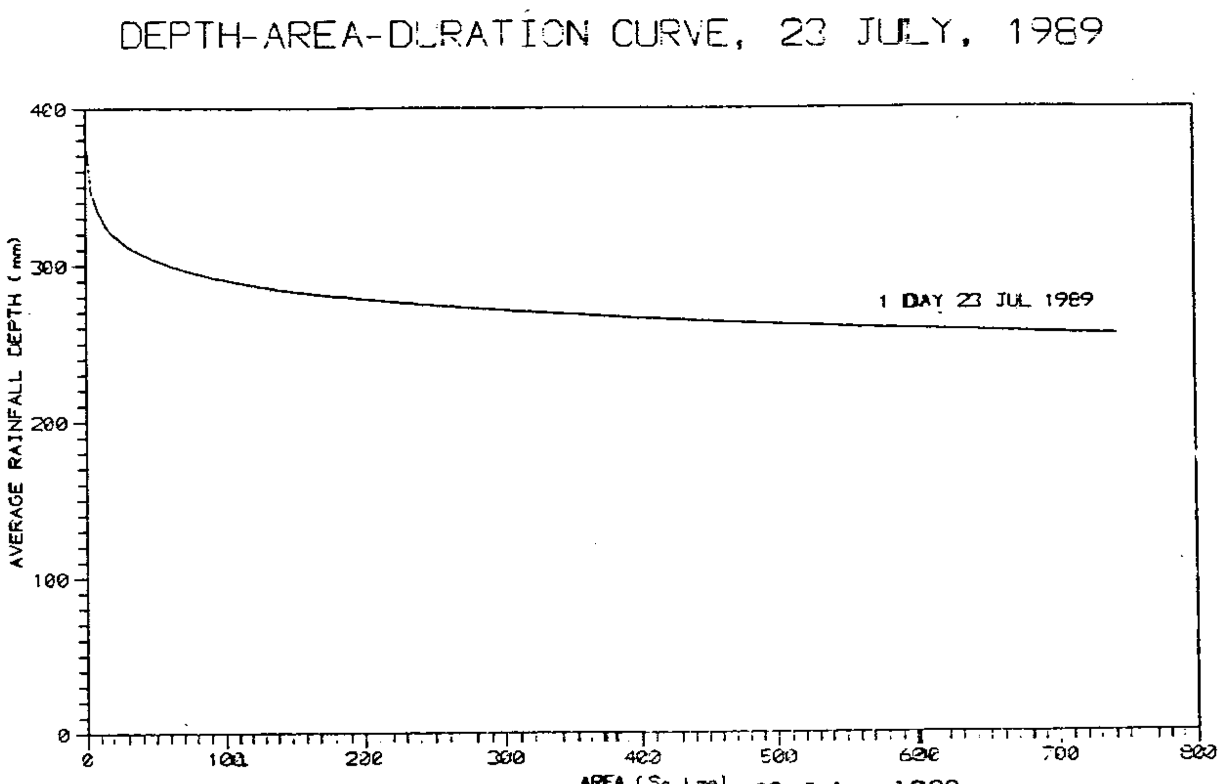


Fig. 22 Depth-Area-Duration Curve, 23 July, 1989

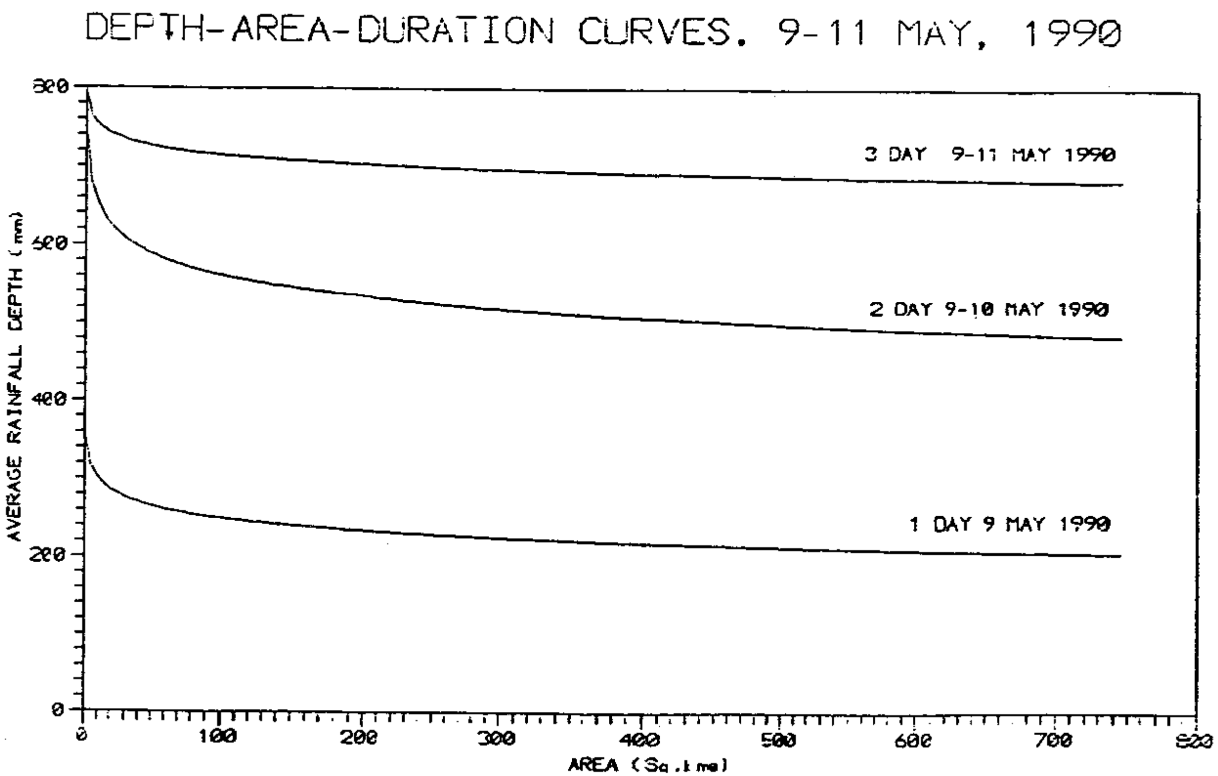


Fig. 23 Depth-Area-Duration Curves, 9-11 May,1990

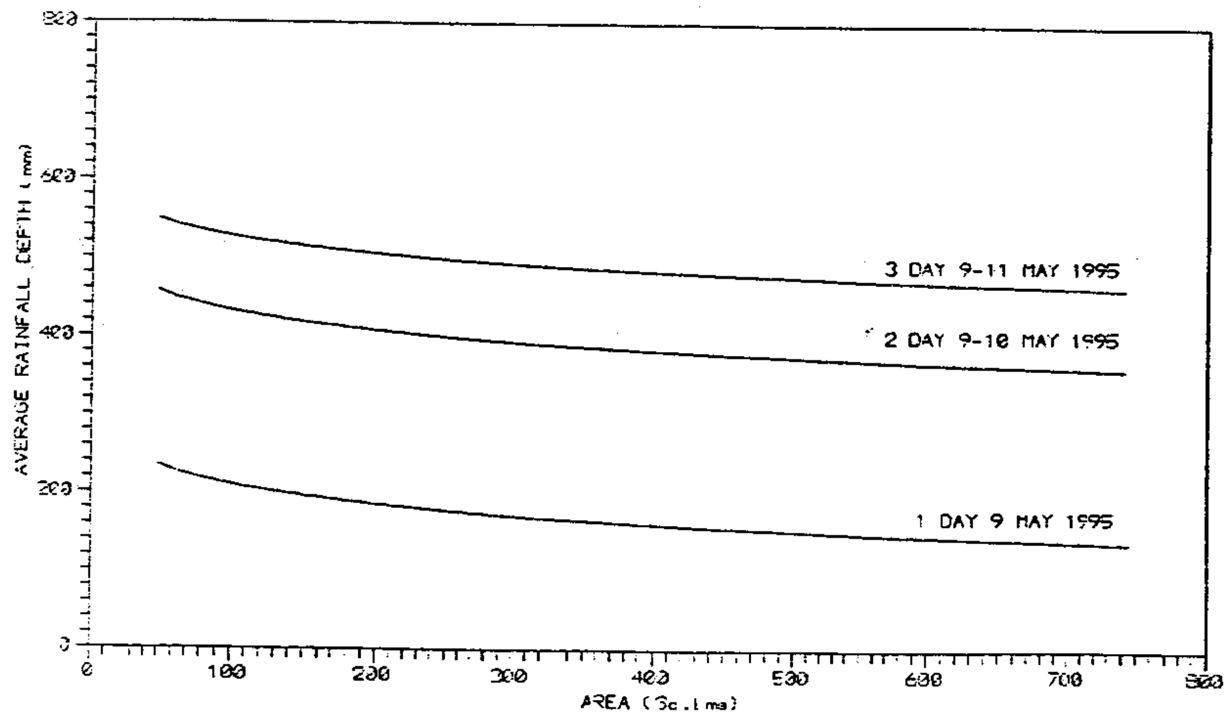


FIGURE 24- DEPTH-AREA-DURATION CURVES, 9,10 & 11 MAY, 1995

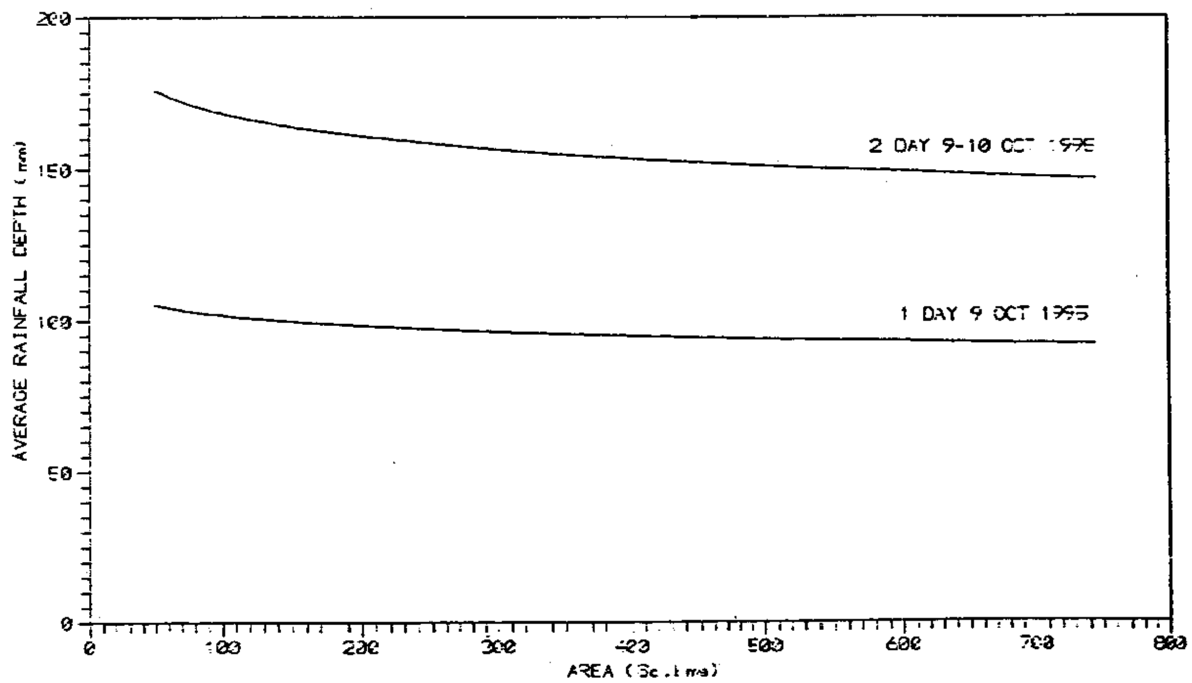


FIGURE 25 DEPTH-AREA-DURATION CURVES, 9-10 OCTOBER, 1995

TABLE NO. : 4

DEPTH-AREA-DUARTION STATISTICS OF RAIN DEPTHS OF SELECTED RAIN STORMS

AREA SQ.KMS	NOVEMBER 1976 1 DAY NOV.26	NOVEMBER 1976 2 DAY NOV. 26-27	NOVEMBER 1977 1 DAY NOV.20	NOVEMBER 1977 2 DAY NOV. 20-21	JUNE 1978 1 DAY JUN.17	MAY 1979 1 DAY MAY.13	NOVEMBER 1979 1 DAY NOV.25	NOVEMBER 1979 2 DAY NOV. 25-26
POINT	169.7	284.0	241.6	307.6	140.4	146.6	74.0	303.0
50	161.6	280.6	239.7	306.9	139.1	136.8	70.0	279.1
100	159.3	273.6	230.9	296.2	132.5	133.7	66.0	259.9
150	152.1	263.6	219.9	289.9	128.6	131.9	63.7	248.7
200	147.0	256.5	212.2	285.4	125.8	130.6	62.1	240.8
250	143.1	251.0	206.1	282.0	123.7	129.6	60.8	234.6
300	139.8	246.6	201.2	279.1	121.9	128.8	59.7	229.6
350	137.1	242.8	197.0	276.7	120.5	128.1	58.9	225.3
400	134.7	239.5	193.4	274.7	119.2	127.5	58.1	221.6
450	132.6	236.6	190.2	272.8	118.0	127.0	57.4	218.4
500	130.8	234.0	187.3	271.2	117.0	126.5	56.3	215.5
550	129.1	231.6	184.8	269.7	116.1	126.1	56.3	212.8
600	127.5	229.5	182.4	268.4	115.3	125.7	55.8	210.4
650	126.1	227.5	180.2	267.1	114.5	125.3	55.3	208.2
700	124.8	225.7	178.2	266.0	113.8	125.0	54.9	206.2
745.4	123.7	224.2	176.5	265.0	113.2	124.7	54.5	204.4

Table No. : 4 (contd....)

AREA SQ.KMS	OCTOBER 1980 1 DAY OCT.18	OCTOBER 1980 2 DAY OCT. 18-19	AUGUST 1983 1 DAY AUG.08	AUGUST 1983 2 DAY AUG. 08-09	OCTOBER 1983 1 DAY OCT.04	OCTOBER 1983 2 DAY OCT. 04-05	SEP.1984 1 DAY SEP.11
POINT	99.8	181.0	157.6	199.7	97.5	207.7	119.2
50	96.9	178.8	128.0	184.5	93.6	217.9	115.0
100	93.8	172.6	114.5	171.0	86.3	197.6	112.2
150	92.0	169.0	106.6	163.1	82.1	185.7	104.6
200	90.7	166.4	101.0	157.5	79.1	177.3	99.3
250	89.7	164.4	96.7	153.2	76.7	170.8	95.2
300	88.8	162.8	93.1	149.7	74.8	165.4	91.8
350	88.2	161.4	90.1	146.7	73.2	160.9	88.9
400	87.6	160.2	87.5	144.1	71.8	157.0	86.4
450	87.0	159.1	85.2	141.8	70.6	153.6	84.3
500	86.5	158.2	83.2	139.7	69.4	150.5	82.3
550	86.1	157.3	81.3	137.9	68.4	147.7	80.5
600	85.7	156.6	79.6	136.2	67.5	145.1	78.9
650	85.4	155.8	78.1	134.6	66.7	142.8	77.6
700	85.0	155.2	76.6	133.2	65.9	140.6	76.3
745.4	84.8	154.6	75.4	132.0	65.3	138.8	74.9

Table No. : 4 (contd....)

AREA SQ.KMS	OCT. 1985 1 DAY OCT.11	AUGUST 1986 1 DAY AUG.12	2 DAY AUG. 12-13	OCT. 1987 1 DAY OCT.16
POINT	99.8	198.0	372.0	152.8
50	99.7	195.1	370.1	145.2
100	94.3	190.0	360.4	141.3
150	91.2	177.1	337.2	139.1
200	88.9	168.0	320.7	137.5
250	87.2	160.9	307.9	136.3
300	85.8	155.1	297.5	135.2
350	84.6	150.2	288.7	134.4
400	83.5	146.0	281.0	133.7
450	82.6	142.2	274.3	133.0
500	81.8	138.9	268.3	132.4
550	81.1	135.8	262.8	131.9
600	80.4	133.1	257.8	131.4
650	79.8	130.5	253.2	131.0
700	79.2	128.2	249.0	130.6
745.4	78.7	126.2	245.4	130.2

Table No. : 4 (contd....)

AREA SQ.KMS	JUL 1988 1 DAY JULY.29	JUL 1989 1 DAY JULY.23	MAY 1990 1 DAY MAY.09	2 DAY MAY. 09-10	3 DAY MAY. 09-11	NOV 1992 1 DAY NOV.16
POINT	218.3	310.0	275.8	590.8	744.0	138.8
50	214.9	303.3	264.7	588.0	726.1	135.2
100	207.5	290.8	249.4	561.3	714.9	121.3
150	191.5	283.6	240.4	545.7	708.4	113.2
200	180.2	278.4	234.0	534.6	703.8	107.4
250	171.4	274.4	229.1	526.0	700.2	102.9
300	164.2	271.1	225.1	518.9	697.2	99.3
350	158.1	268.3	221.7	513.0	694.8	96.2
400	152.8	265.9	218.7	507.8	692.6	93.5
450	148.2	263.8	216.1	503.3	690.7	91.2
500	144.0	261.9	213.8	499.2	689.0	89.0
550	140.3	260.2	211.7	495.5	687.5	87.1
600	136.8	258.7	209.7	492.2	686.1	85.4
650	133.7	257.2	208.0	489.1	684.8	83.8
700	130.8	255.9	206.3	486.2	683.6	82.3
745.4	128.3	254.8	204.9	483.8	682.6	81.0

Table No. : 4 (contd....)

AREA SQ.KMS	NOVEMBER 1994 1 DAY NOV.01	2 DAY NOV. 01-02	MAY 1995 1 DAY MAY.09	2 DAY MAY. 09-10	3 DAY MAY. 09-11	OCTOBER 1995 1 DAY OCT.09	2 DAY OCT. 09-10
POINT	158.2	228.2	217.0	458.6	620.4	106.0	186.2
50	151.7	228.2	235.3	457.4	549.6	105.2	176.0
100	140.6	216.0	210.3	432.6	527.7	101.8	168.4
150	134.2	208.9	195.8	418.1	514.9	99.8	164.0
200	129.6	203.8	185.4	407.8	505.8	98.3	160.9
250	126.0	199.8	177.4	399.9	498.7	97.2	158.5
300	123.1	196.6	170.8	393.3	493.0	96.3	156.5
350	120.7	193.9	165.3	387.8	488.1	95.6	154.8
400	118.6	191.6	160.5	383.0	483.9	94.9	153.4
450	116.7	189.5	156.3	378.8	480.2	94.3	152.1
500	115.0	187.6	152.5	375.1	476.8	93.8	150.9
550	113.5	185.9	149.1	371.7	473.8	93.3	149.9
600	112.1	184.4	145.9	368.5	471.1	92.9	148.9
650	110.8	183.0	143.1	365.7	468.5	92.5	148.1
700	109.6	181.7	140.4	363.0	466.2	92.1	147.3
745.4	108.6	180.6	138.1	360.8	464.2	91.8	146.6

Table No. 5: Details of selected rainstorms for temporal distribution analysis.

Serial Number	From	To	Duration (Hours)	Total Rainfall (mm)
S1	4th hr 19th July '77	3rd hr 21st July '77	48	286.1
S2	2nd hr 12th May '79	1st hr 14th May '79	48	211.1
S3	1st hr 25th Nov. '79	24th hr 25th Nov. '79	24	285.3
S4	6th hr 15th Oct. '87	5th hr 16th Oct. '87	24	150.8
S5	14th hr 8th May '90	13th hr 10th May '90	48	610.2
S6	2nd hr 8th May '95	1st hr 10th May '95	48	443.6
S7	1st hr 9th Oct. 95	24th hr 9th Oct. '95	24	220.7
S8	23rd hr 15th Jun. '96	22nd hr 16th Jun. 96	24	181.1

Fig No. 26 : Hourly Rainfall distribution at Kakinada IMD station on 19-21 Nov 1977

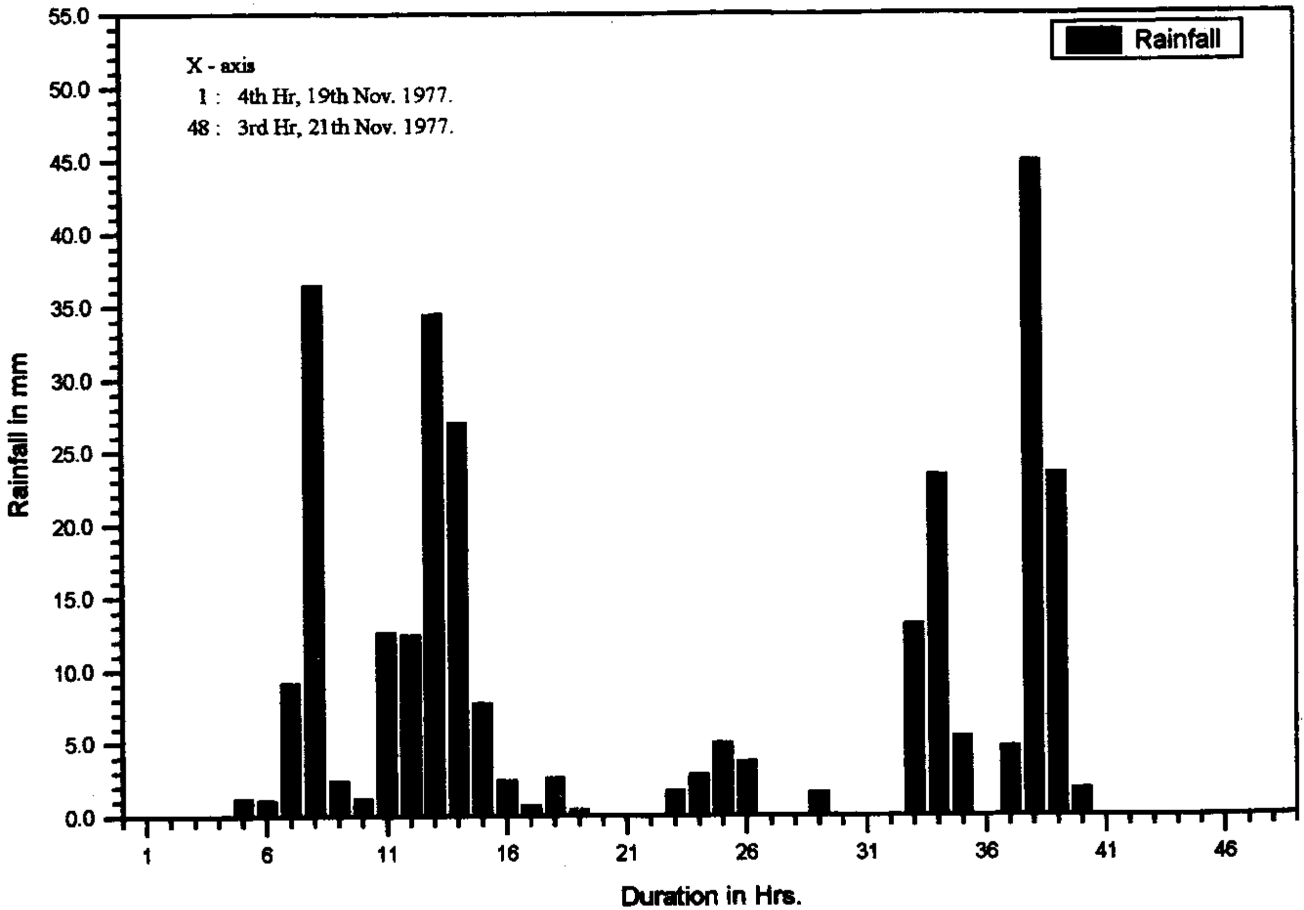


Fig No. 27: Hourly rainfall distribution at Kakinada IMD station on 12-14 May 1979

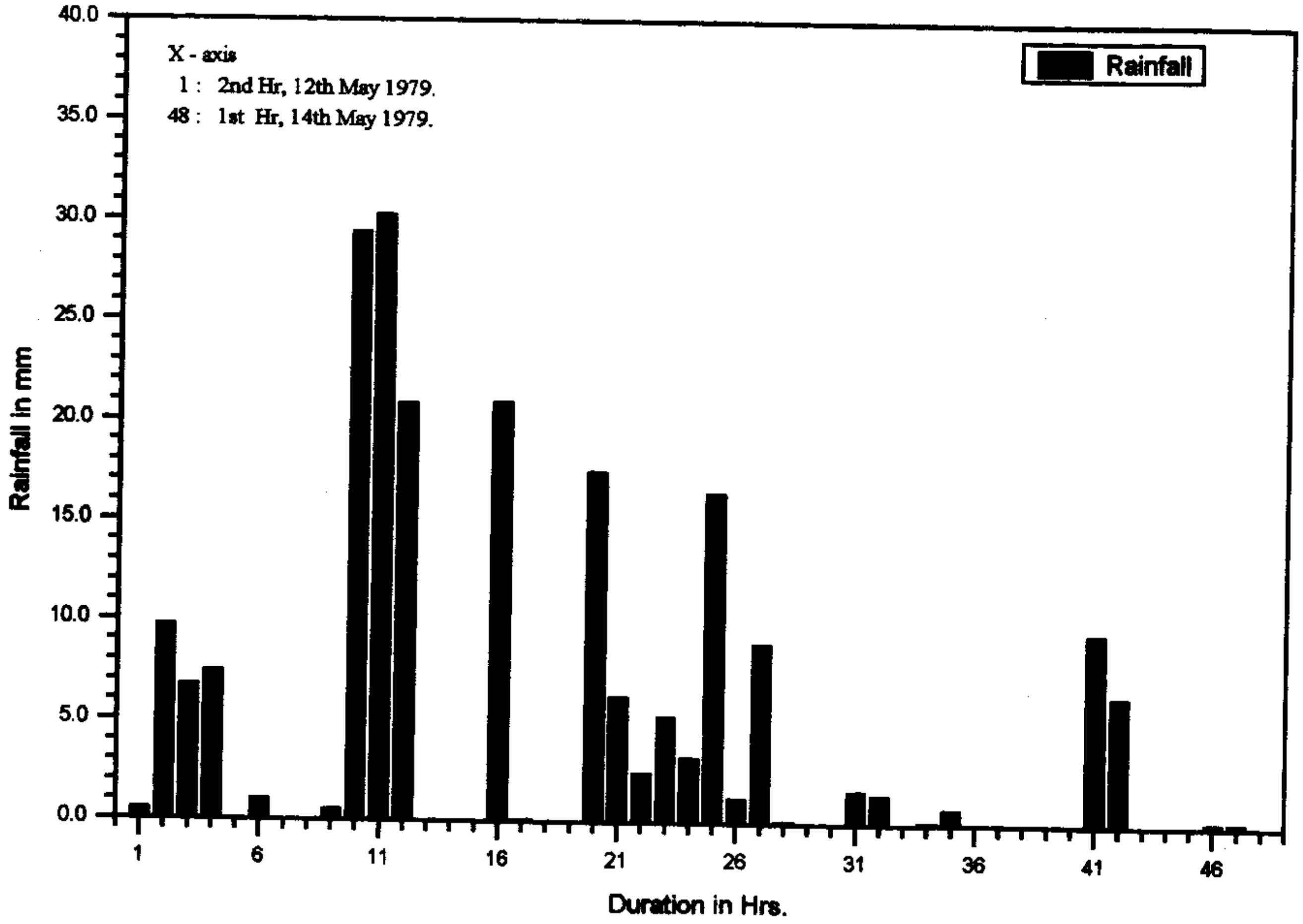


Fig No. 28 : Hourly Rainfall distribution at Kakinada IMD station on 25 Nov 1979

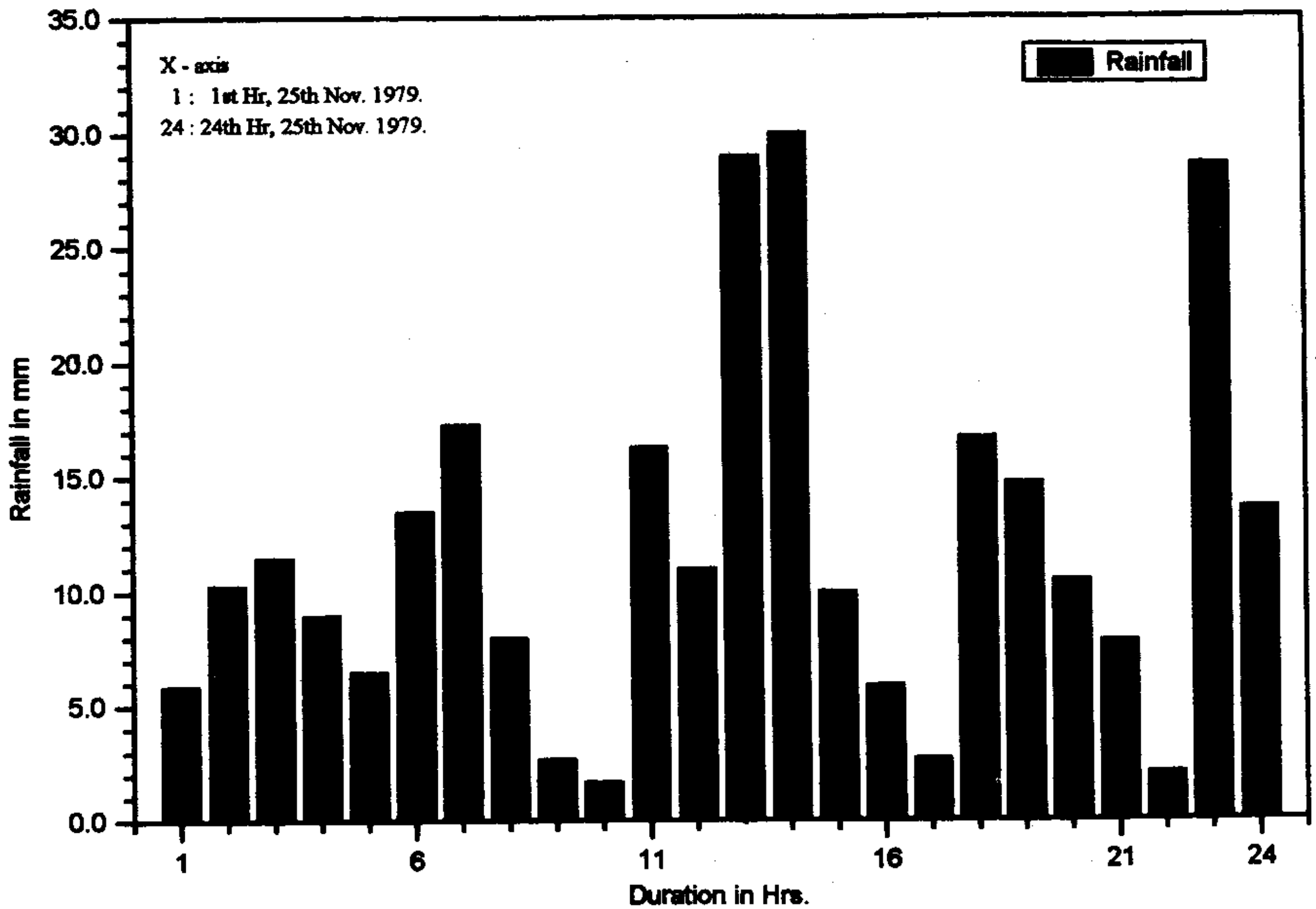


Fig No. 29 : Hourly Rainfall distribution at Kakinada IMD station on 8-10 May 1990

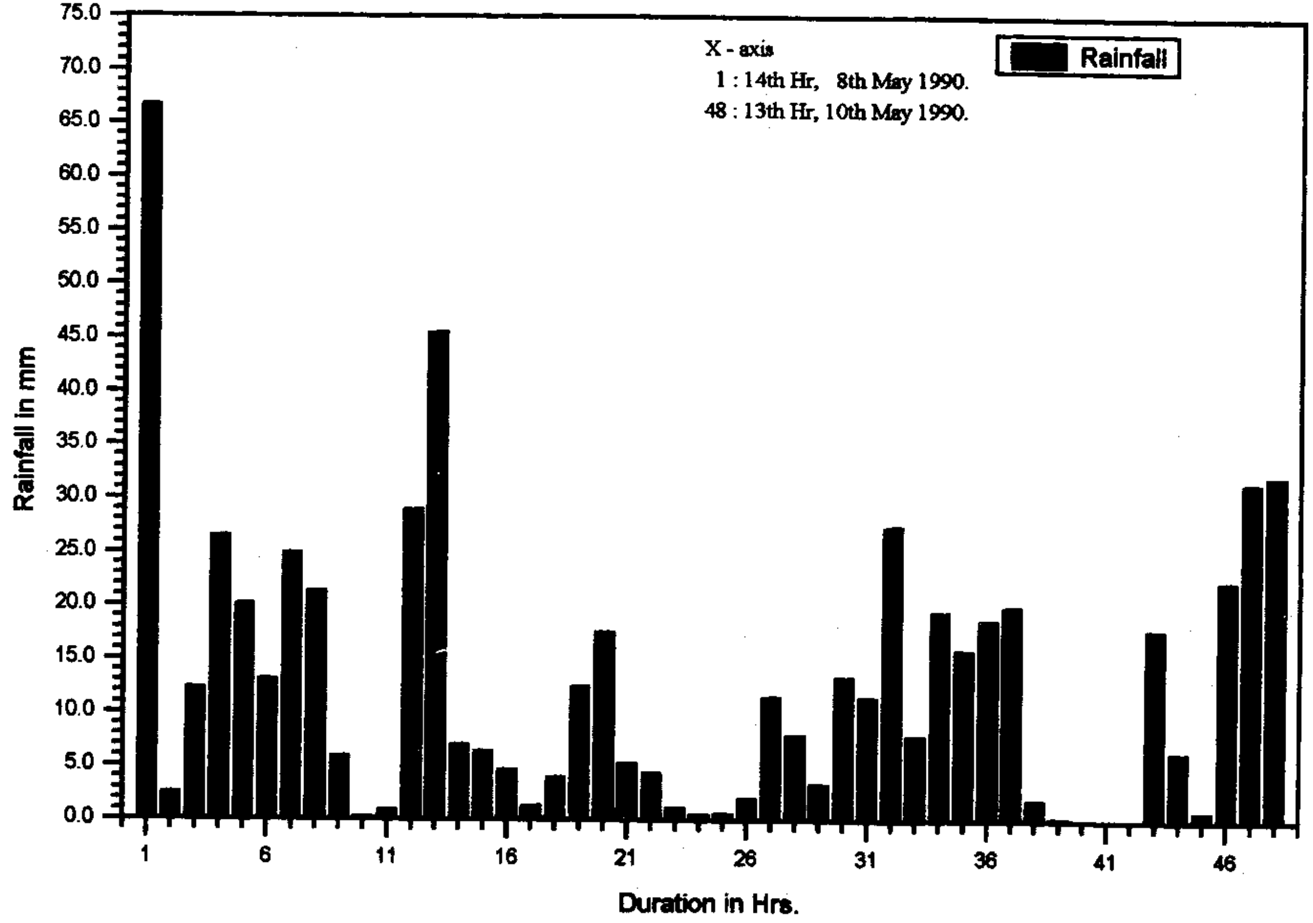


Fig No. 30 : Hourly Rainfall distribution at Kakinada IMD station on 8-9 May 1995

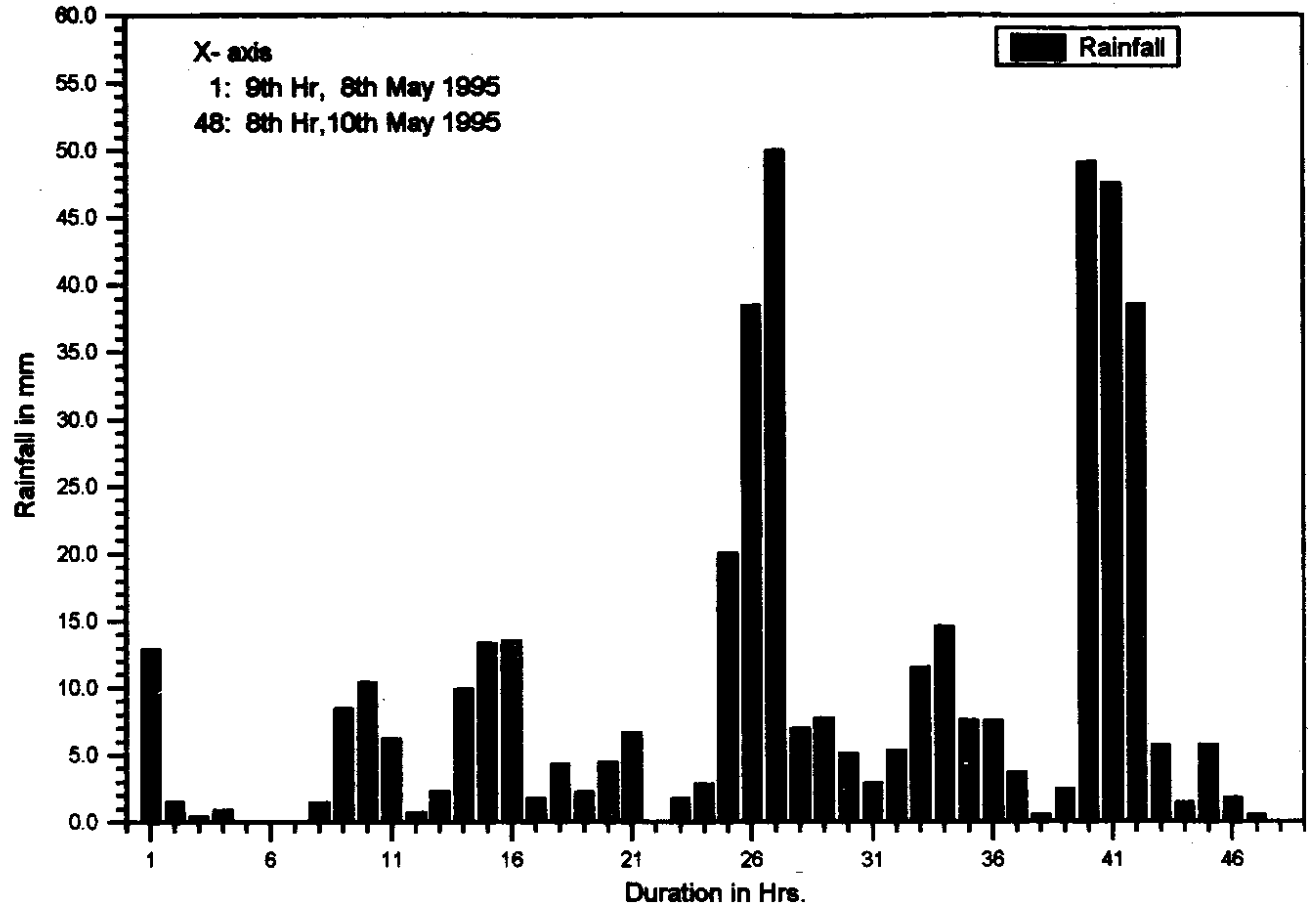


Fig. No. 31 : Hourly Rainfall distribution at Kakinada IMD station on 15-16 June 1996

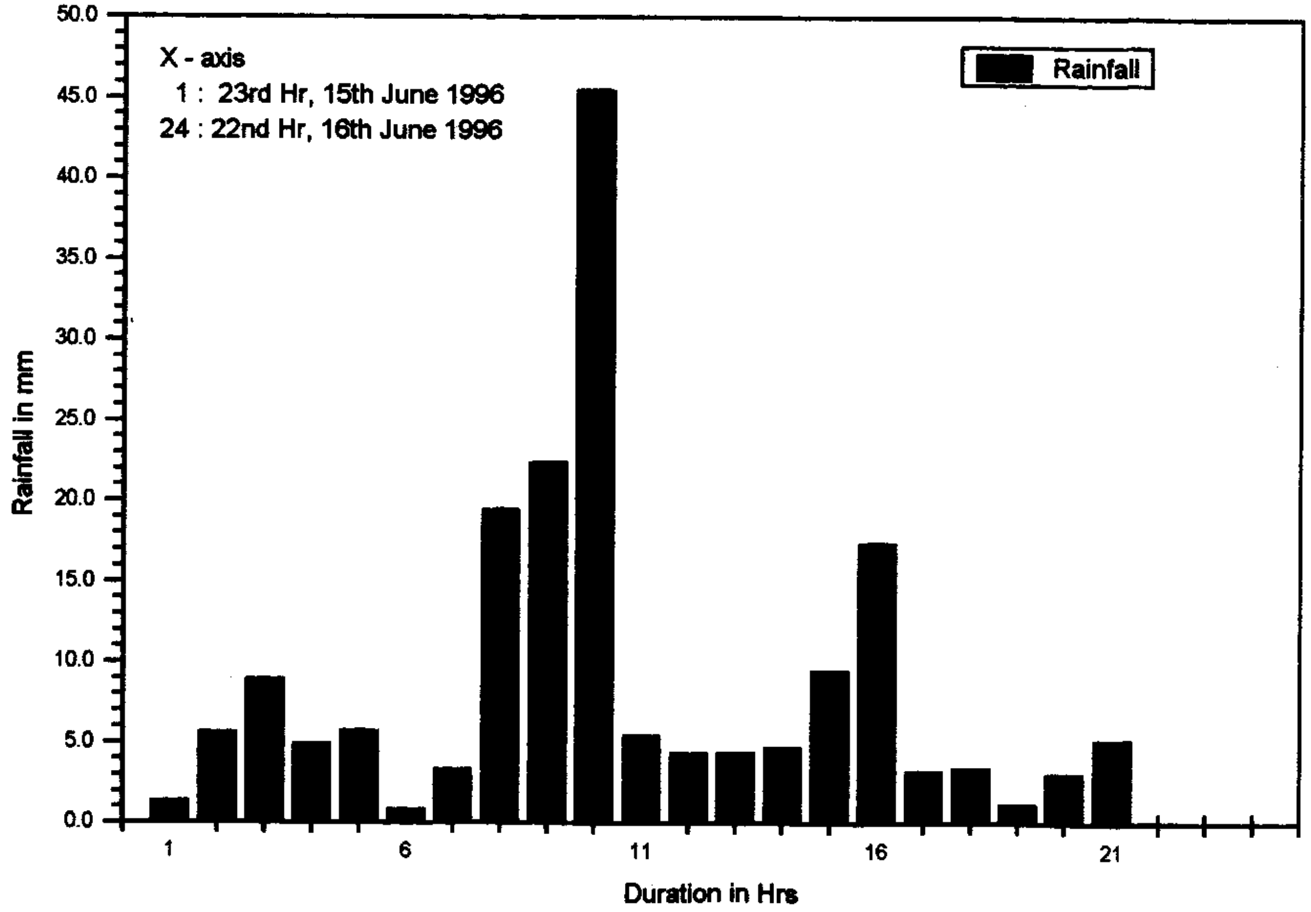


Fig No. 32 : Time distribution and average envelope curves of Kakinada for 24 hr duration storms.

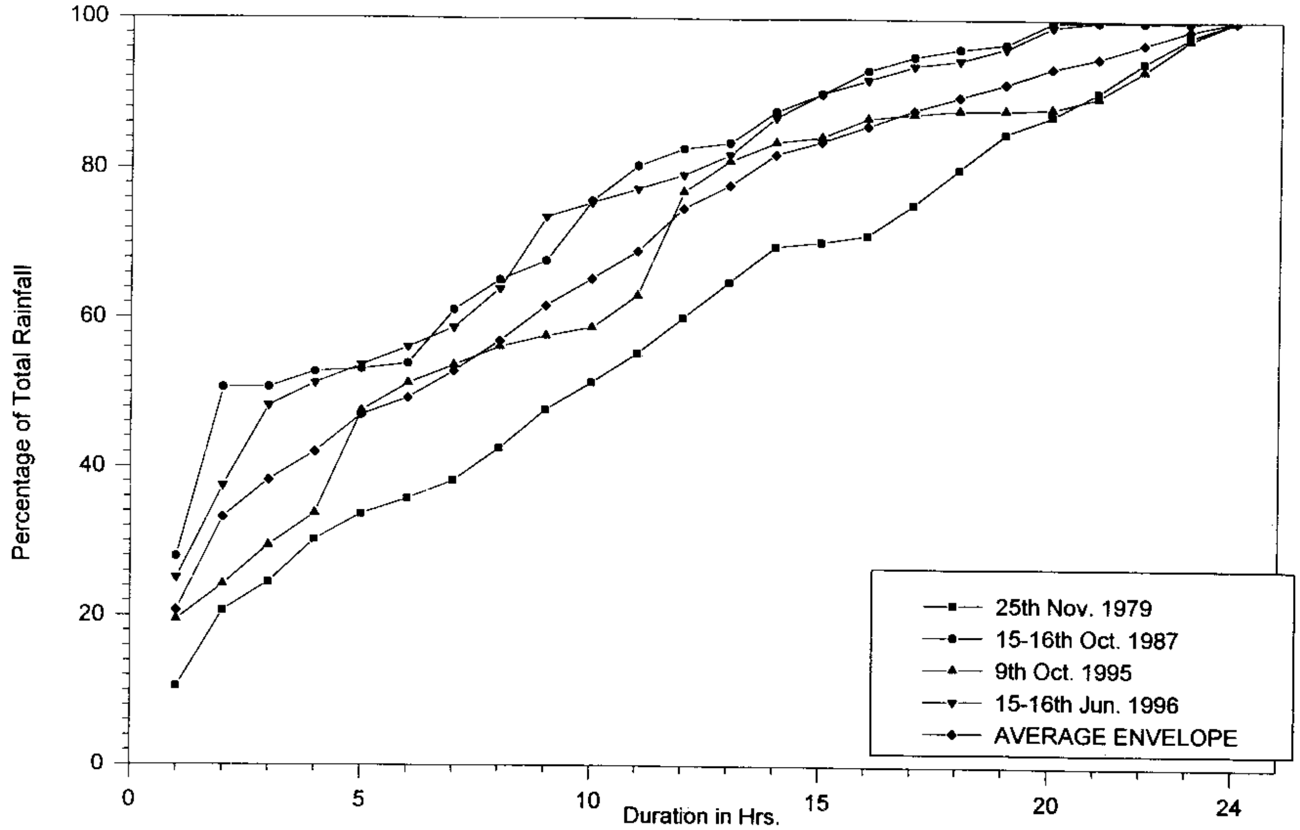
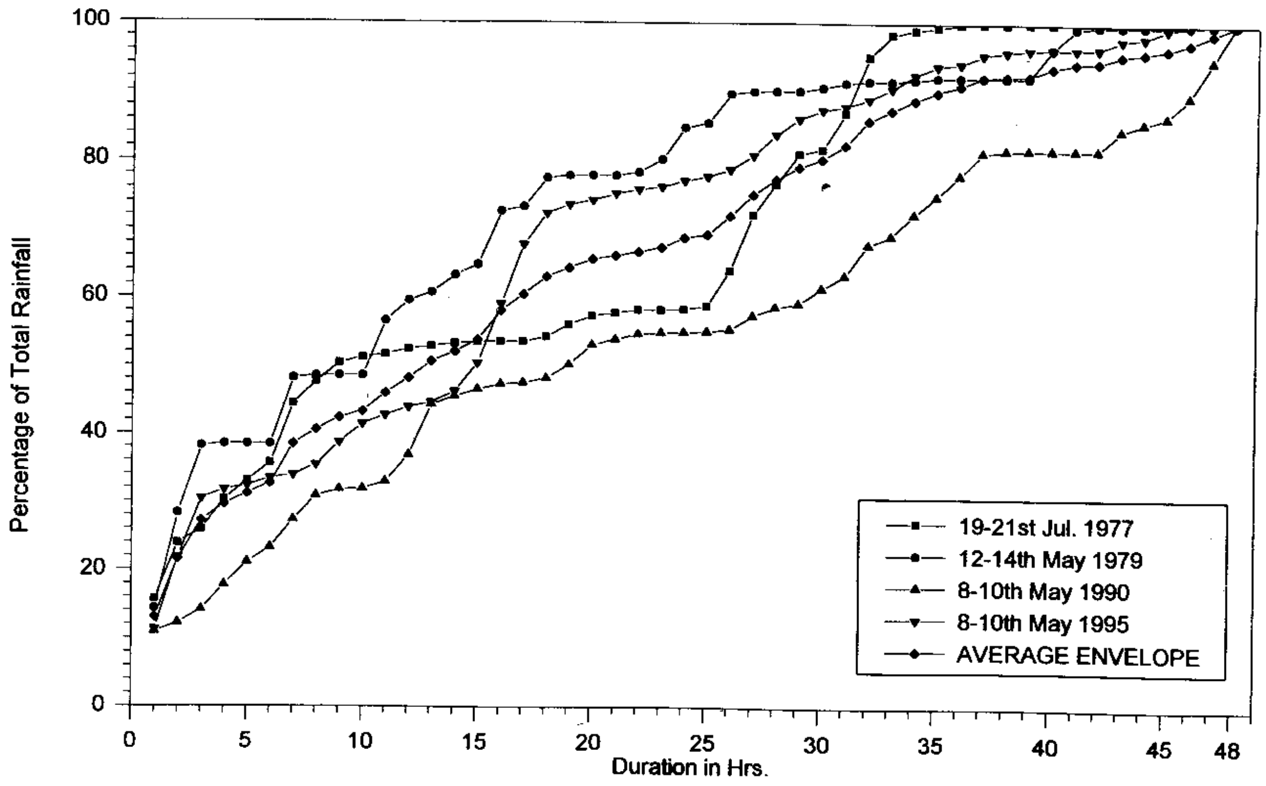


Fig No. 33 : Time distribution and average envelope curves of Kakinada for 48 hour duration storms



1. Compute the maximum hourly rainfall totals for 1,2,3,6,9,12,15,18,21,24,.... n hours using only consecutive hourly rainfall data.
2. Express the maximum rainfall totals computed in step 1 as percentage to the total rainfall amount of selected storm duration.
3. Repeat the procedure in step 1 and 2 from all the selected storm spells.
4. Plot the percentages of the different duration from each spell on a graph paper and draw smooth curves. Separate graphs are plotted for 24 hour and 48 hour duration storms.
5. Plot an average envelop curve passing through the average rainfall percentage for each duration from out of different storm spells selected.

The rainfall distribution in percentage of total rainfall for 24 hr and 48 hr duration storm spells are given in the table no. 6.

The following observations can be made from the average time distribution curve.

50 % of the rainfall was occurred in the first 6 hrs, 40 % in the next 12 hrs and 10% in the last 6 hrs of the 24 hr storm spells.

50 % of the rainfall was occurred in the first 12 hrs, 36 % in the next 24 hrs and 14% in the last 12 hrs of the 48 hr storm spells

It is apparent that considerable rainfall was experienced in the beginning of the storm spells.

Table No.: 6 Details of rainfall distribution (percentage of total rainfall) from average envelop curves for 24 hr and 48 hr duration storm spells.

Spell duration	Spell duration percentage			
	25	50	75	100
24 hours	50	70	88	100
48 hours	50	68	90	100

6.0 CONCLUSIONS

From the study, it could be broadly summarised that

- Examination of daily rainfall data of the period 1976-96 has shown that there are about 19 severe rainstorms, which affected the study area.
- From the Spatial variation analysis of the selected heavy rainstorms occurred over the study area during 1976-96, it reveal that the rainstorms of 23 July, 1989 (1- day), 9-11 May 1990 (2-day and 3-day), have contributed the highest average rainfall depths of 254.8 mm, 483.8 mm and 682.6 mm for 1,2,3 day duration respectively.
- From the Temporal variation analysis of the selected rain storms occurred over the study area, it has been observed that 50 percentage of the rainfall in a storm spell occurred in the 25 percentage of the storm duration and the remaining 50 percentage of the rainfall occurred in the remaining 75 percentage of the storm duration.
- Examination of daily rainfall data of stations within the basin has shown that one station, i.e., Kakinada received rainfall of the order of 310 mm in one day.
- The frequency of cyclones crossing AP coast during 1977-96 period ,is maximum in the month of November, with 10 cyclones crossing in this month. Similarly , the frequency of maximum daily rainfall is highest again in the month of November.
- During the storm on 9-11 May, 1990 , the study area experienced about 16% of the annual rainfall in 1 day, 34 % of annual rainfall occurred in just 2 days , and 47 % of the annual rainfall in 3 days.
- The flood/inundation problem is coupled with the favorable antecedent soil moisture condition, as most of the storms occurred in post-monsoon season.
- It has been observed that the study area experiences heavy rainfall after the cyclonic storm crosses the coast.
- From the isohyetal maps it has been observed that rainfall is concentrated in lower part of the study area and decreasing towards the land, i.e., towards the upstream of the rive catchment.
- From the Time distribution curves, it has been observed for the most of the storms, that considerable rainfall occurred at the beginning and at the end of each rainstorm spell.

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