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DEVELOPMENT OF HYDROLOGICAL DROUGHT INDEX BASED ON RESERVOIR LEVEL

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PREFACE

In arid and semi arid regions, the increasing demand of water and high variability of rainfall necessitate the need for temporary storage of water to meet the demand during the period of its deficiency. During the period of deficiency in a normal year, the water from a temporary storage is supplied at a demand close to a value of its mean availability. This supply of water could be termed as threshold discharge. The threshold discharge of a reservoir changes from year to year depending upon the demand. In a drought year, the demand increases, the availability of water in temporary storage reduces and therefore the threshold discharge to meet the demand is not achieved during the period of its deficiency. The storage structures in such condition needs the nomograms to indicate the deficiency in meeting the threshold discharge.

This report presents the nomograms in terms of reservoir level and for different threshold discharge to have an idea of reservoir level being in normal, mild and moderate drought situation. The nomograms not only give the drought index for a reservoir in terms of reservoir lever but also yields the number of days, the water could be supplied at required threshold discharge.

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ABSTRACT

A drought index based on reservoir levels has been developed by the analysis of daily stream flow into the Malaprabha and Ghataprabha reservoirs, in Belgaum district of Karnataka. Part of the catchment area as well as the command areas of the above reservoirs fall in the classified drought prone area as per the Central Water Commission (CWC). The analysis include the annual flow departure analysis, analysis of maximum drought volume (storage volume), analysis of water available days and mean monthly available storage in terms of reservoir level. The results of the analysis are presented in the form of nomograms for the identification of drought based on the existing reservoir level at different threshold discharge. Another drought index is presented, as mean reservoir level minus half of its standard deviation for mild drought and mean reservoir level minus its standard deviation for identification of moderate drought respectively.

1.0 INTRODUCTION

The reservoirs are mainly built with the objective of storing the river flow to meet the water demand (total water requirement at any point of time) in arid and semi arid regions, during the periods of its deficiency. In such cases, it becomes important for the reservoir authorities to know an index for identification of drought, interms of reservoir level. It is also necessary for authorities to know, the number of days for which water could be supplied at specific threshold discharge. At present, no specific guidelines are available and the authorities take decision either by their experience or through decisions based on the amount of rainfall and storage available or expected to arrive. However, the total rainfall alone exactly does not reflect the position of reservoir level. In view of this, it is necessary to have some nomograms in terms of reservoir level and for different threshold discharge to have an idea of reservoir level being in normal, mild, or moderate drought situation and the number of days the water could be supplied at required threshold discharge with no deficiency.

In arid and semi-arid regions, the water level in reservoirs frequently drops due to low availability of flow in streams. For such situation, it is important for reservoir authorities to know an index for identification of drought in terms of reservoir level. It also becomes important to know, the number of days for which water could be supplied at specific threshold discharge.

The number of days water could be supplied is analysed as the period for which river flow combined with stored volume in reservoir is able to meet the threshold discharge at different level of storage in the reservoir and since the actual demand of the area is not known, the analysis is repeated for different threshold discharges. The threshold discharges are taken as the percentage of mean daily flow such that it covers the reservoir supply ranges in a normal and drought year situations. The objectives of the study thus could be listed as below:

1. Development of nomograms for the estimation of water available days at different reservoir level.
2. To develop nomograms for identification of drought for different reservoir level.

2.0 REVIEW

The deviation of stream flow from the normal has been utilized as an index to characterize the hydrological drought and the occurrence of such phenomena at certain number of time classify the area as drought prone. The CWC, 1982 has suggested that, the runoff, if found to be less than 75 percent of the normal runoff at a site, the year would be considered as drought year and if it occurs in 25 percent or more than 25 percent time of year, the area would be considered as drought prone.

Based on the guide lines, the NIH has analysed the river flow data of Krishna basin at eight different discharge measuring sites. Similarly the Godavari basin has been analysed for four different sites (NIH CS-37). The results in the form of flow duration curves, deficiency of the volume and dry spells are reported.

In low flow analysis, the drought volume and drought duration are normally estimated imposing a threshold discharge, which s usually a proportion of mean flow. The calculation procedure uses the Ripple Mass Diagram to calculate maximum annual drought volume/drought duration (Cunnane, 1981). In some cases the frequency analysis of drought volume and duration is also conducted. The analysis results in deciding the capacity of storage structure to meet a particular threshold discharge at all times, when the river flow is not able to supply the demand.

3.0: GENERAL DESCRIPTION OF KRISHNA BASIN

Krishna basin lies between 13° 30' to 18° 44' N latitude to 73° 12' to 81° 36' 10" E longitude, covering a part of Maharashtra, Karnataka and Andhra Pradesh (Fig. 1). The climate of the basin is characterized by a hot summer and general dryness during the major part of the year except during Southwest monsoon. The rainy season generally commences in the month of June and lasts till October. With the withdrawal of the monsoon around in first week of October, the day temperature increases slightly. However, the night temperature decreases steadily with the day after the withdrawal of monsoon. Rainfall of about 564.88 mm, which forms 72 percent of the total annual rainfall in the basin is received during the southwest monsoon season.

3.1: The Malaprabha Sub-basin and Reservoir

The Malaprabha river is one of the main tributaries of the

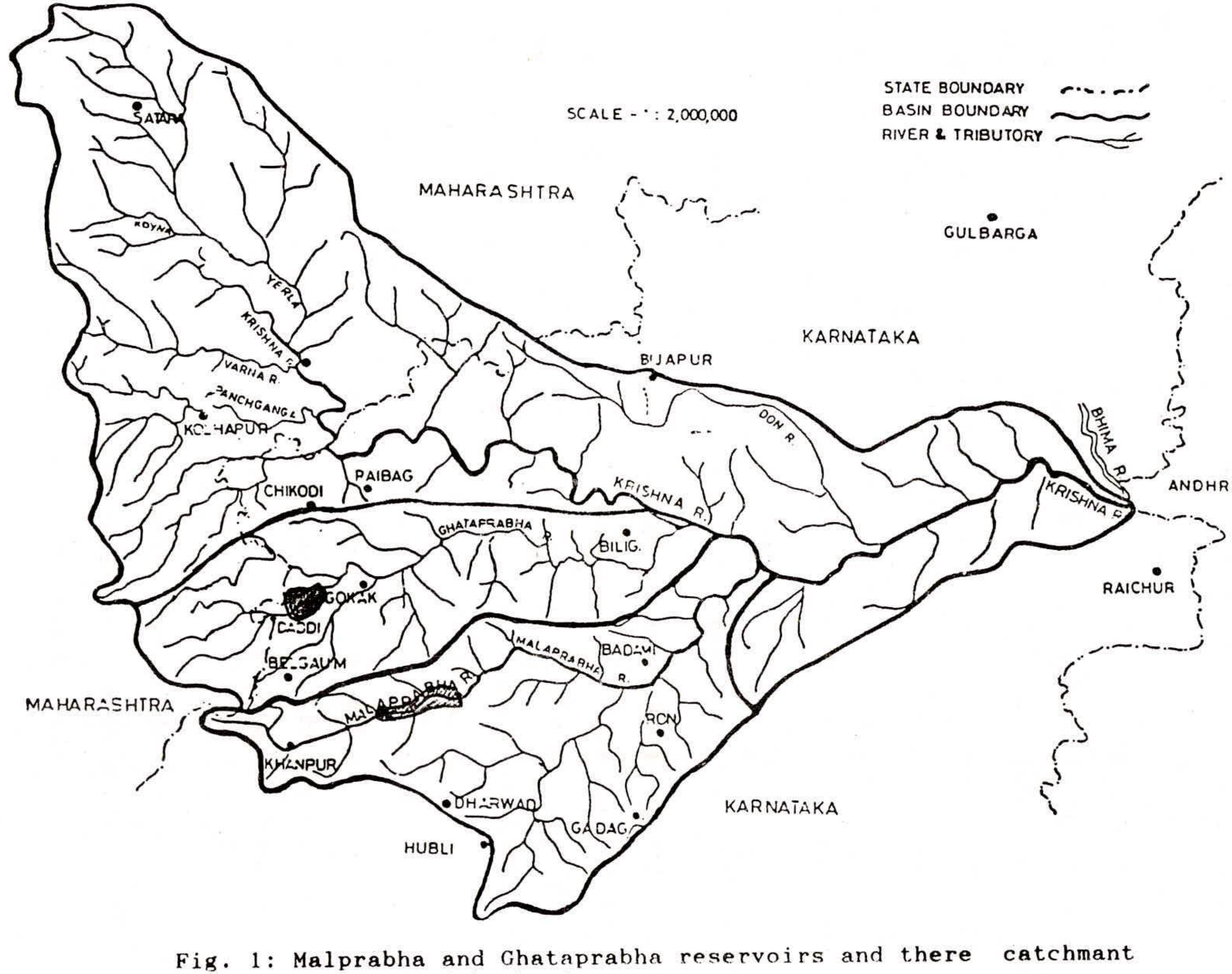


Fig. 1: Malprabha and Ghataprabha reservoirs and there catchmant area in Krisha basin.

river Krishna. It has its source in the Western Ghats at an altitude of 792 m above 36.0 km. south west of Belgaum district in Karnataka state. The river travels a distance of 306.0 km. in Belgaum and Dharwar districts before joining river Krishna at Kapil Sangam. The area drained by this river from its origin to its confluence with Krishna is 11, 649 sq. km. The slope of the sub-basin is triangular in general. The terrain is flat to gently undulating except for a few hillocks and valleys. In general the climate of the sub-basin is dry except in monsoon season and fall in to drought prone area classified by Indian Meteorological Department.

The major storage scheme in the Malaprabha sub-basin is Malaprabha reservoir. It is a composite dam of 154.53 m length and 40.23 m height at Naviluteerth in Saundatti Toluka of Belgaum district. It has the gross capacity of 1068 MCM at FRL 633.83 m. The catchment area up to the dam site is 2564 sq. km. with the yield of 1205 MCM. The storage of dam mainly meets the irrigation demand of Dharwad and Belgaum in Kharif season.

There are three gauge discharge sites on the river Malaprabha. The sites are maintained by Water Resources Development Organization. The sites are Khanapur, Santhebestwood and Bidi respectively having catchment are of 326 sq. km., 37.24 sq. km. and 82.88 sq. km. The sites Santhebestwad and Bidi being in the drought prone area and contribute a very low flow (negligible) only in monsoon months and, therefore, have been closed. The one still running measuring site is Khanpur. The reservoir level/gross capacity curve for Malaprabha is shown in

Fig. 2.

3.2: The Ghataprabha Sub-basin and Reservoir

The Ghataprabha river is one of the right bank tributaries of the Krishna in its upper reaches. The catchment of the sub-basin lies approximately between the northern latitudes of 15° 45' and 16° 25' and eastern longitudes 74° 00' and 75° 55'. The river Ghataprabha originates from the Western Ghats in Maharashtra at an altitude of 884 m, flows westwards. In Karnataka, the river flows 216 km. through the Belgaum district past Bagalkot. Its principal tributaries are the Tamraparni, the Hiranyakashi and the Markandeya. Most of the basin is flat to gently undulating except for isolated hillocks and valleys. The sub-basin is approximately triangular in shape. The climate of the sub-basin is marked by hot summer and mild winter. The monsoon sets early in June and continues to the end of October. The sub-basin experiences only the South West monsoon and the period is generally from June to October and two third of the area falls in drought prone area as specified by Indian Meteorological Department.

The major storage scheme in Ghataprabha is located near Hidkal in Hukkeri Taluk in Belgaum District. The total catchment area up to the reservoir site is 1412 sq. km. with an yield of 69.6 MCM. At full reservoir level (FRL) of 662.94 m, the storage capacity of reservoir is 1448 MCM. The total command area covered by the project is 3,17,447 hectares. The storage of the dam is mainly used for irrigation.

The gauge discharge site mainly contributes to the reservoir is Daddi, which has a catchment area of 1150.0 sq. km. and is located upstream of project. The reservoir level/gross capacity curve of Ghataprabha is shown in Fig. 2.

4.0: METHODOLOGY

The daily in flow to the reservoir is subjected to the analysis in order to find the monograms for the identification of drought. The analysis carried out are as listed below.

1. Annual flow departure.
2. Maximum drought value.
3. Days of water availability.
4. Monthly mean available storage.

The objective of the study is to analyse the reservoir inflow to identify an index for drought in terms of reservoir level. With such an objective, it is important to know the limitation and applicability of above analysis. The analysis reported above are for the river flow with emphasis on low flow having objective to know about departure of low flow and reservoir storage to meet the demand during the lean flow period. The application of above analysis is therefore widely applicable to the conditions of arid to semi-arid regions. The above analysis are not intended for conditions where the regulation of the peak flow or routing through reservoir is to be considered. The flow departure analysis, results in the flow departure from its mean without giving any attention to the existing demand at that point of river.

The maximum drought volume at any site is analysed to decide the storage volume of a reservoir in order to supply the water during the period of deficiency for a given demand. In the present analysis of maximum drought volume, the demand is considered as the direct demand at that particular point. The direct water requirement includes (a) water supply for domestic, trade, agricultural and municipal uses including losses, (b) water requirement for diluteation of sewage in rivers, tanks etc. (c) water requirement for hydroelectric power generation. The analysis is suitable for arid and semi-arid zones.

The analysis of water available days also considers the volume of water received in the river over and above the drought volume, which could be stored and utilized to compensate for the next drought volume. The analysis of mean monthly available storage also considers the drought volume as well as the demand as explained earlier.

4.1: Data Requirement

The analysis requires the daily inflow to the reservoir and reservoir level/capacity curve. In addition, the daily demand at the point is required if available. Since, the daily demand of the area is not known, the analysis is carried out for different threshold discharges as the percent of mean flow.

The present analysis has been carried out for Malaprabha and Ghataprabha reservoirs located in semi-arid zone. For the analysis of Malaprabha reservoir the daily river flow of fourteen years, starting from 1972-73 to 1985-86 and for Ghataprabha the daily river flow of ten years, starting from 1979-80 to 1988-89 were considered.

4.2 Selection of Base Period and Threshold Discharge

The base period in the analysis is considered as a year and any carry over effect of drought from one year to next year is not considered to confirm with the assumption in estimation procedure of maximum drought volume. The assumption is that, all flows in the current base period are greater than the threshold discharge. The assumption says that, at the end of each year there is one value of maximum drought. The assumption is based on the fact that the reservoir is depleted due to drought in one year, at beginning of next year, there will be no storage in the reservoir to supply during deficiency. As such carry over of drought in case of reservoir physically has no meaning and finding an index for an empty reservoir has no significance. This carry over effect of drought could be true for an aquifer which is considered as a ground water reservoirs.

The other reason for not considering the carry over affect of drought volume from year to year is the nature of storage in the reservoir. The nature of storage in reservoir is limited by a minimum and maximum value, with objective to utilise the storage most economically before the rains of next base period starts. The possibility of excess mining and its replenishment is not possible to such storage. Therefore, the carryover of drought volume from year to year is not considered.

The decision of assigning a demand to be supplied by the reservoir is a complex process. The demand at a point on a reservoir varies from year to year and on the local requirements. The demand in a year followed by a drought year also varies. Therefore, the matter of deciding the demand on a reservoir is left to the user, based on local requirements and existing reservoir level. Since the actual demand of the area is not known, the analysis is carried out for different threshold discharges. The values of threshold discharges is taken as the percentage of mean daily flow such that it covers the reservoir supply ranges from normal to drought situations. The threshold discharges considered are 20%, 30%, 40%, 60% and 75% of mean daily flow.

4.3: Annual Flow Departure

The percent departure on annual basis is the departure of annual flow from its long term mean. The analysis highlights the year of high and low flows. The years of low flow could be classified in drought scale as per the criteria of CWC 1982. The analysis requires the long term flow data and does not consider the effects of demand on drought identification. The analysis has been carried out as per the procedure defined by CWC, 1982. The mean daily flow is converted to mean annual flow and is subjected to the departure analysis. A commonly used index as suggested by CWC, 1982 has been applied to classify the drought. The criteria says as follows;

If;

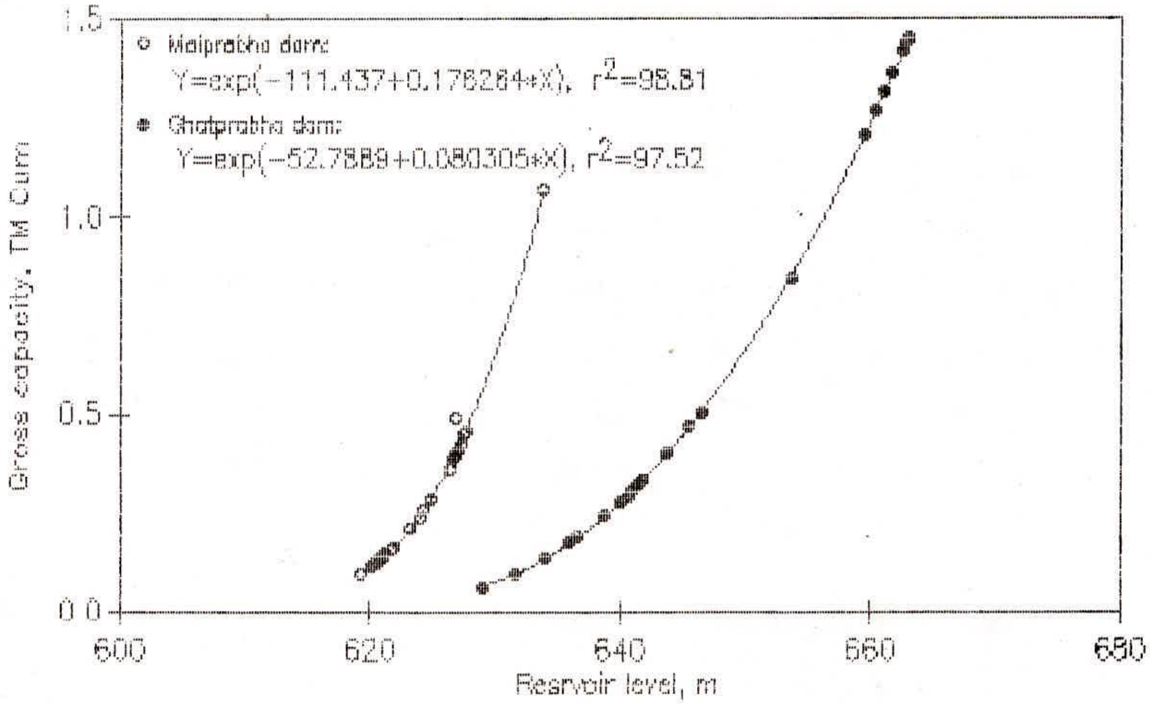
a. Percent departure is greater than 50 % (Severe drought)
b. Percent departure is in between 25-50 % (Moderate drought)

This analysis at present is carried out only to have an idea of pattern of yearly river flow to reflect the situation of flow in each year.

4.4: Maximum Drought Volume

The maximum drought volume is the storage volume required at the beginning of the drought to prevent water supply for falling below the demand for the duration of the drought in a base period of a year. The definition of drought volume itself defines the duration of drought for a particular demand during any period of stream flow record.

The drought volume in a single drought consist of a single deficit followed by a surplus which should make recovery of the deficit and if the flow drops below the threshold discharge before the recovery can occur, the drought is continued into next time step till the recovery is obtained. An example is shown in Fig. 3. The net deficit at each time step is calculated till the volume becomes surplus related to some specific threshold discharge. At the end of each surplus the maximum deficit volume is the drought volume in one drought element. It is, therefore, at high threshold discharge, there may be more numbers of drought elements with high drought volume but for low threshold discharge the number of drought elements as well as drought volume will be low. The method estimates the maximum drought on annual basis as one base period. The base period ends when there is no further flow less than the threshold discharge i.e. the next monsoon should have been started. The procedure has been defined by Institute of Hydrology (1980). This procedure allows



. Fig. 2 : Reservoir level / gross capacity curve for Malaprabha and Ghataprabha reservoirs.

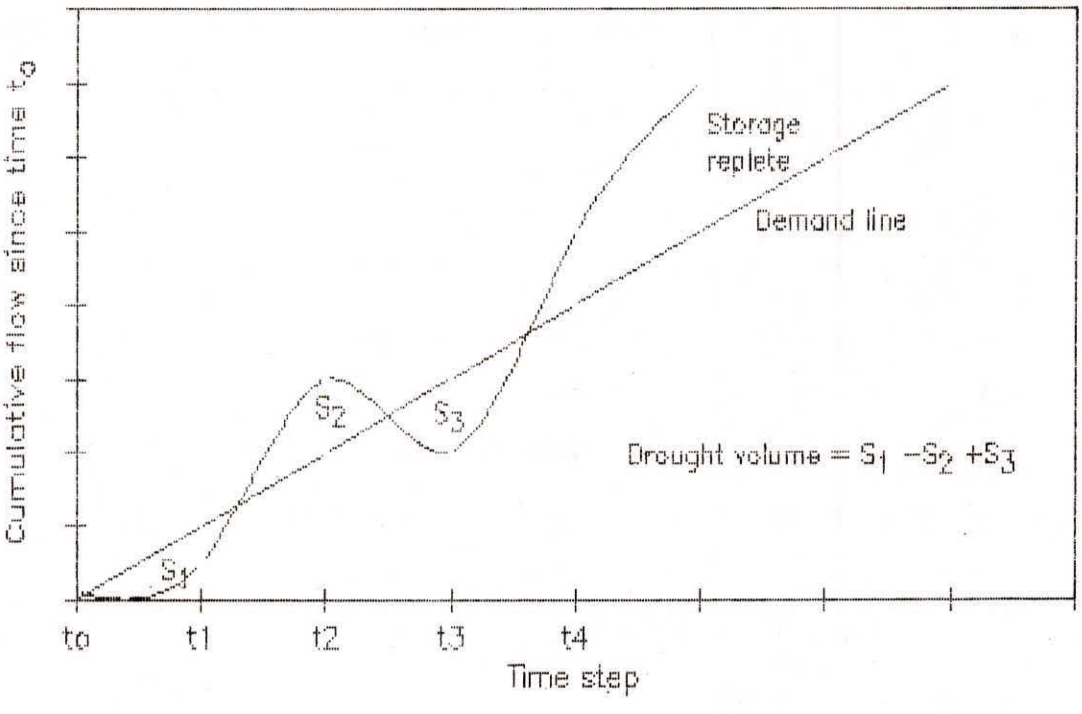


Fig.3 : Systematic diagram of drought volume at different time step.

for the effect of possible carry over of a previous drought element in the same base period.

The maximum drought volume is estimated for each year using the mean daily inflow and superimposing a threshold discharge as percentage of mean daily flow. The analysis results in maximum drought volume for a base period as one year. By statistical analysis of maximum drought volume of a number of years , the required maximum storage volume for different return period is also estimated. The analysis of drought duration, the duration of low flow, could also be carried out on the similar guidelines, but not considered in this report.

The maximum drought volume is obtained by viewing the flow record and deciding a common date as the start of monsoon to all years for which data has been considered. For different return period the drought volume is plotted against threshold discharge as a percentage of mean flow for the purposes of interpolating the drought volume (storage required) for other demand. This maximum drought volume related to a threshold discharge are arranged in ascending order and there plotting position are marked using an Extreme Value Type 1 distribution.

The cumulative distribution function of the Extreme value 1 type distribution is;

$$F(q) = \exp[-e^{\{(q-u)/\alpha\}}] \qquad \ldots\ldots(1)$$

where; u, α are the parameters of location and scale respectively and are determined from sample data. F(q) is the non exceedable probability of q (data) in the series.

By replacing $(q-u)/\alpha = Y$, the equation (1) reduces to:

$$\ln\{F(Y)\} = -e^{-Y} \quad \ldots\ldots(2)$$

where; Y is called the Extreme Value 1 standardized normal variate or reduced variate and has parameters u=o and α=1. An appropriate expression for probability value F_i corresponding to Y_i has been given by Gringorten as:

$$F_i = (i - 0.44)/(N + 0.12) \quad \ldots\ldots(3)$$

where; N is the sample and i is the rank counted from the smallest value. The values of F_i is used with equation (2). Thus the drought volume (S) can be represented by plotting position (Y) as a line 'S = a + b Y' and the constants are estimated by a lest square analysis of 'S' on 'Y'. The return period (T_p) could be estimated by $Y = -\ln(1/T_p)$.

4.5 Water Available Days

The duration for which the supply is greater than the threshold discharge is considered as the water available day. The days water available from a reservoir is dependent on the storage volume of the reservoir and threshold discharge. An analysis for water available days at different demand has been carried out in order to yield a series of graphs relating the above parameters for Malaprabha and Ghataprabha reservoir at different storage. For the case, when the storage volume at the beginning is sufficiently high, such that, to prevent the supply for falling below a threshold discharge, there will be no day with short of water supply. The stored volume will be utilized to prevent the flow to fall below threshold discharge. Such a condition could only happen when either storage volume is very high or the threshold discharge is very low, i.e. the condition of uneconomical management of storage. For the conditions, when the storage at the beginning is not sufficient, the water supply normally goes down resulting in short of water supply and turns to the situation drought by a short of supply at threshold discharge. The water available days is defined as to the situation when:

Available cumulative threshold discharge > Cumulative demand

4.6: Monthly Mean Available Storage

Monthly mean available storage is estimated at different threshold discharge from daily river flow data. The monthly mean storage volume is than converted to level of storage structure. Based on numbers of year data, the monthly mean level and its standard deviation is estimated. A criteria for drought is given by relating monthly mean level to its standard deviation and half of standard deviation as follows;

For mild drought;
Storage level < Monthly mean level - Standard deviation/2

For moderate drought;
Storage level < Monthly mean level - Standard deviation

5.0: RESULTS AND DISCUSSION

The mean daily flow at Malaprabha and Ghataprabha reservoir site is estimated as 25.7 m^3/sec and 66.7 m^3/sec based on fourteen and ten years daily flow data. The annual departure from its mean for both Malaprabha and Ghataprabha are reported in Table 1.

Table 1. Annual flow departure for Malaprabha and Ghataprabha reservoirs.

	Malaprabha reservoir			Ghataprabha reservoir		
Sl. No.	Year	Percent departure	Remarks	Year	Percent departure	Remarks
1	1972-73	-35.19	M.D.	1979-80	9.32	N.F.
2	1973-74	-8.52	N.F.	1980-81	13.16	N.F.
3	1974-75	27.70	N.F.	1981-82	12.12	N.F.
4	1975-76	22.42	N.F.	1982-83	31.66	N.F.
5	1976-77	-20.63	L.F.	1983-84	11.88	N.F.
6	1977-78	2.30	N.F.	1984-85	17.53	N.F.
7	1978-79	-18.01	L.F.	1985-86	-27.19	M.D.
8	1979-80	8.48	N.F.	1986-87	-33.00	M.D.
9	1980-81	26.93	N.F.	1987-88	-48.02	M.D.
10	1981-82	15.14	N.F.	1988-89	12.53	N.F.
11	1982-83	38.65	N.F.			
12	1983-84	-1.03	N.F.			
13	1984-85	-18.92	L.F.			
14	1985-86	-39.33	M.D.			

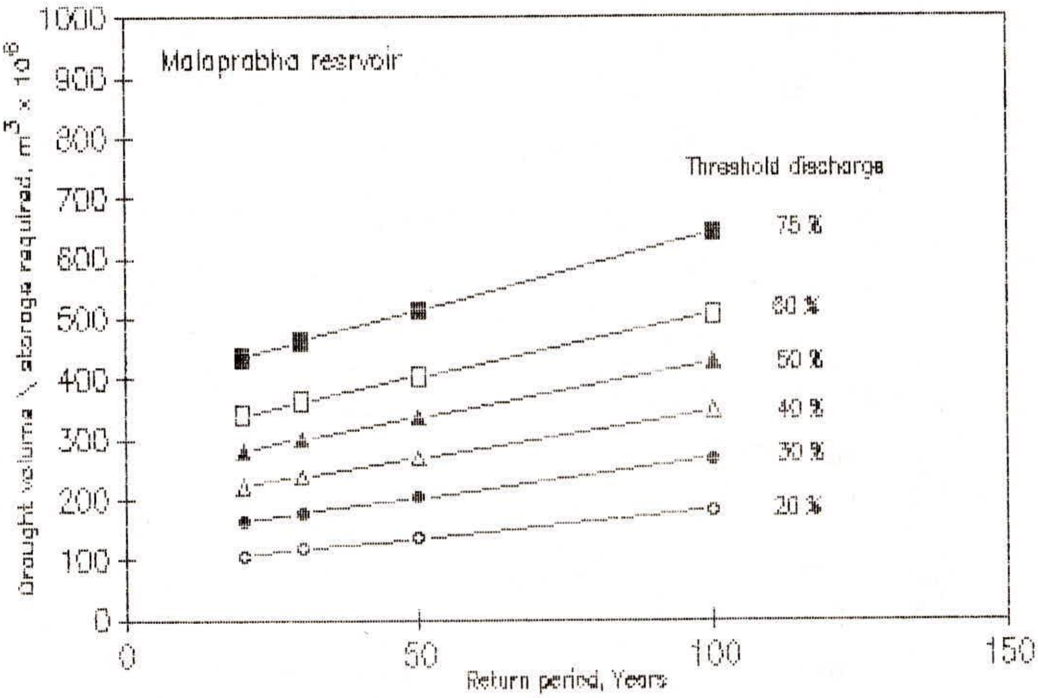
M.D.: moderate drought, L.F.: low flow, N.F.: normal flow

As per criteria of CWC, the river flow to Malaprabha basin received moderate drought in years 1972-73 and in year 1985-86 having percent departure respectively -35.19 and -39.33. The years 1976-77, 1978-79 and 1984-85 received the low flow with percent departure as -20.63, -18.01 and -18.92. The Ghataprabha basin site received moderate drought in years 1985-86, 1986-87 and 1987-88 respectively having percent departure as -27.19 , -33.00 and -48.02 respectively and the rest of the years the basin received normal flow.

In the analysis of maximum drought volume, the first step is to decide the time of on set of monsoon, such that, all the flows beyond this time is above threshold discharge in order to fulfil the limitation of the procedure. The daily river flow of all the years along with its mean flow for both Malaprabha and Ghataprabha reservoir sites are reported in Fig. 1 to Fig. 14 and Fig. 15 to Fig. 24 (Appendix-I). It could be observed that no particular date of start of monsoon could be assigned. On an average the monsoon starts in the month of June in both Malaprabha and Ghataprabha sites. It is, therefore, the June 1 is considered as the date beyond which all flows are assumed greater than the threshold discharge.

The maximum drought volume (storage required) for different return periods at different threshold discharge for Malaprabha and Ghataprabha reservoirs and reported in Fig. 4. In case of Malaprabha reservoir a storage volume of around 500×10^6 m^3 will meet threshold discharge of 75 % of mean flow with failure once in 40 year. Similarly in Ghataprabha reservoir a storage volume of 1500×10^6 m^3 will meet the demand of 75 % of mean flow with a failure once in 60 years (Fig. 5). In both the cases when the threshold discharge is reduced, the risk of failure to supply water decreases.

The maximum drought volume as a percent of mean annual flow value has also been shown in Fig. 5 for Malaprabha and Ghataprabha reservoirs. It can be seen that the curves (Fig. 5) of Malaprabha and Ghataprabha at each threshold discharge are nearly the same. Therefore, a mean volume could be suggested for estimating storage volume of un-gauged sites in the region.



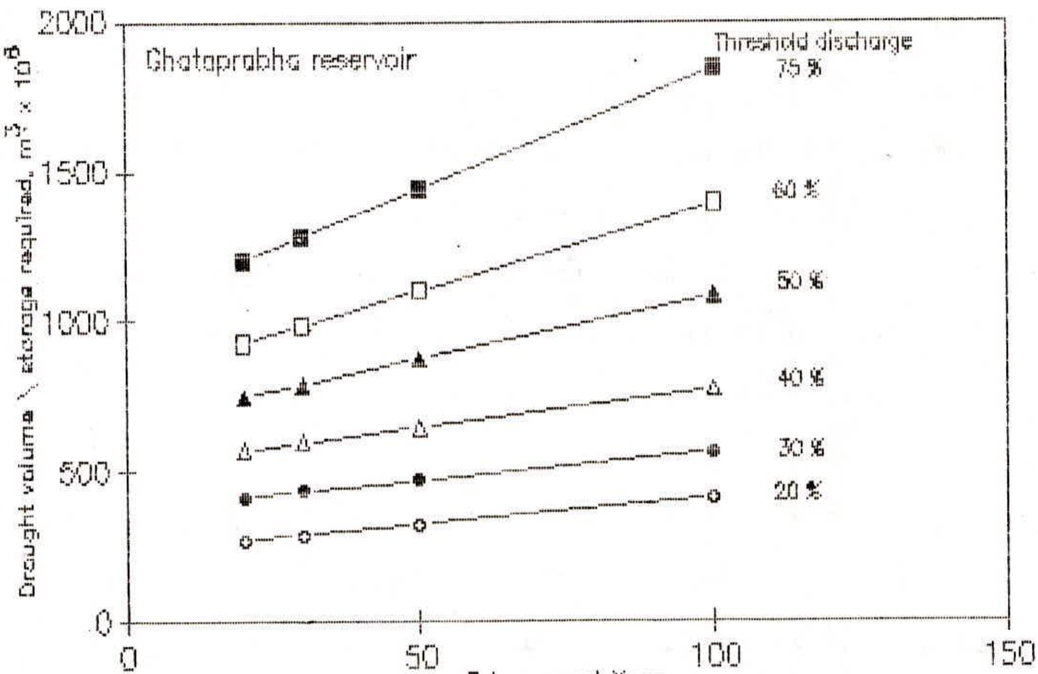


Fig. 4: Estimated drought volume / storage volume required at different threshold discharge and return period for Malaprabha and Ghataprabha reservoirs .

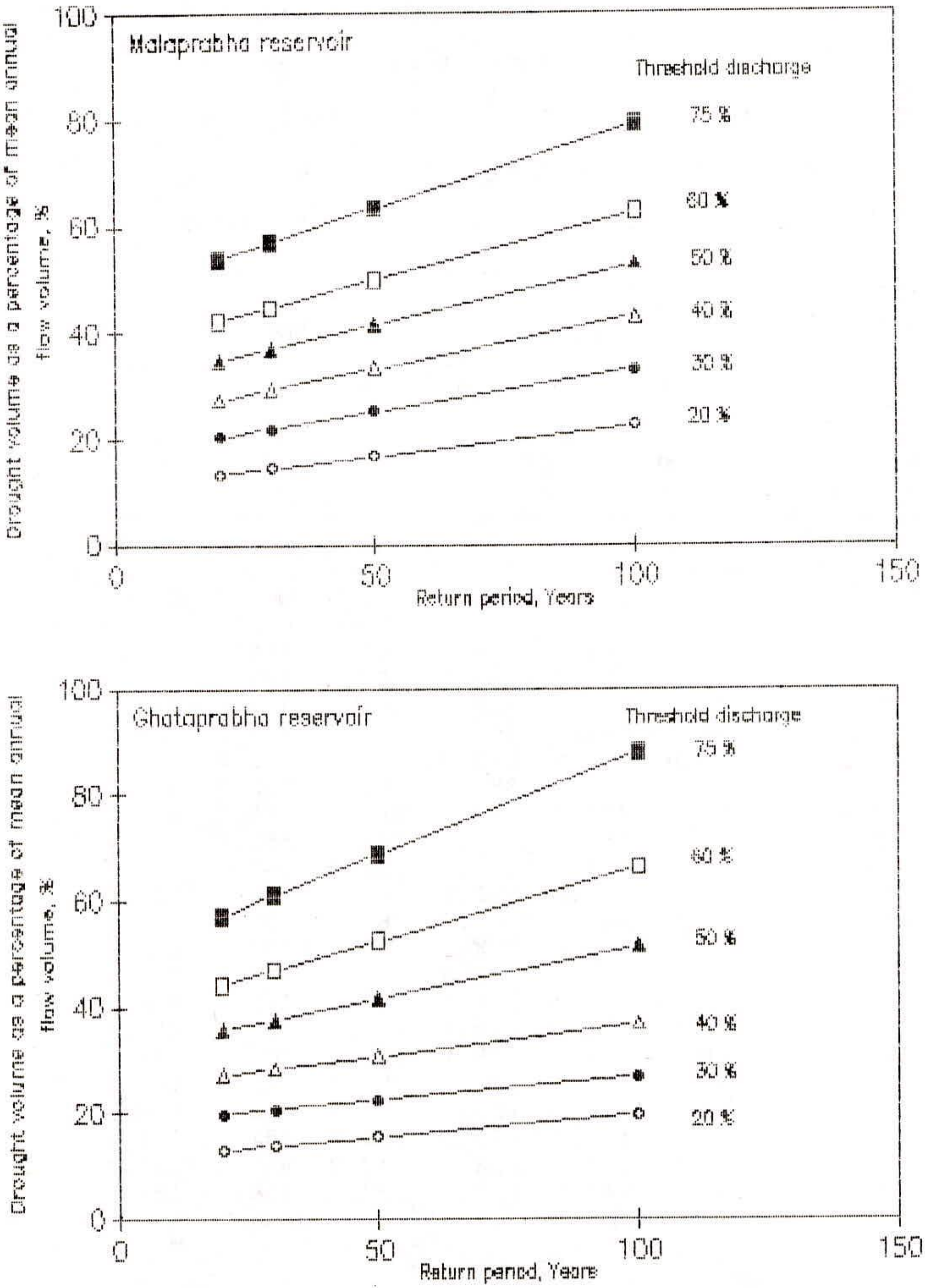


Fig.5 : Drought volume as a percentage of mean annual flow volume at different threshold discharge and return period for Malaprabha and Ghataprabha reservoirs .

Water available days at different demand and reservoir level is estimated. The average number of water available days in a year for Malaprabha case is reported in Table 2, Fig. 6. It can be observed, with the help of figure 6, that a reservoir level of 50 percent will meet a threshold discharge of around 50 percent of mean flow on an average for 362 days of the year. Similarly a reservoir level of 65 % or above will meet a threshold discharge of 75 % of the mean flow on an average 352 days.

Table 2: Average number of water available days / year for Malaprabha reservoir for average condition.

Sl. No.	Reservoir level %	Average number of water available days, days/year Threshold discharge as a percent of mean daily flow 20.0%	30.0%	40.0%	50.0%	60.0%	75.0%
1	100.0	365.0	364.6	363.9	363.9	362.2	352.3
2	95.0	365.0	364.6	363.9	363.9	362.2	352.3
3	90.0	365.0	364.6	363.9	363.9	362.2	352.3
4	85.0	365.0	364.6	363.9	363.9	362.2	352.3
5	80.0	365.0	364.6	363.9	363.9	362.2	352.3
6	75.0	365.0	364.6	363.9	363.9	362.2	352.3
7	70.0	365.0	364.6	363.9	363.9	362.2	352.3
8	65.0	365.0	364.6	363.9	363.9	362.2	**352.3**
9	60.0	365.0	364.6	363.9	363.9	362.2	341.0
10	55.0	365.0	364.6	363.9	363.9	360.2	315.6
11	50.0	365.0	364.6	363.9	**362.6**	333.6	289.5
12	45.0	365.0	364.6	363.9	336.5	303.7	262.9
13	40.0	365.0	364.6	346.0	305.4	274.6	239.3
14	35.0	365.0	361.0	311.8	274.4	248.7	218.7
15	30.0	365.0	327.4	278.1	246.9	225.8	200.4
16	25.0	356.5	289.1	248.1	222.8	205.8	184.1
17	20.0	312.7	253.9	221.7	201.6	188.0	169.6
18	15.0	266.6	222.8	198.2	182.9	172.0	156.7
19	10.0	225.6	195.3	177.3	165.6	157.5	144.6
20	5.0	189.0	170.3	158.7	149.2	143.0	133.4
21	0.1	151.2	144.7	138.1	129.2	126.6	121.6

The maximum and minimum water available days is also estimated by separating the fourteen years data in to normal flow years and low flow years (Fig. 6). It can be seen that the number of water available days at threshold discharge of 75 % of

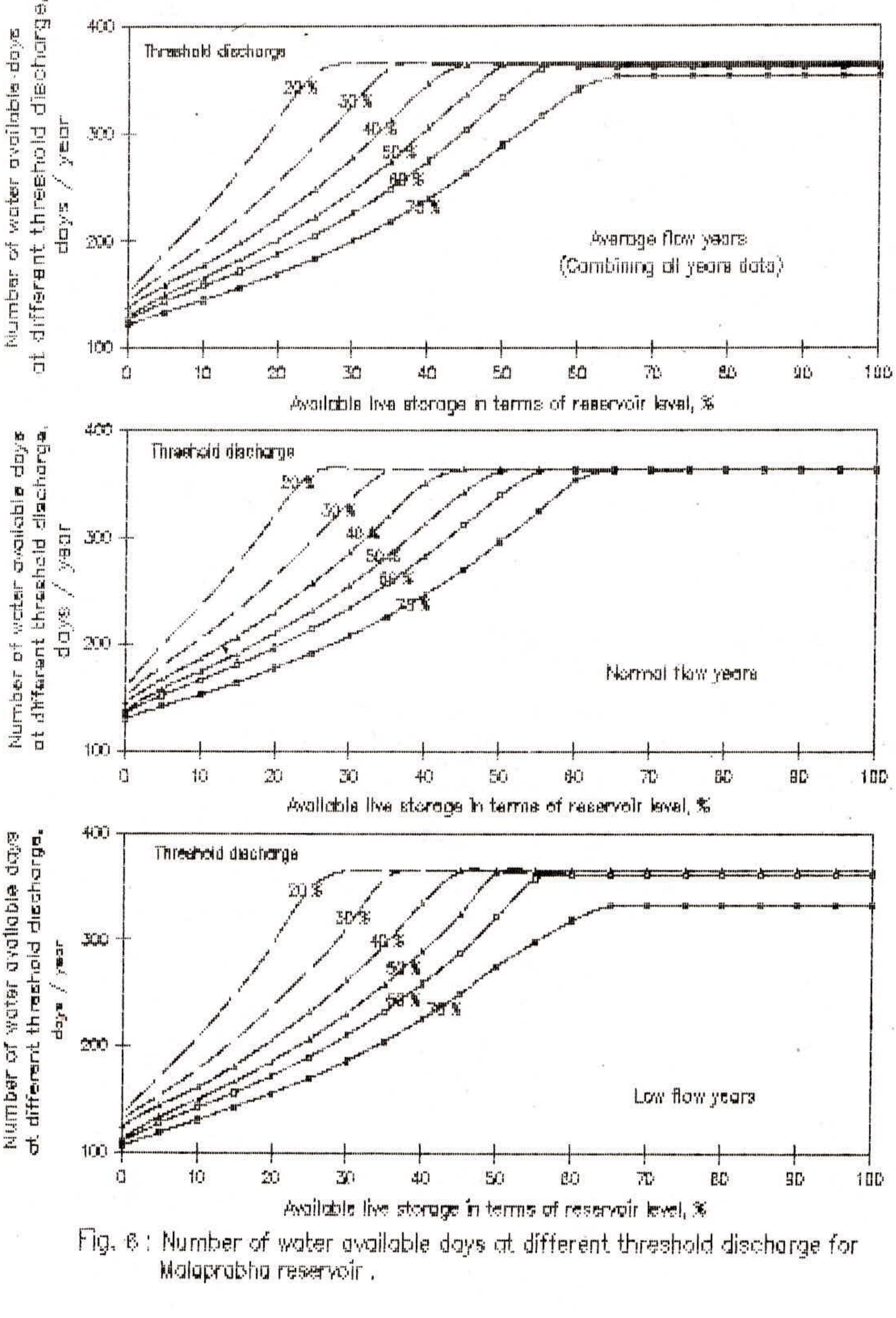


Fig. 6 : Number of water available days at different threshold discharge for Malaprabha reservoir .

mean flow and at 65 % reservoir level are on average 363 days for normal year and 332 days for drought year, well above and below the average number of days as 352 for the average condition of reservoir.

The average number of water available days in a year for Ghataprabha is reported in Table 3. A reservoir level of 50 percent will meet a threshold discharge of 50 percent of mean flow for 228 days on an average in a year. Similarly, a threshold discharge of 75 percent of mean flow with 95 percent or above reservoir level, will meet the threshold discharge of 343 days on an average in a year (Table 3).

Table 3: Average number of water available days / year for Ghataprabha reservoir for average condition.

Sl. No.	Reservoir level %	Average number of water available days, days/year Demand as a percent of mean daily flow 20.0%	30.0%	40.0%	50.0%	60.0%	75.0%
1	100.0	365.0	365.0	364.7	363.5	357.5	343.3
2	95.0	365.0	365.0	364.7	363.5	357.5	**343.3**
3	90.0	365.0	365.0	364.7	363.5	357.5	340.5
4	85.0	365.0	365.0	364.7	363.5	357.0	316.7
5	80.0	365.0	365.0	364.7	363.5	341.1	290.8
6	75.0	365.0	365.0	364.7	356.7	312.9	267.9
7	70.0	365.0	365.0	364.7	324.7	286.2	247.8
8	65.0	365.0	365.0	343.0	295.7	262.1	229.1
9	60.0	365.0	365.0	311.6	270.1	240.8	212.1
10	55.0	365.0	341.3	283.8	247.7	222.1	197.1
11	50.0	365.0	309.0	259.2	**228.2**	205.9	183.9
12	45.0	358.3	280.6	238.1	211.1	191.5	172.1
13	40.0	325.1	255.6	219.2	196.1	178.7	161.3
14	35.0	292.5	233.9	202.9	182.7	167.1	151.7
15	30.0	263.7	214.8	188.3	170.7	156.6	142.9
16	25.0	238.6	197.9	175.1	159.3	146.6	135.2
17	20.0	216.7	182.6	162.7	148.7	138.0	128.2
18	15.0	197.1	168.5	150.5	139.4	129.8	122.4
19	10.0	179.0	153.6	139.4	130.2	123.8	117.7
20	5.0	160.7	142.8	129.8	123.7	118.1	113.6
21	0.1	146.1	131.3	117.9	115.1	110.4	107.0

The maximum and minimum water available days is also estimated by separating the ten years data in to normal flow years and low flow years (Fig.7). It can be seen that the number of days water available for a threshold discharge of 75 % of mean flow and at 65 % reservoir level are on average 232 days for normal year and average 204 days for drought year, well above and below the average number of days as 228.

Thus the nomograms presented in Fig. 6 and Fig. 7 could be used for drought identification and indexing, by knowing the threshold discharge and the available storage in terms of reservoir level. At the same time, the nomograms reflect the number of days when the water will not be available at demand. Any situation for which the number of water available days at threshold discharge reduces, turns to the condition of drought.

The mean reservoir level at different threshold discharge and for different months are presented in Fig. 8 for Malaprabha reservoir along with the mean reservoir level minus half of its standard deviation and mean reservoir level minus standard deviation. The mean reservoir level is also reported by splitting the data in to low flow and normal flow conditions (Fig. 9 and Fig. 10).

It can be seen that the mean reservoir level for the years of low flow is always lower than the mean reservoir level of average condition and falls some where in mild drought to moderate drought condition. However, the reservoir level of normal flow is (Fig. 10) always above the average condition of

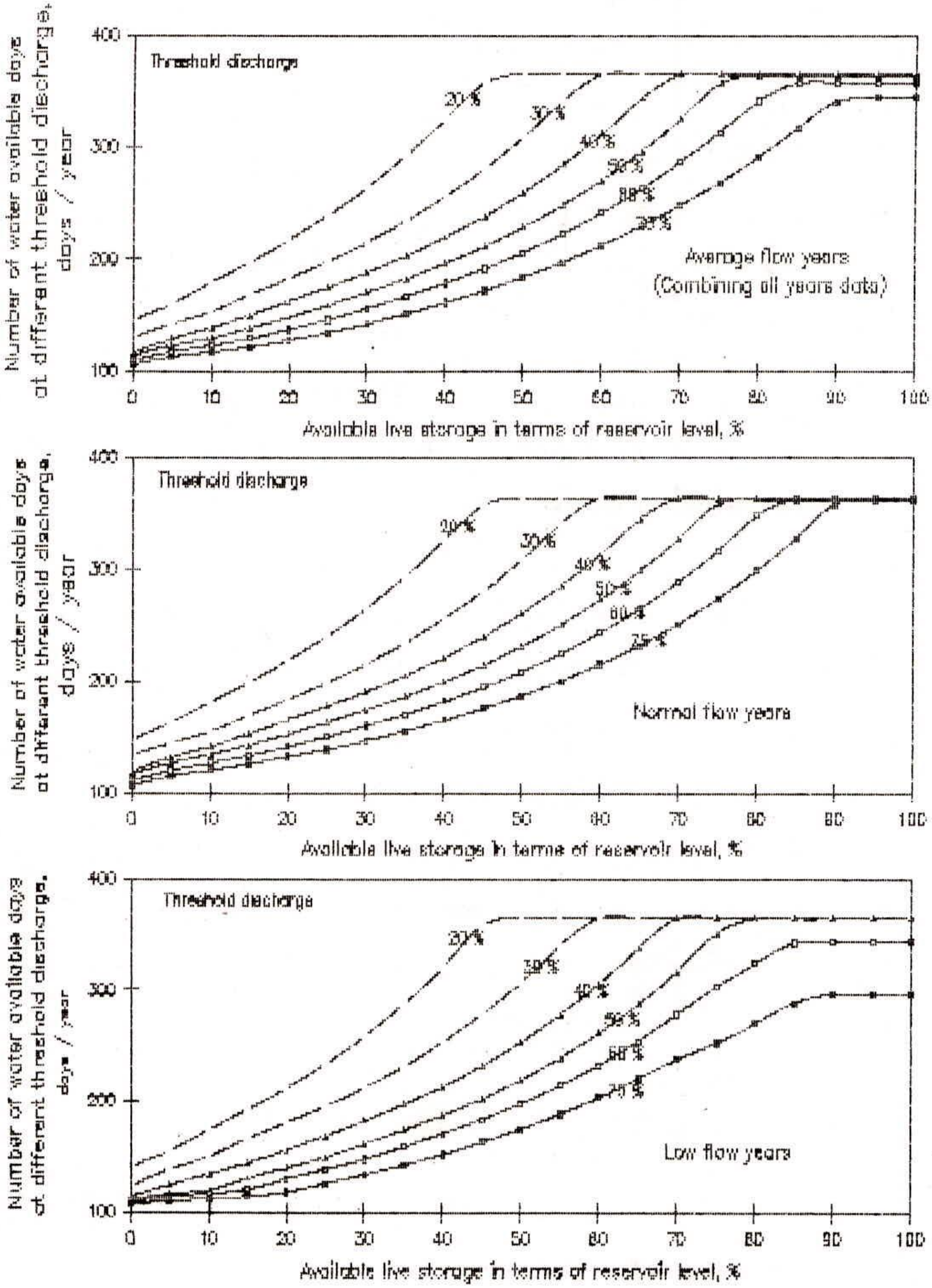


Fig. 7 : Number of water available days at different threshold discharge for Ghataprabha reservoir .

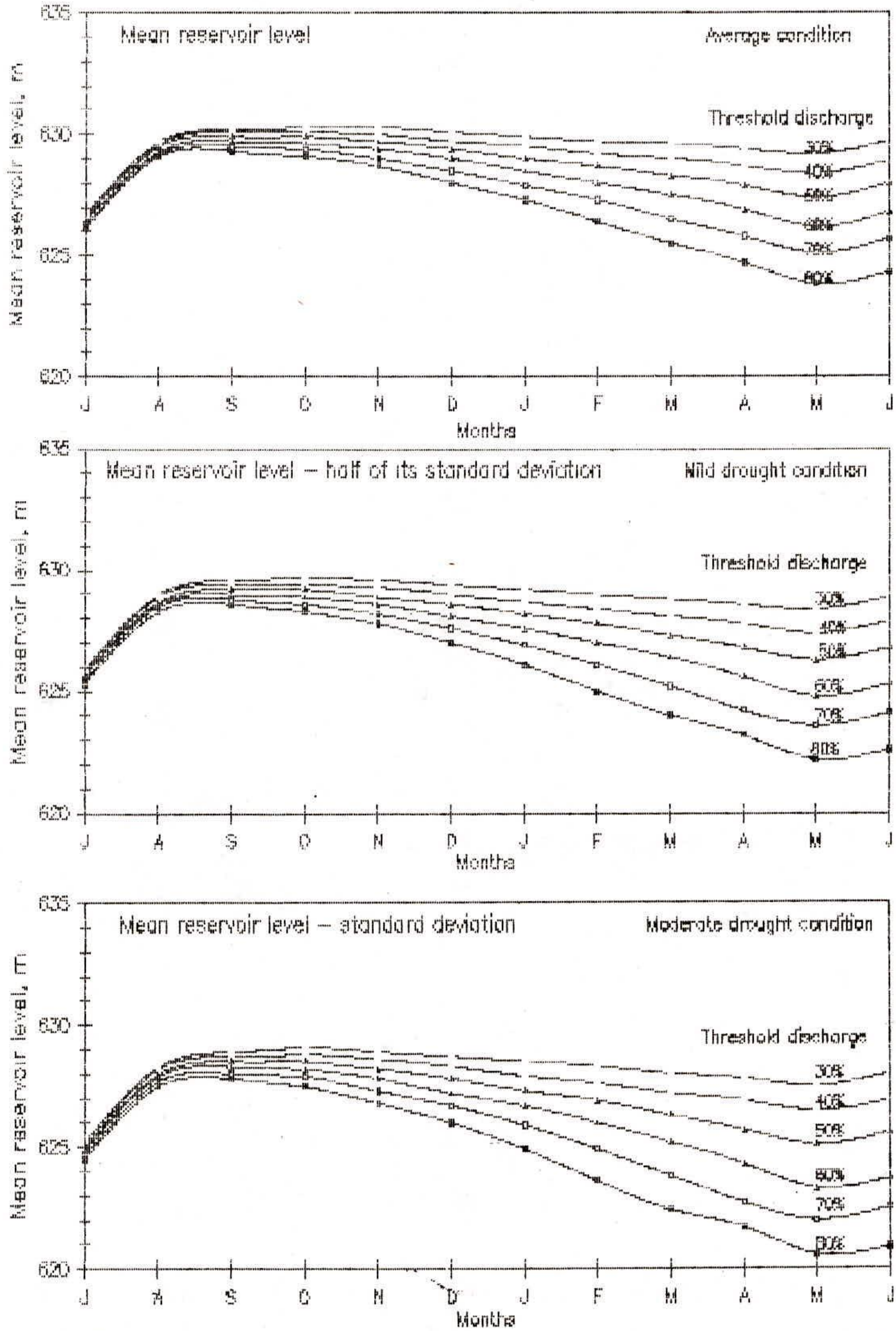


Fig. 8 : Mean reservoir level for different condition of drought at different threshold discharge for Malaprabha reservoir .

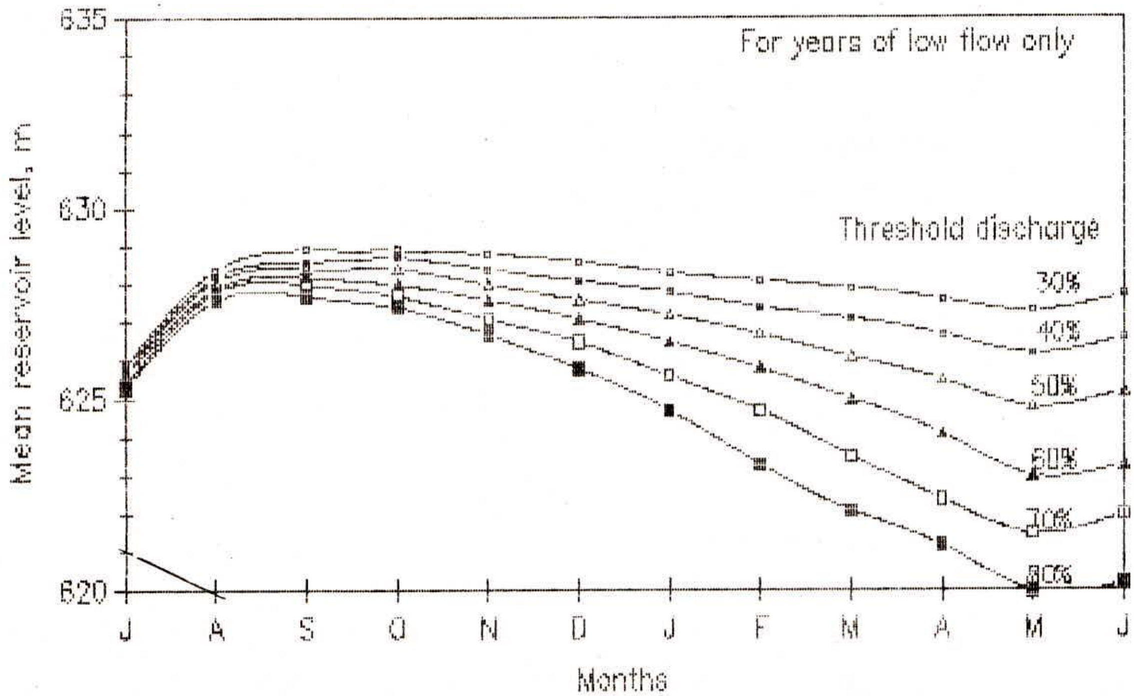


Fig. 9 : Monthly mean reservoir level at different threshold discharge for Malaprabha reservoir (low flow).

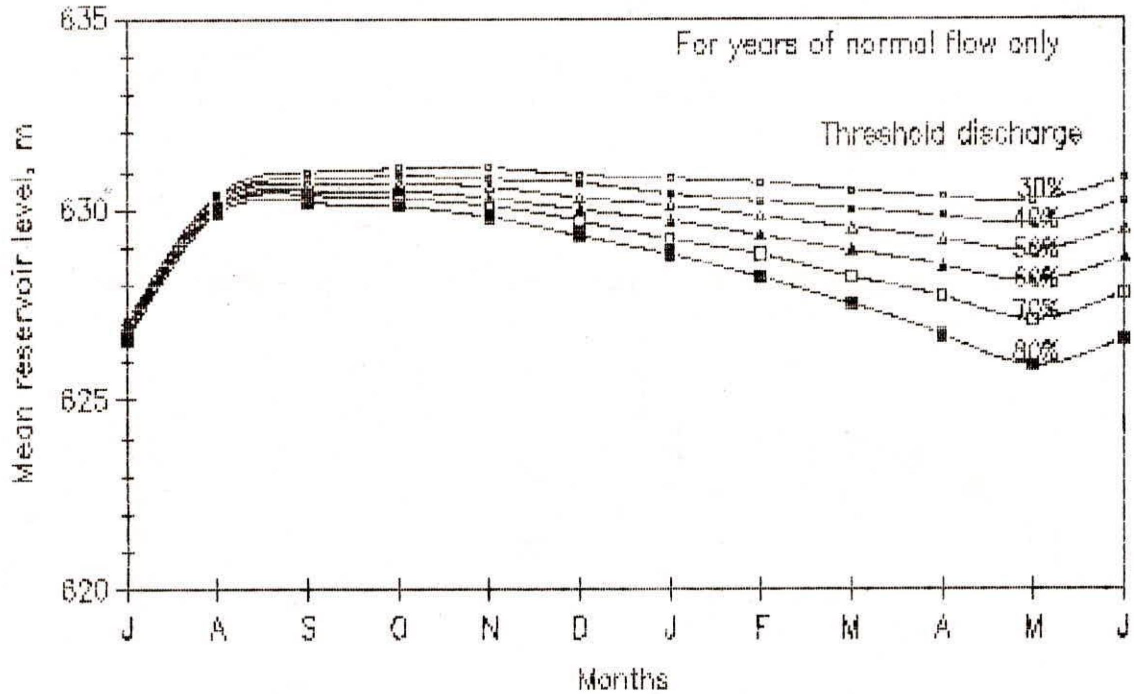


Fig 10: Monthly mean reservoir level at different threshold discharge for Malaprabha reservoir (normal flow).

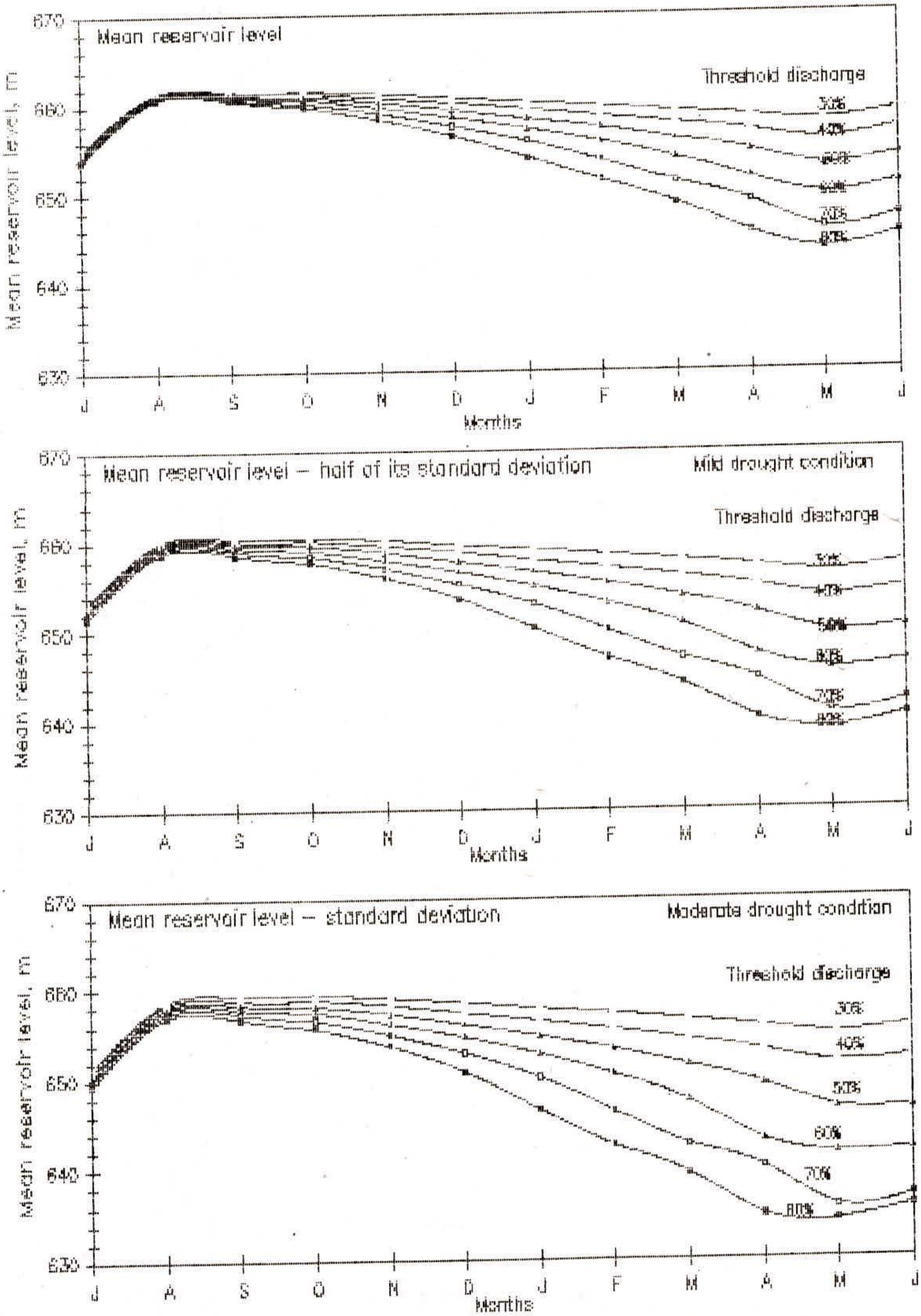


Fig.11: Mean reservoir level for different condition of drought at different threshold discharge for Ghataprabha reservoir .

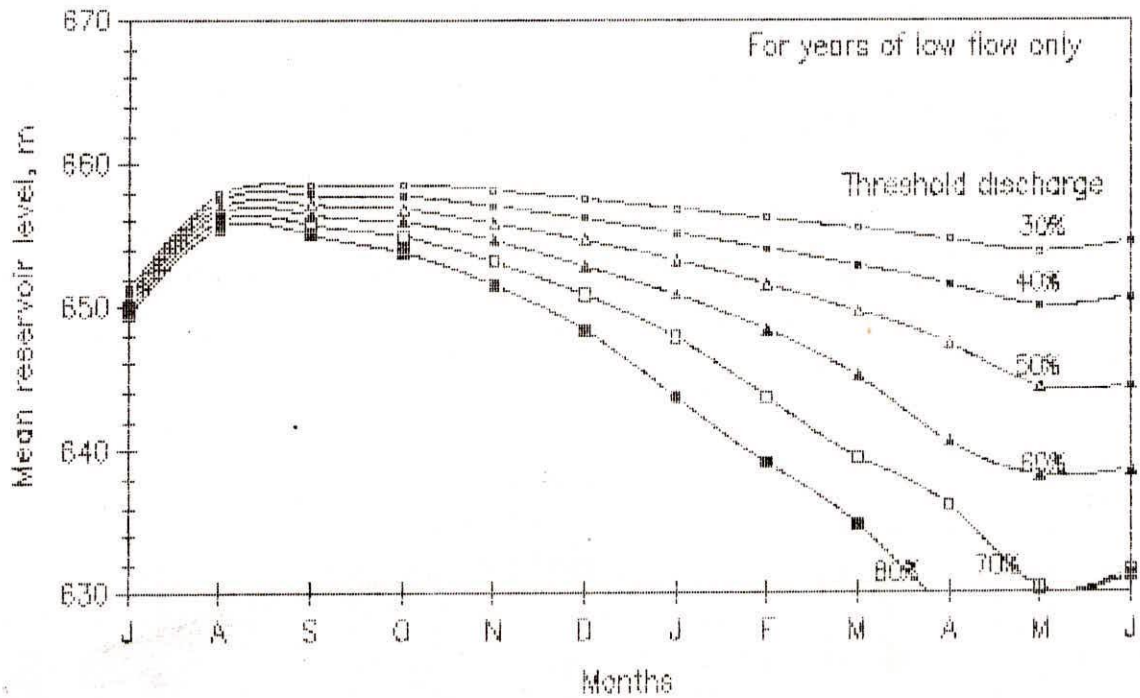


Fig.12: Monthly mean reservoir level at different threshold discharge for Ghataprabha reservoir (low flow).

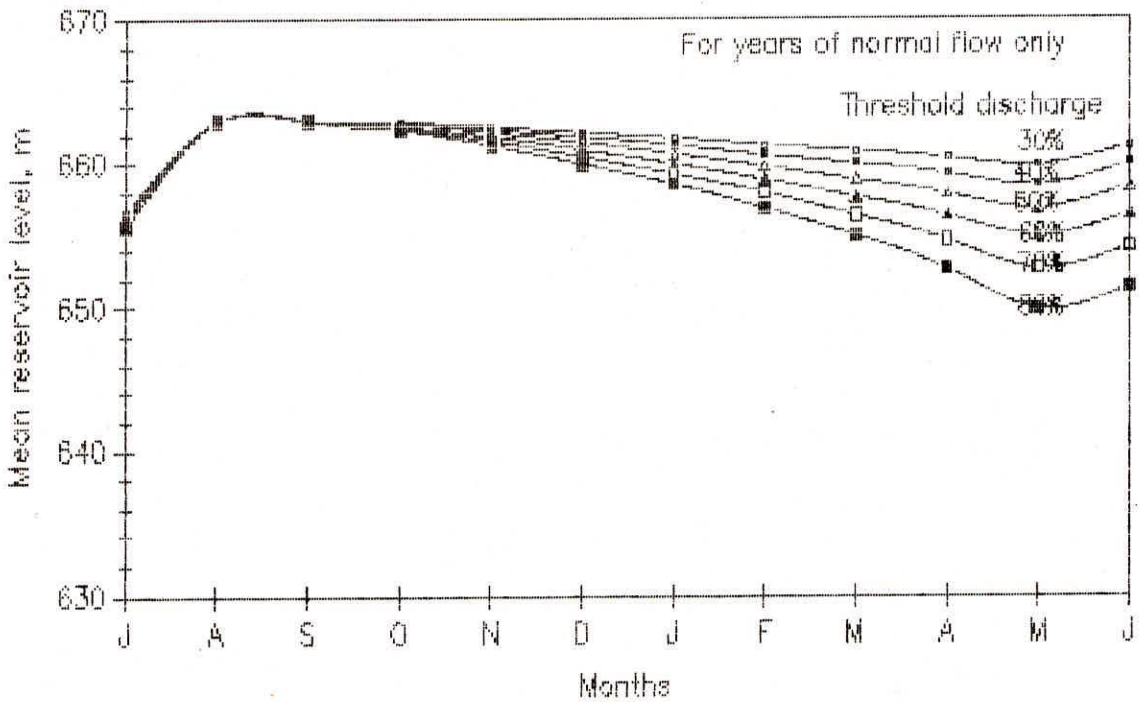


Fig.13: Monthly mean reservoir level at different threshold discharge for Ghataprabha reservoir (normal flow).

mean reservoir level, indicating no drought. Similar results were obtained for Ghataprabha reservoir by comparing the Figures 11, 12 and 13. The results suggest that the criteria of mean minus half of its standard deviation and mean minus its standard deviation could be used as an index for reservoir level for indexing drought.

6.0: CONCLUSIONS

The results discussed earlier led to the following conclusions.

1. The mean daily flow to Malaprabha is 25.7 m^3 /day and of Ghataprabha is 66.5 m^3 /day based on fourteen years and ten years daily data respectively. The annual flow departure analysis indicate that the years 1972-73, 1976-77, 1978-79, 1984-85 and 1985-86 are the years of reduced flows in Malaprabha basin. The years 1985-86, 1986-87 and 1987-88 are the years of reduced flows in Ghataprabha basin.

2. The drought volume (storage volume) of $500x10^6$ m^3 could meet a threshold discharge of 75 percent of mean flow with failure once in 50 years in the case of Malaprabha reservoir and in the case of Ghataprabha reservoir, the drought volume (storage volume) of $1500x10^6$ m^3 could meet a threshold discharge of 75 % of mean flow with failure once in sixty years. The drought volume as a percentage of mean annual flow volume at different threshold discharge and return period appears to be similar. Therefore, a mean value could be suggested for this region for the estimation of drought volume (storage volume) for the unguaged sites.

3. The nomograms presented in Fig. 6 and Fig. 7 could be used as and index for identification of drought for Malaprabha and Ghataprabha by knowing the actual demand and available live storage. The nomograms could also be used to find, number of days the supply to be withheld to meet a particular threshold discharge for full year corresponding to a specific reservoir level.

4. The nomograms of mean reservoir level minus half of its standard deviation (Fig. 8) could be used for identification of mild and moderate drought for Malaprabha reservoir. Similarly, the nomograms in Fig. 11 could be used for Ghataprabha reservoir.

7.0: REFERENCES

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APPENDIX - I

Appendix – I

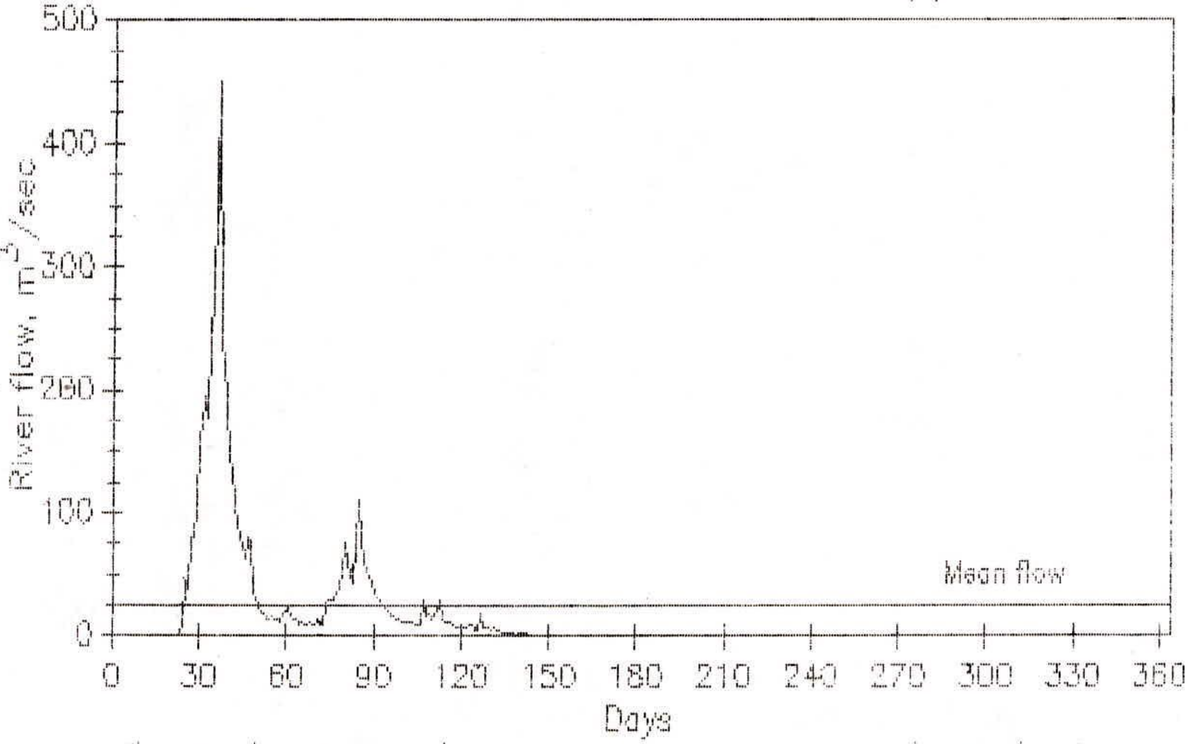

Fig 1: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1972 – 73.

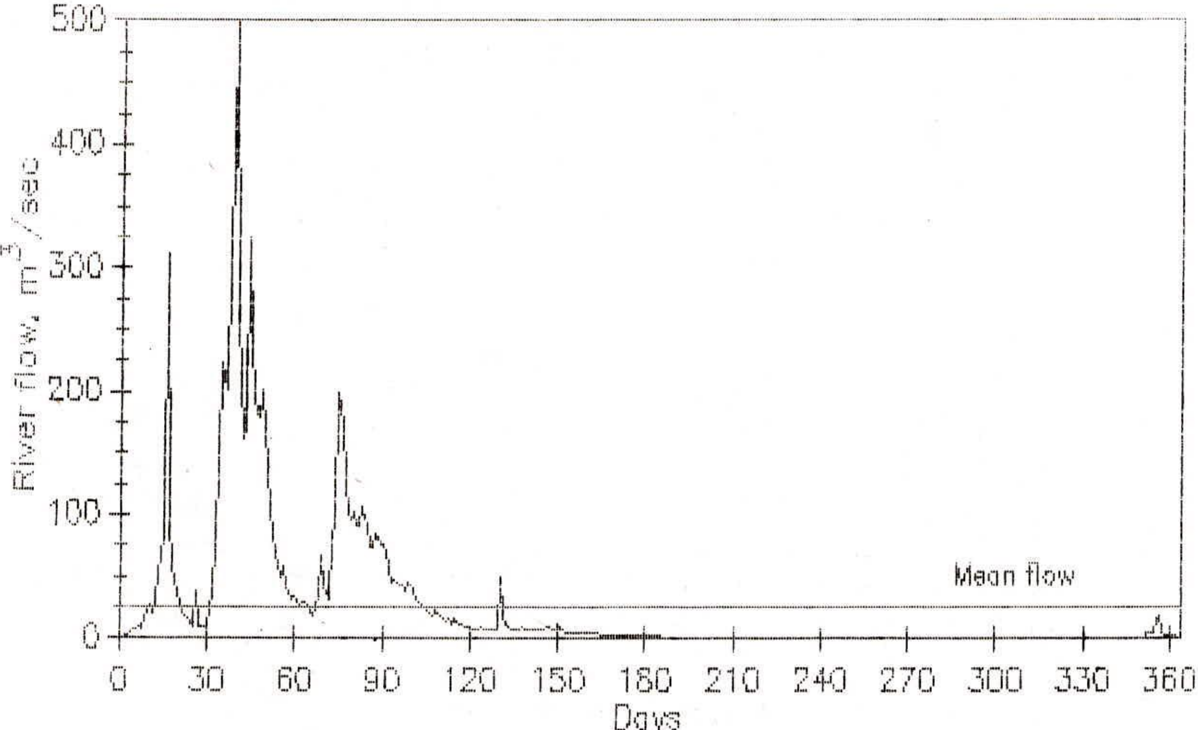

Fig. 2: River flow at site Khanapur of malaprabha basin starting from June 1 for year 1973 – 74.

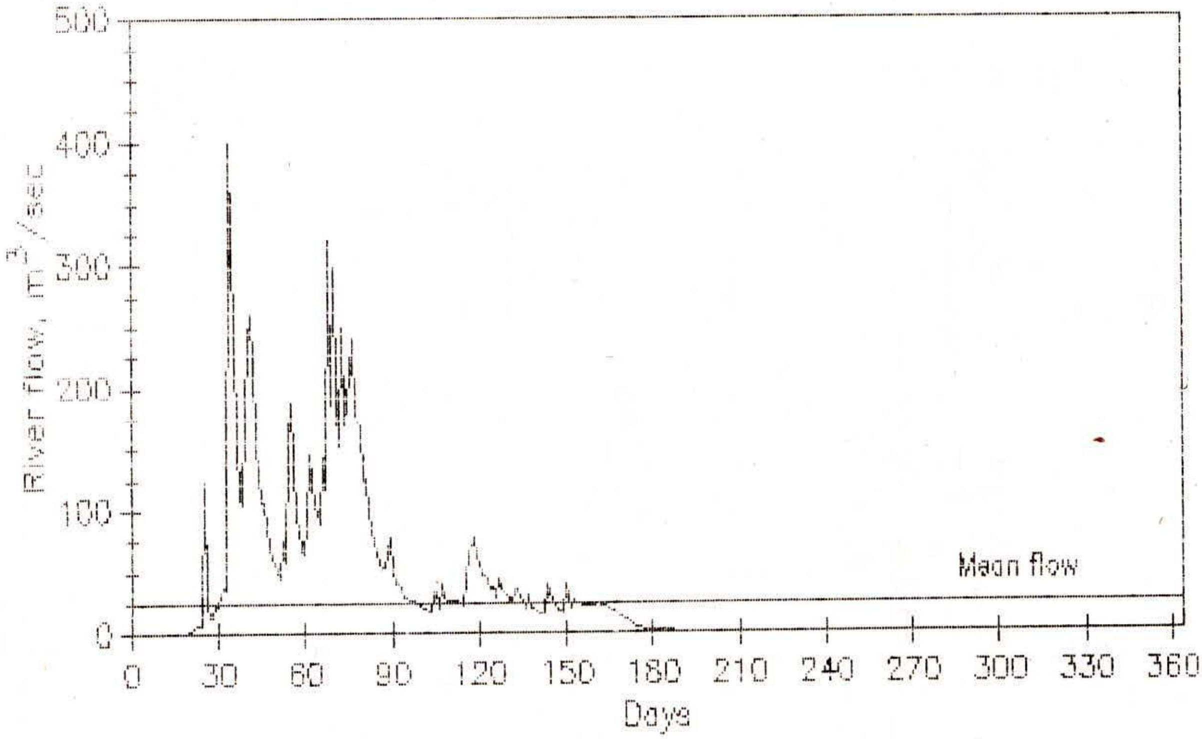

Fig. 3: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1974 – 75.

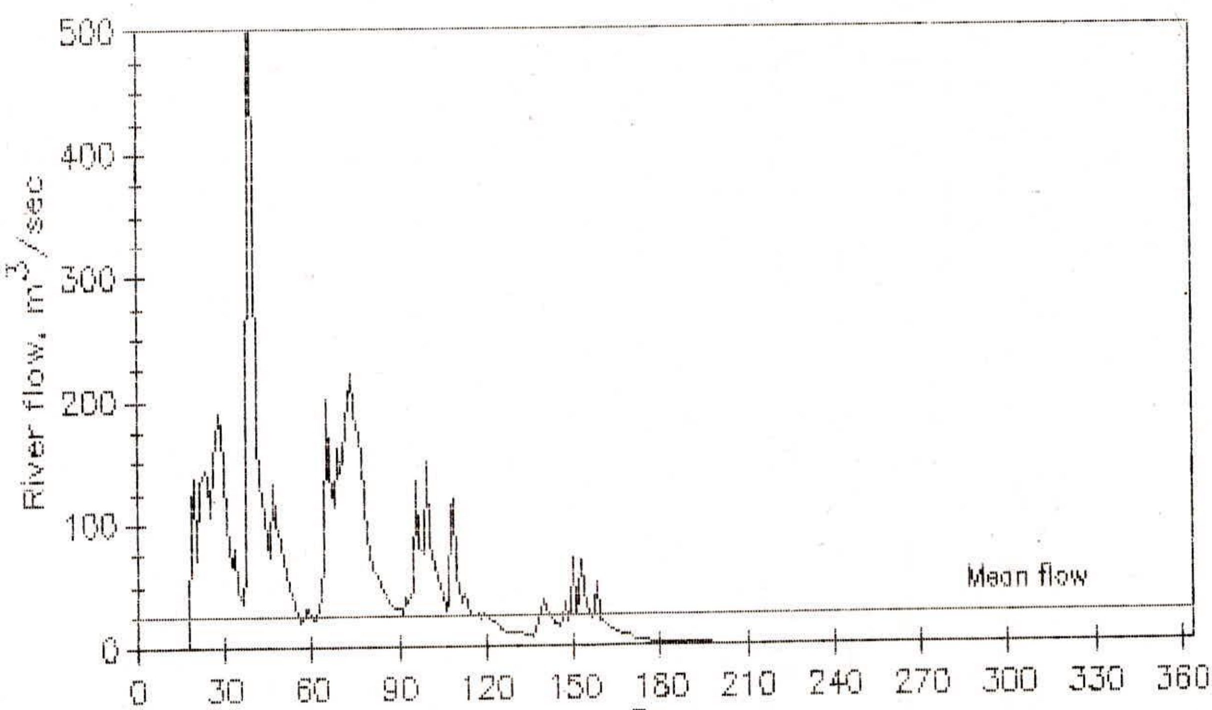

Fig. 4 River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1975 – 76.

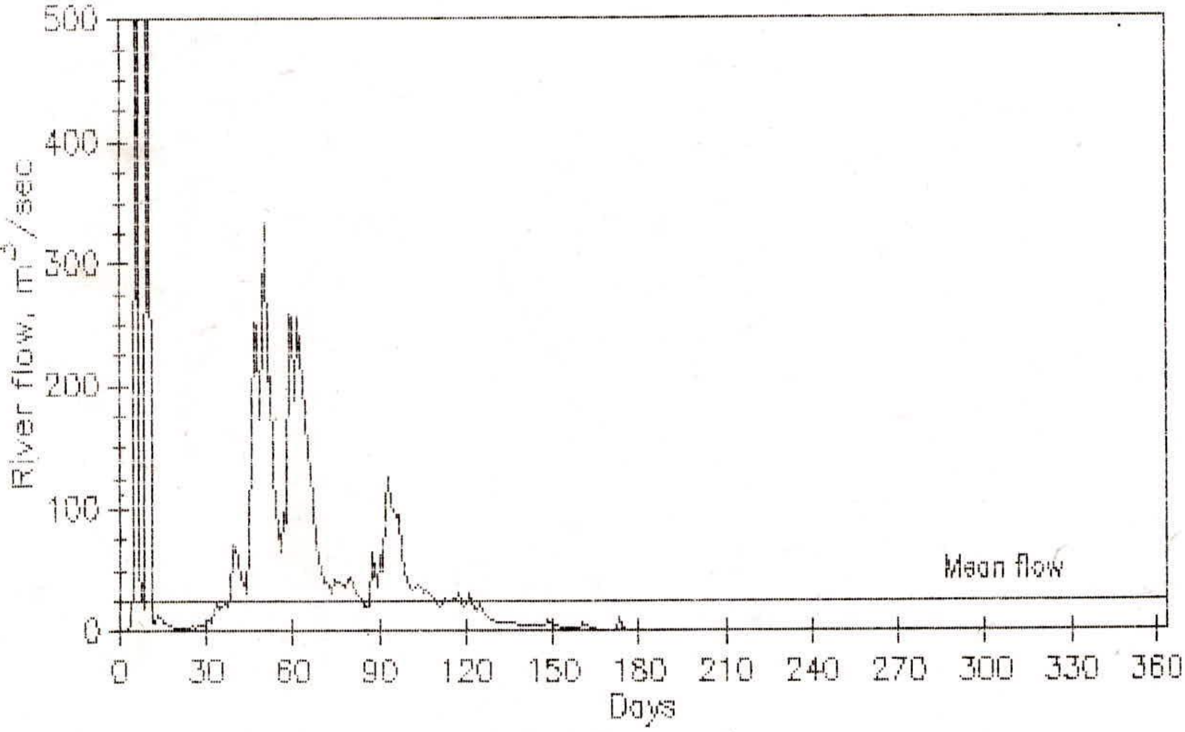

Fig. 5: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1976 –77.

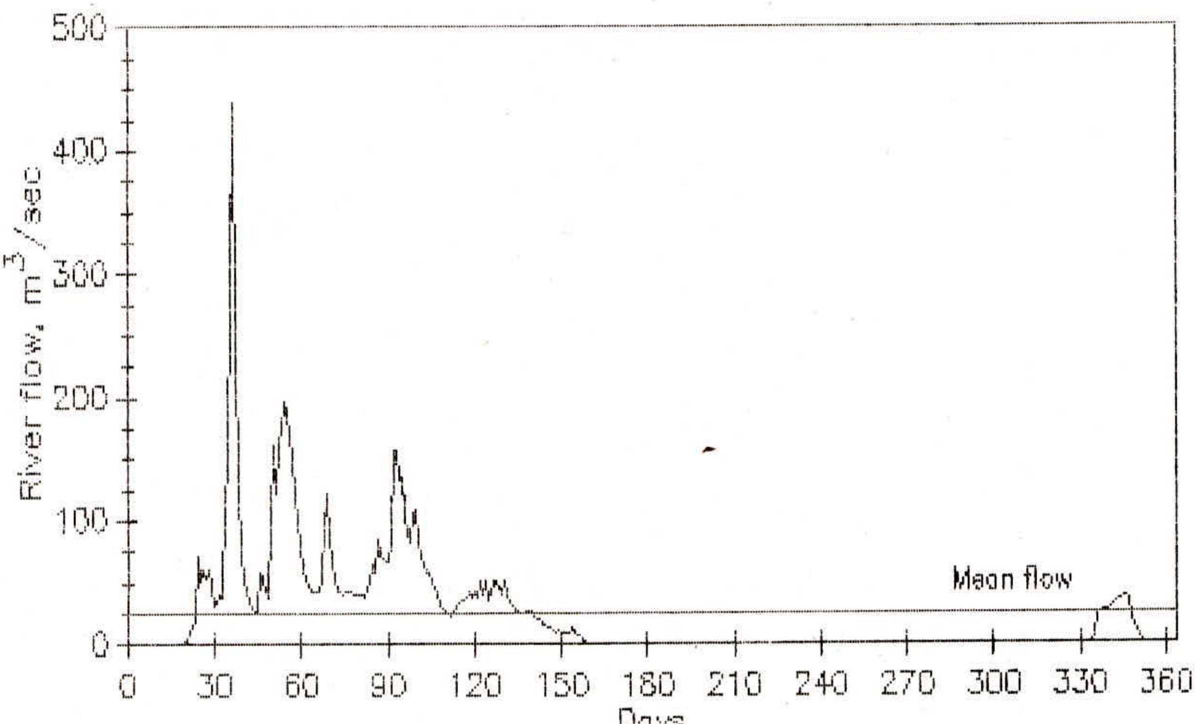

Fig. 6 River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1977 – 78.

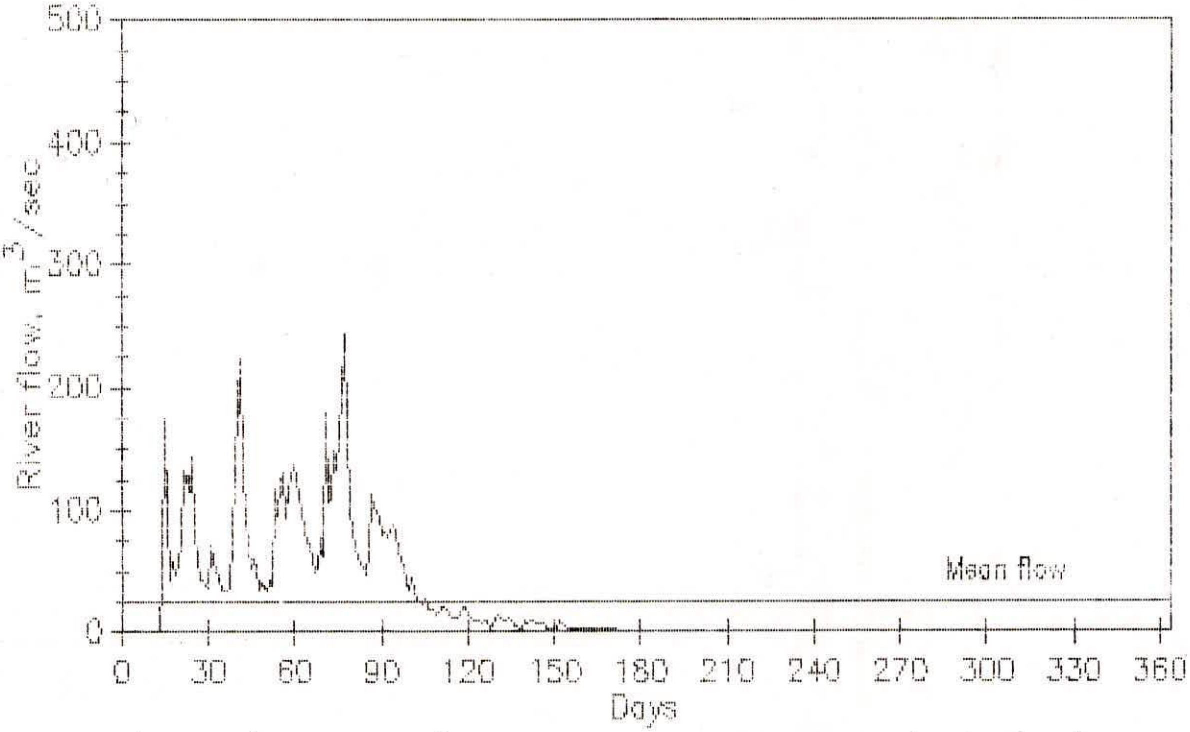

Fig. 7' River flow at site Khanapur od Malaprabha basin starting from June 1 for year 1978 – 79.

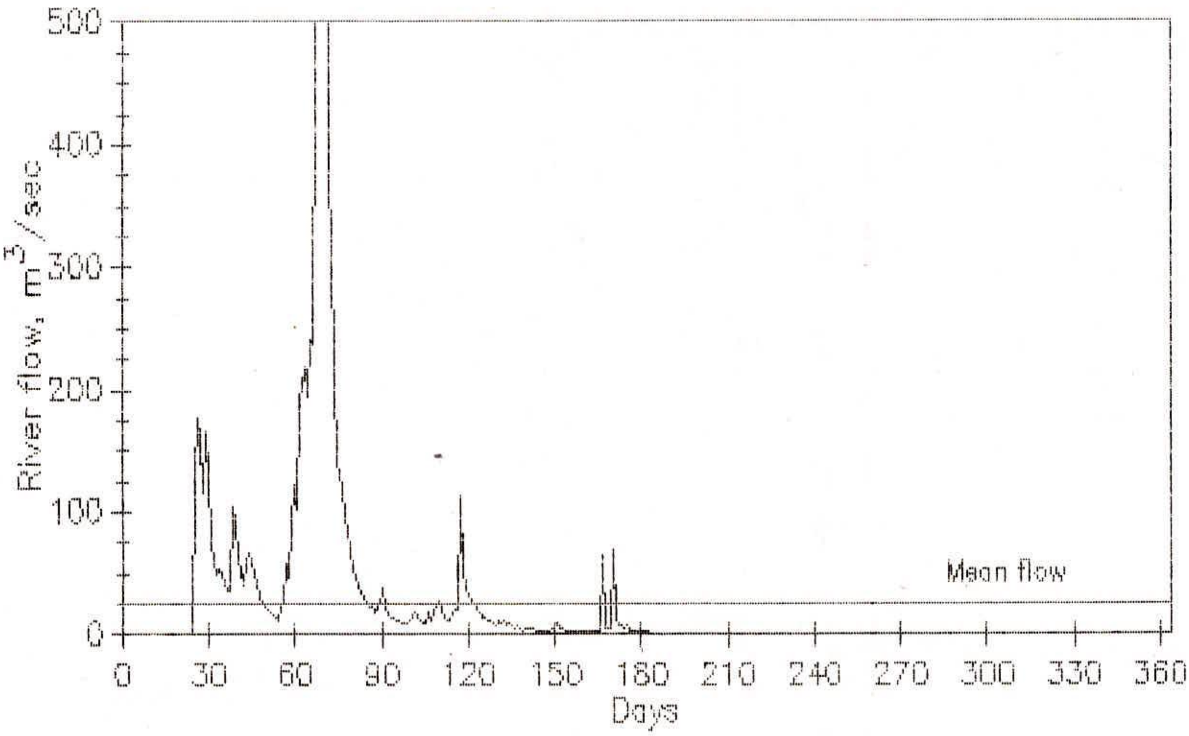

Fig. 8 River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1979 – 80.

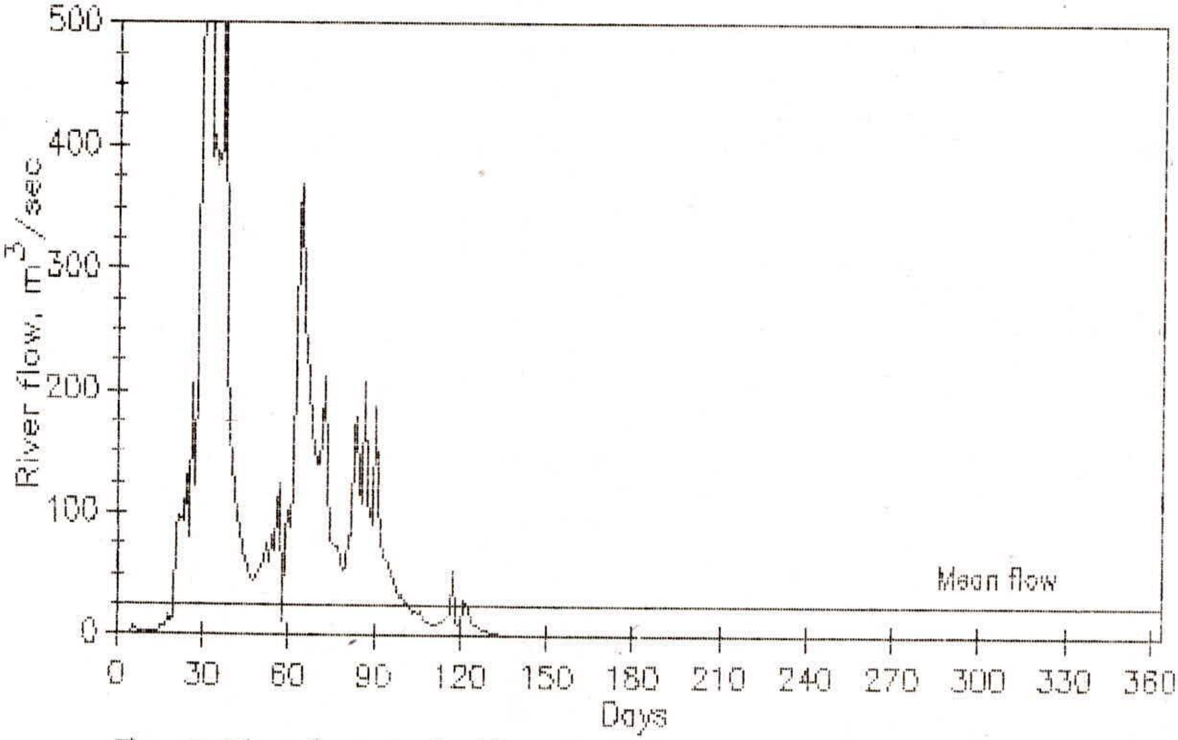

Fig. 9: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1980 – 81.

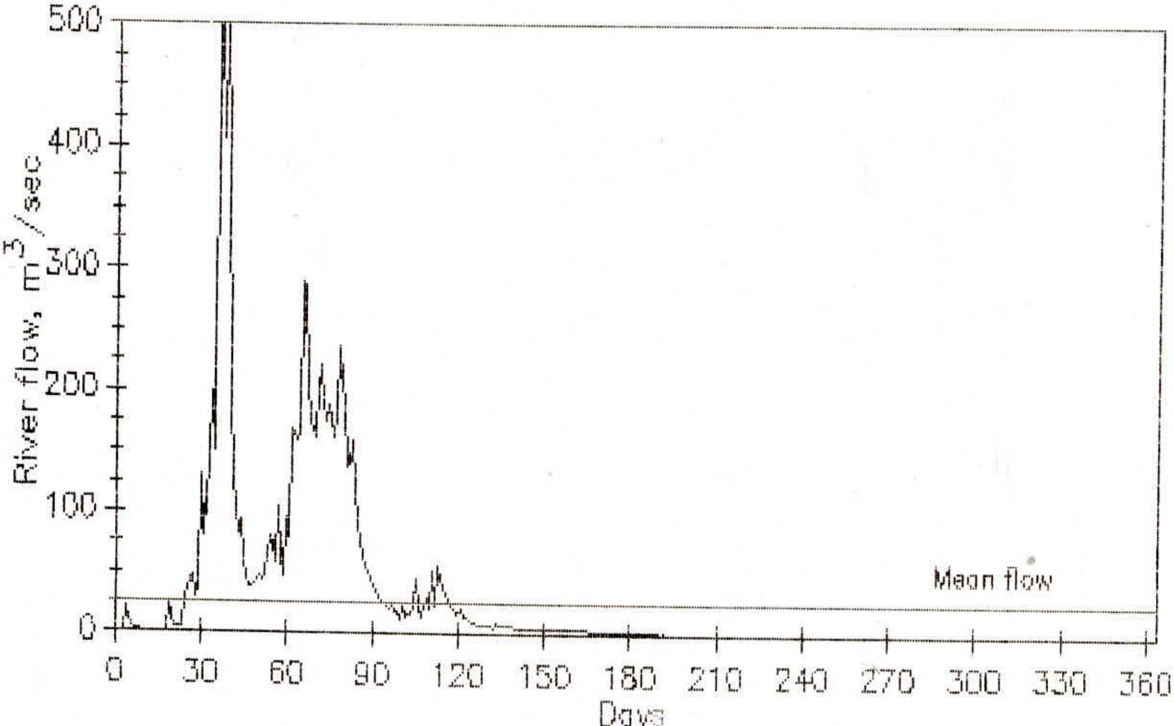

Fig. 10 River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1981 – 82.

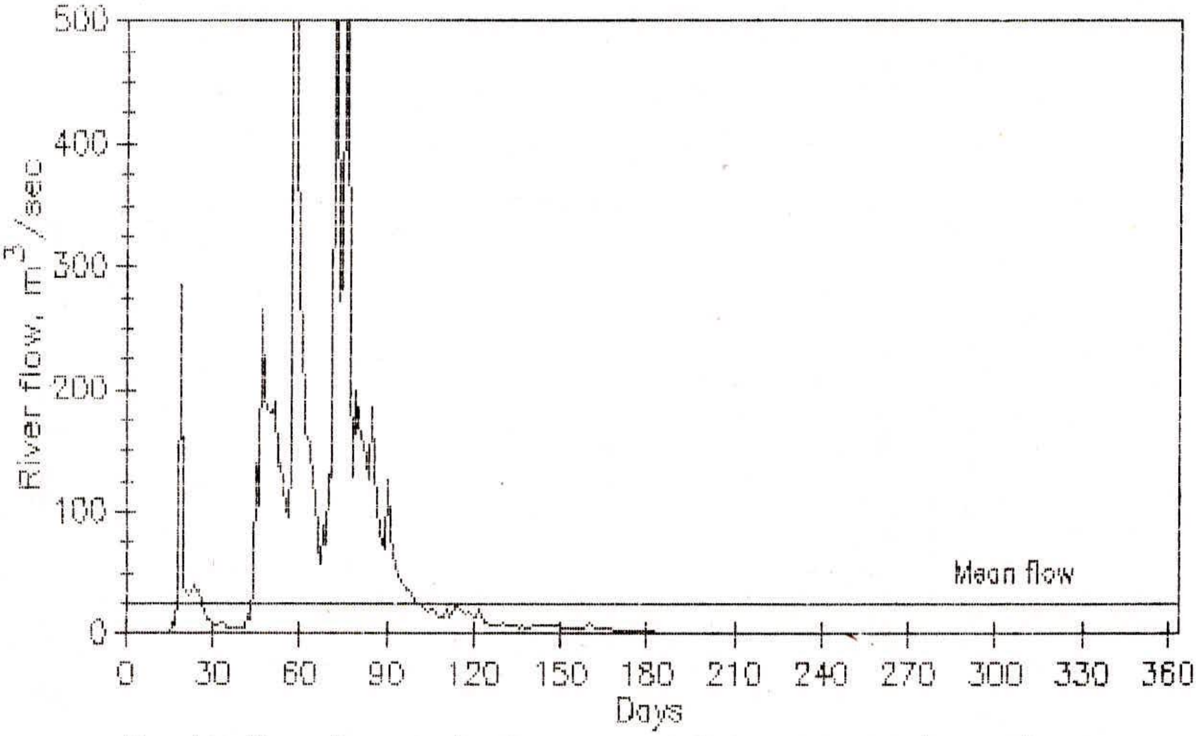

Fig. 11: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1982 – 83.

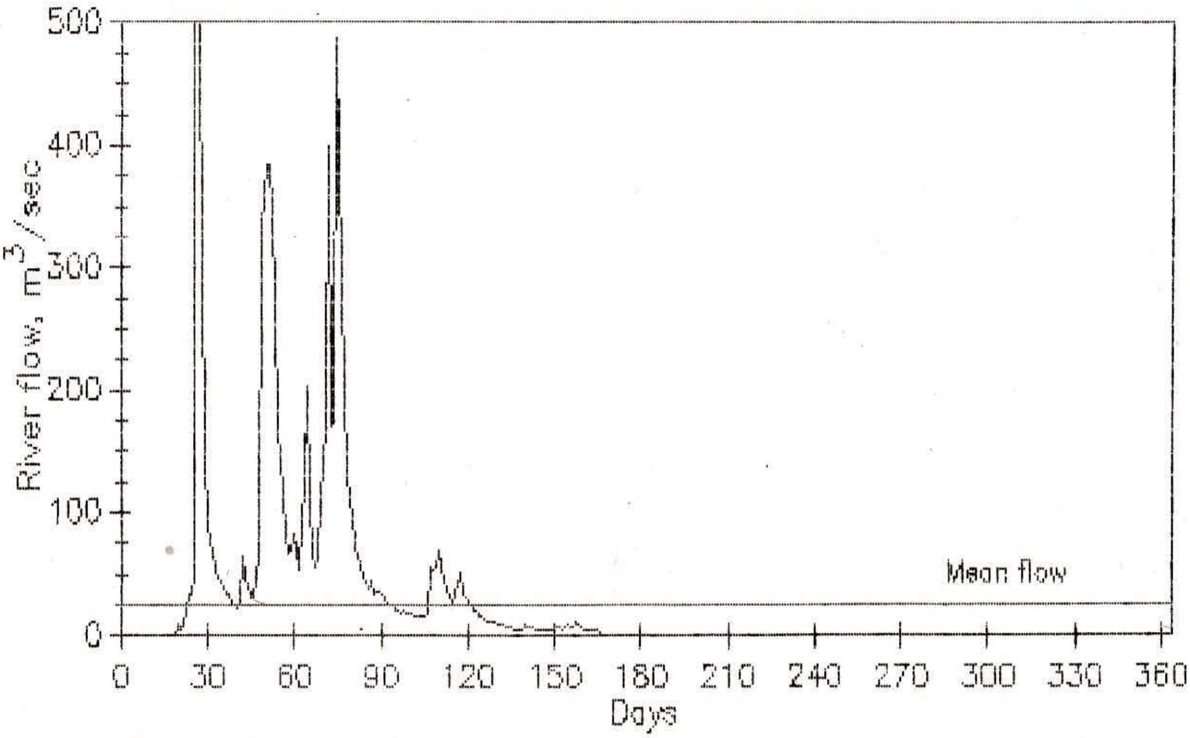

Fig. 12: River flow at site Khanapue of Malaprabha basin starting from June 1 for year 1983 – 84.

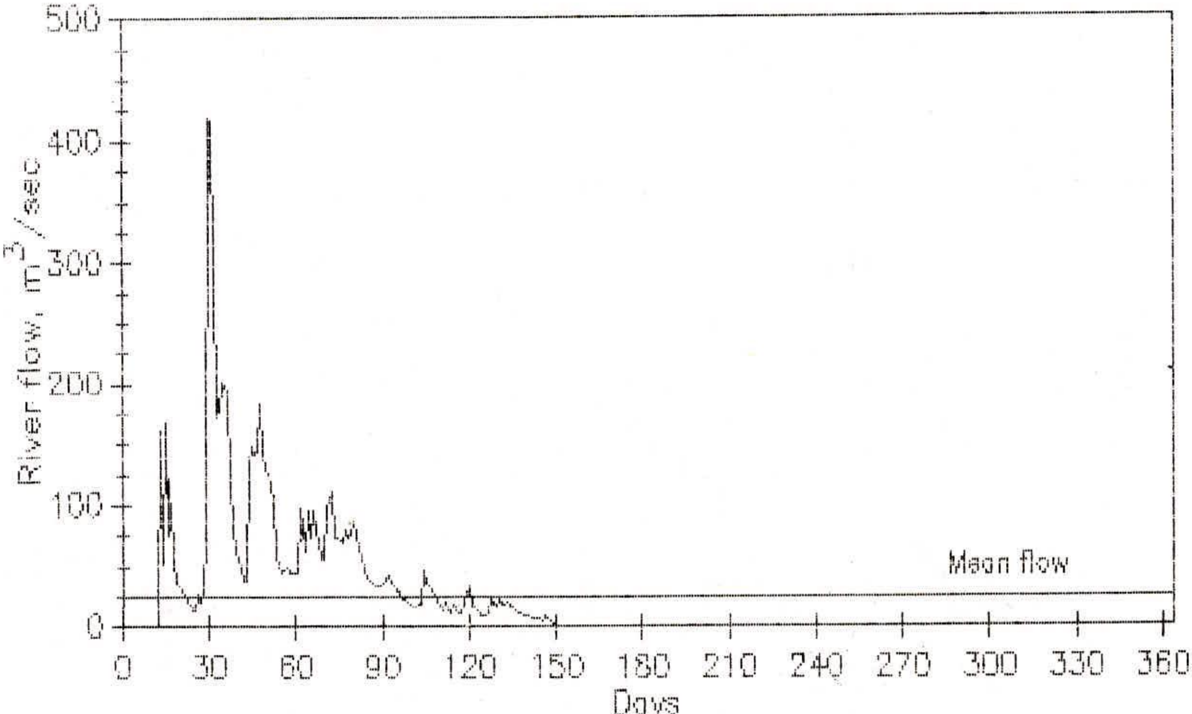

Fig. 13: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1984 – 85.

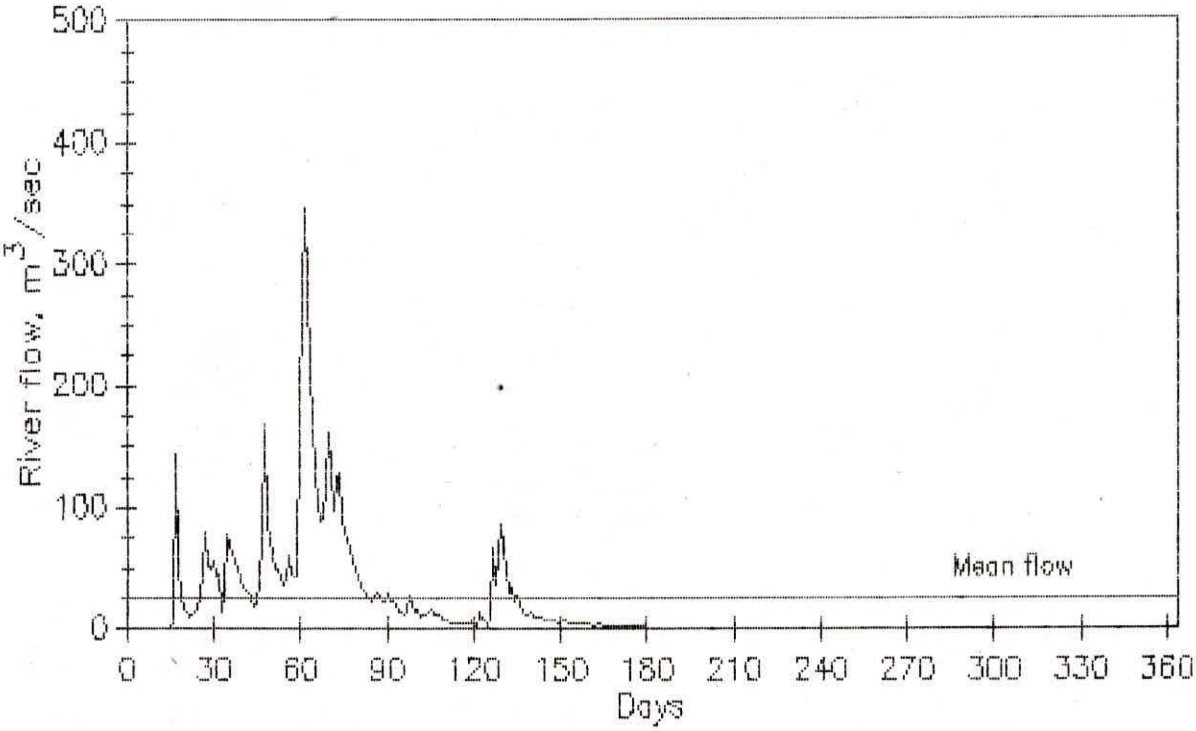

Fig. 14: River flow at site Khanapur of Malaprabha basin starting from June 1 for year 1985 – 86.

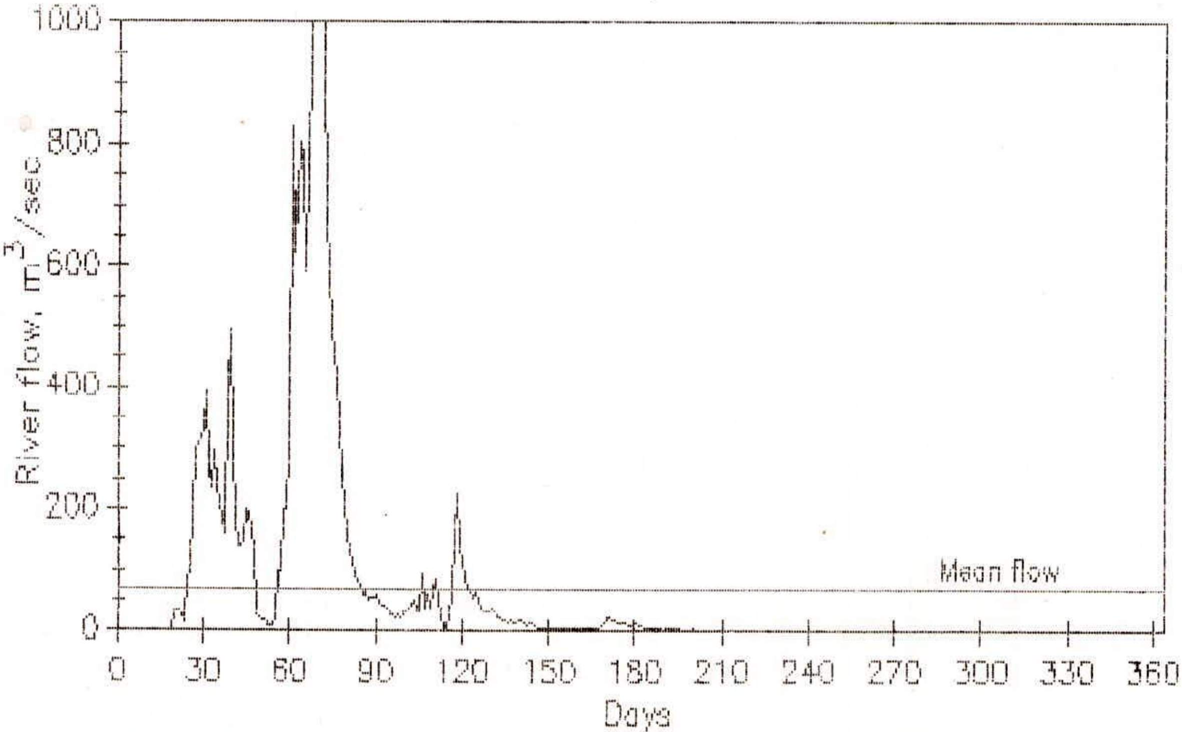

Fig 1 : River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1979 – 80.

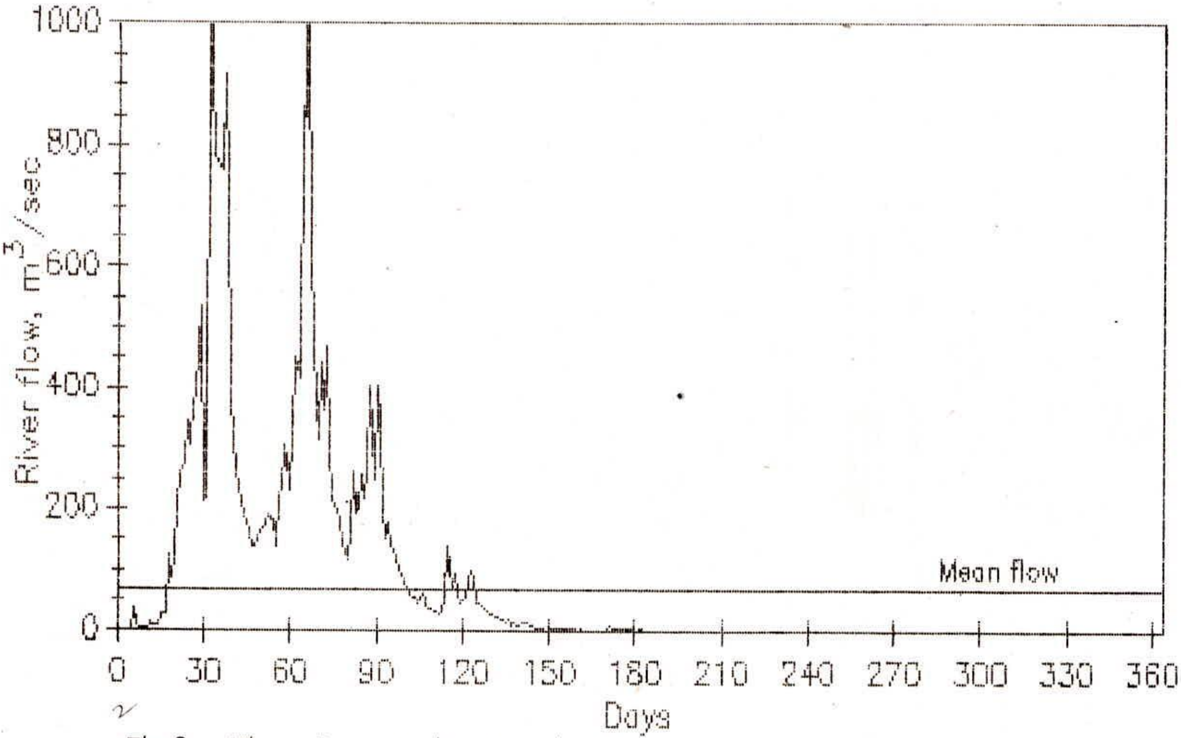

Fig.2: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1980 – 81.

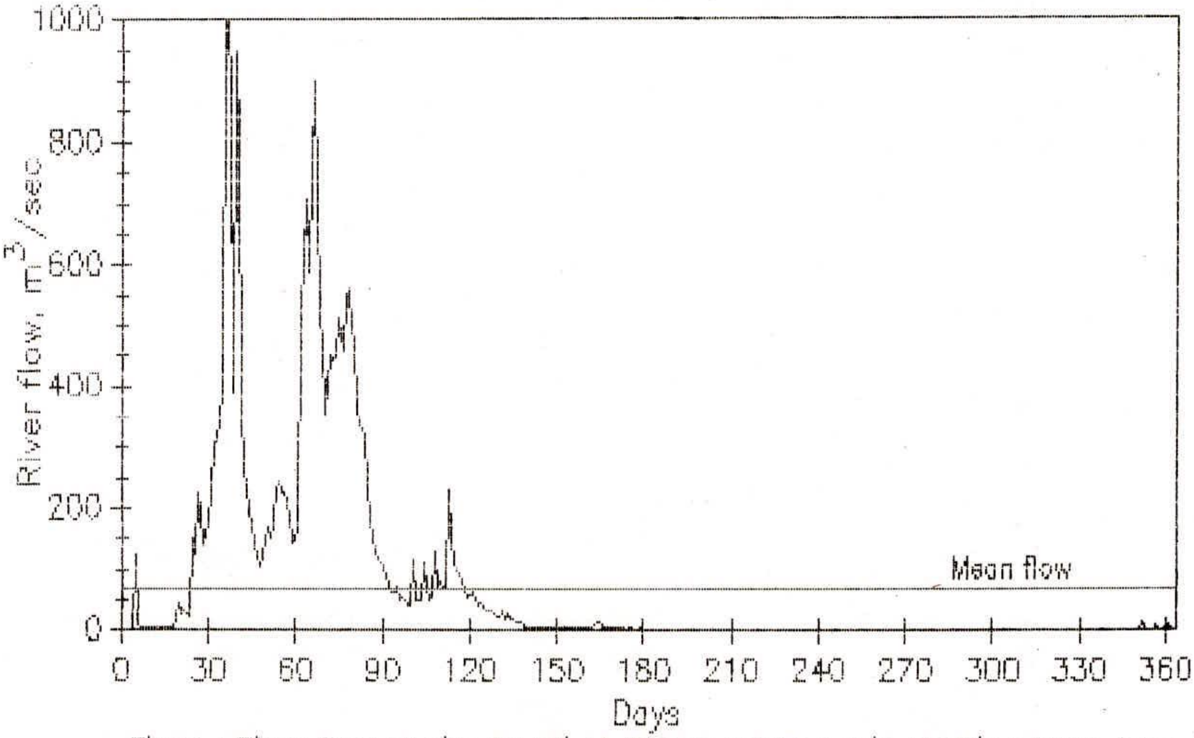

Fig.3: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1981 – 82.

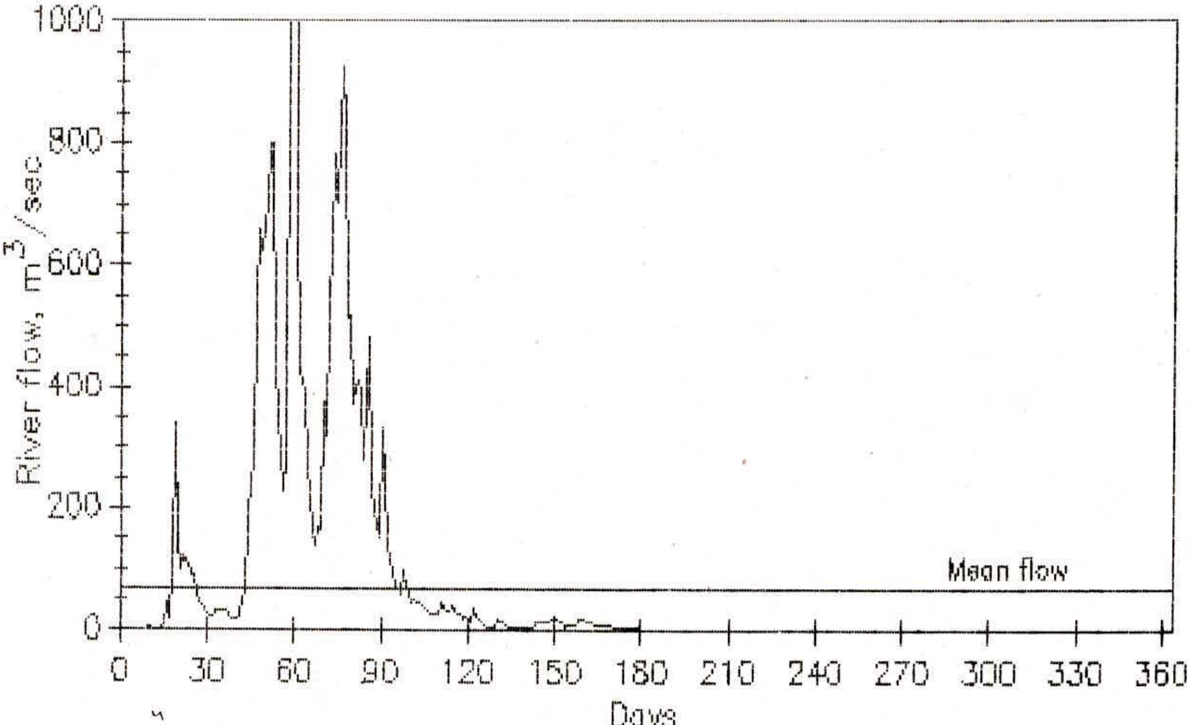

Fig.4: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1982 – 83.

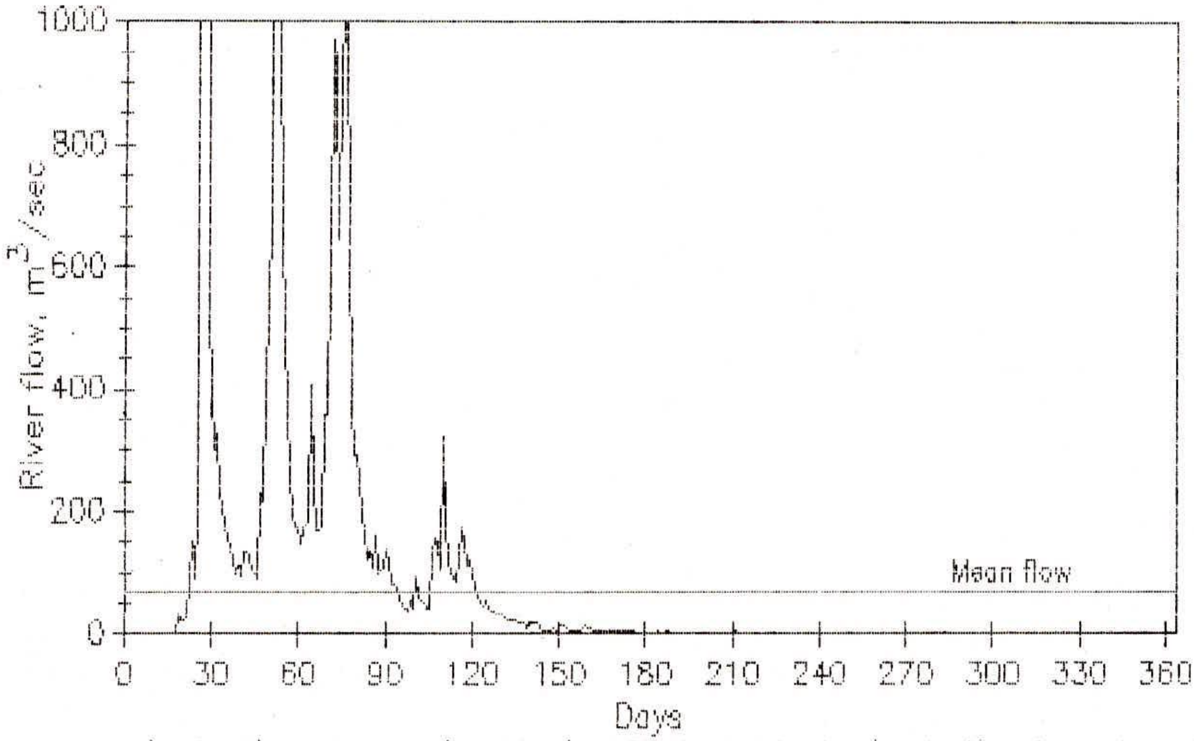

Fig 5: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1983 – 84.

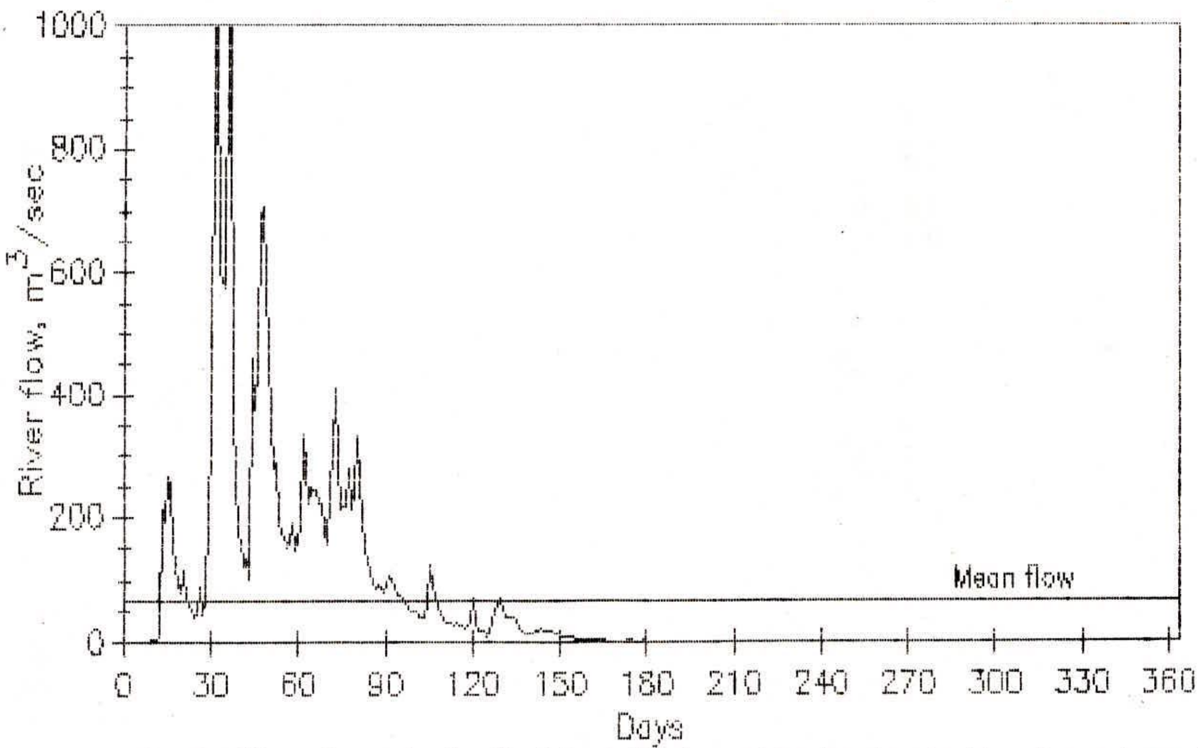

Fig. 6: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1984 – 85.

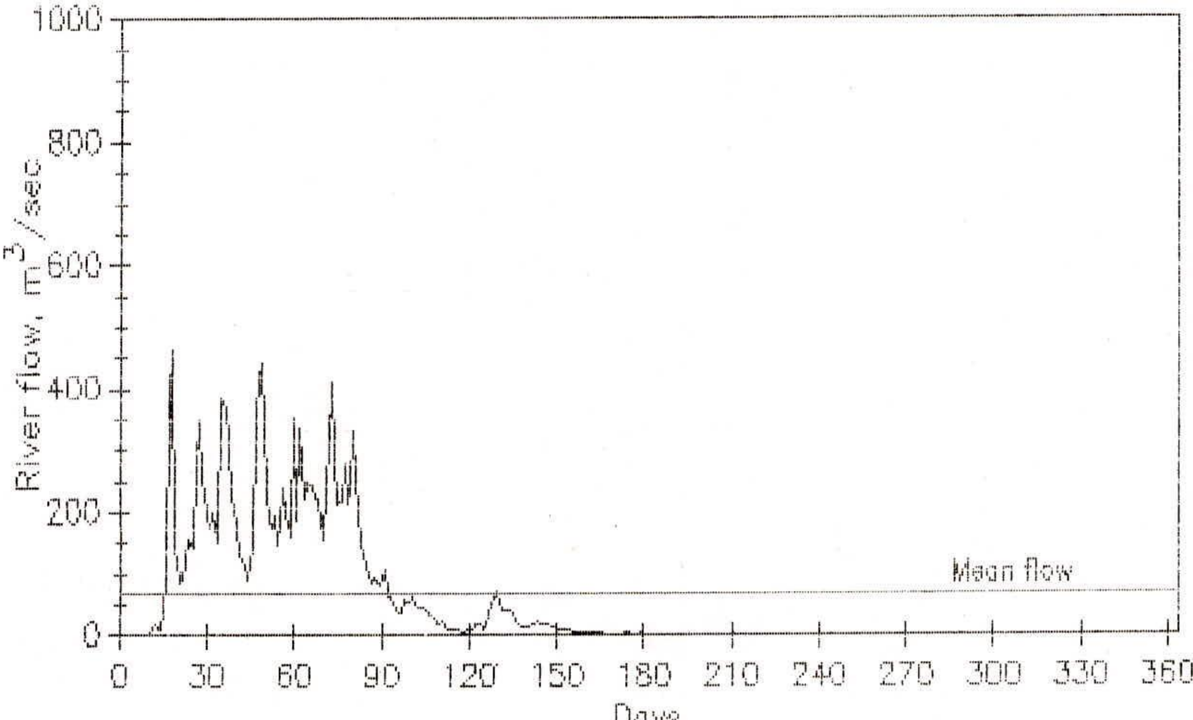

Fig 7: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1985 – 86.

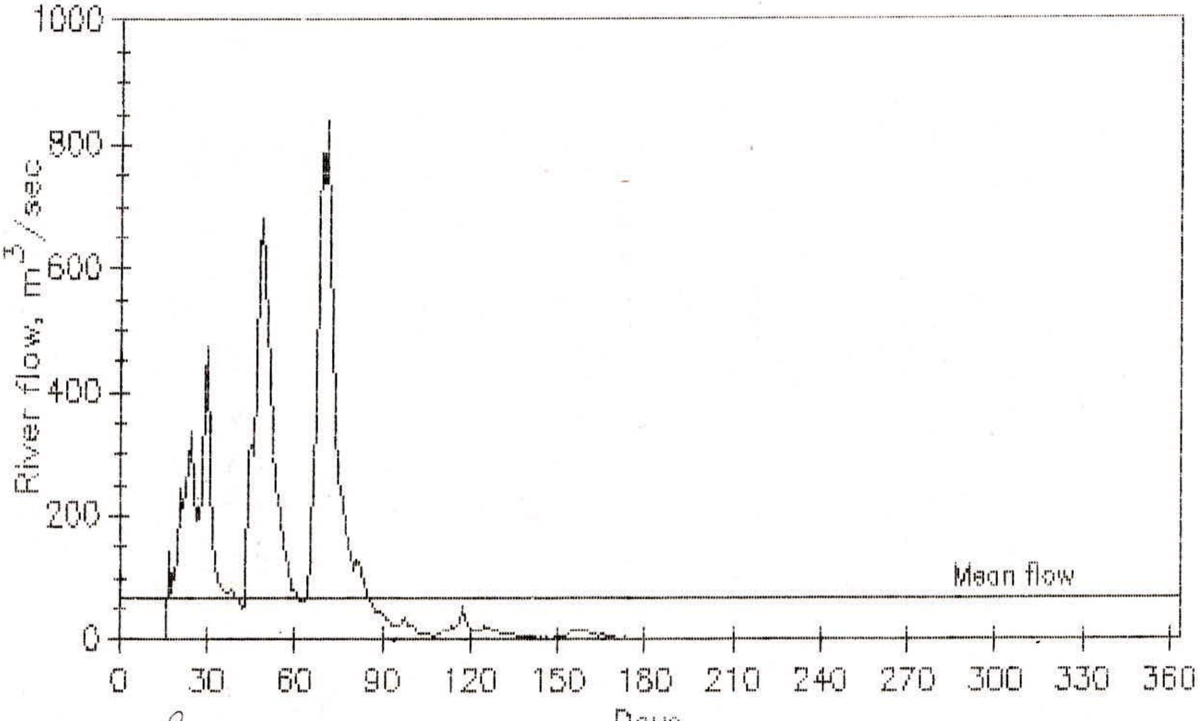

Fig. 8: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1986 – 87.

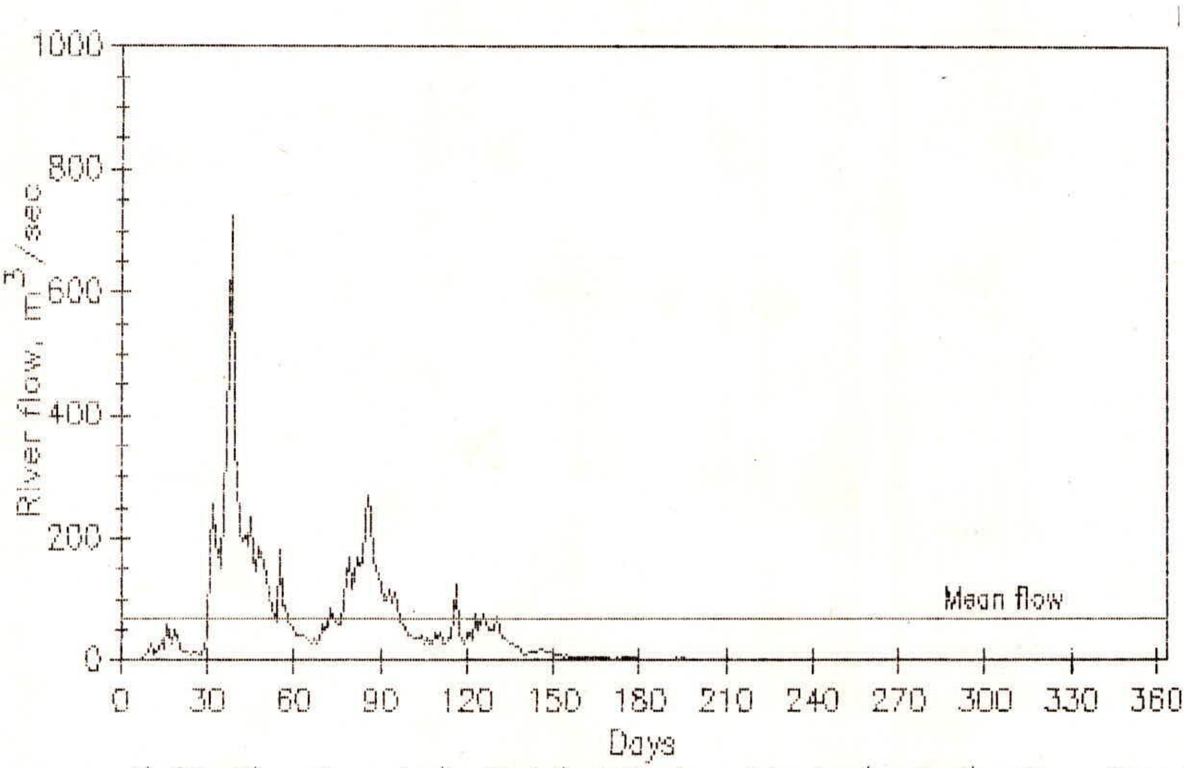

Fig9: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1987 – 88.

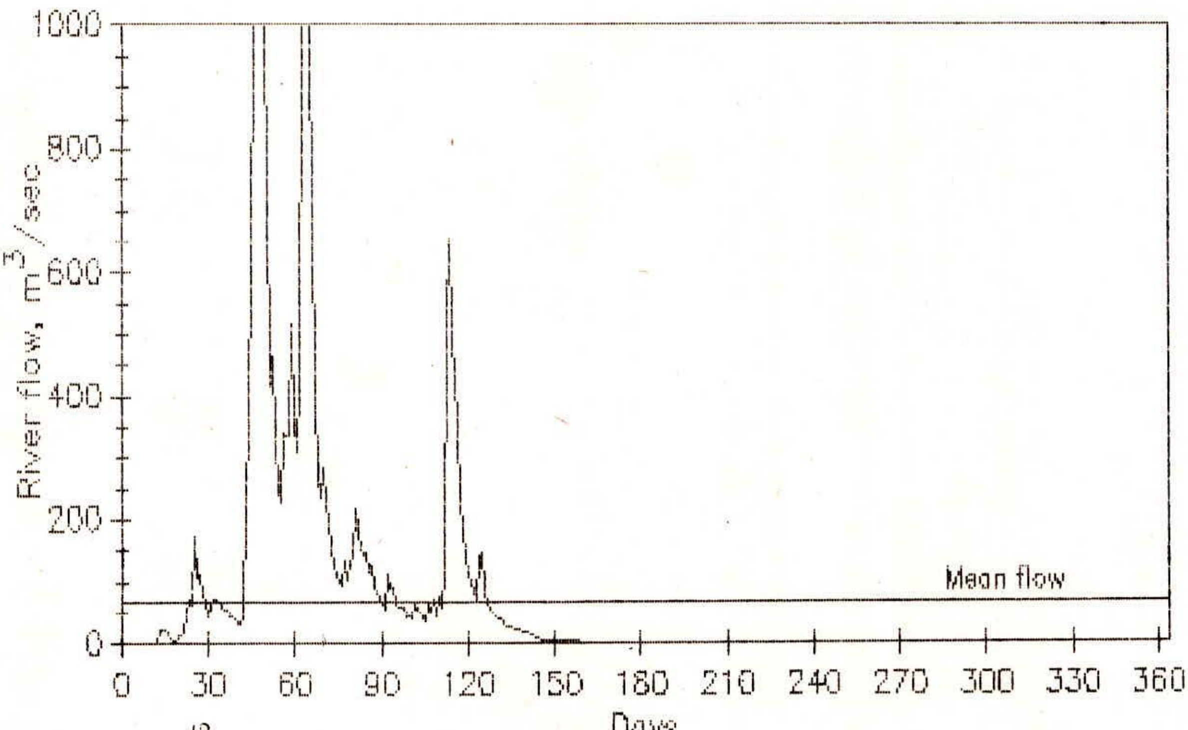

Fig.10: River flow at site Daddi of Ghataprabha basin starting from June 1 for year 1988 – 89.

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