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DEVELOPMENT OF REGIONAL FLOOD FORMULA FOR KRISHNA BASIN

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Content

Abstract

The estimation of the extreme flood at a site is required for the design of a variety of urban planning and river engineering works. An accurate estimatio of extreme flows for the associated recurrence interval is difficult to obtain if the length of the available stream flow records at the site of concern is shorter than the recurrence interval of interest. An even greater difficulty occurs if there is no flow record available at the site of interest. To cater the problem arising due to an insufficient length of data record, the trade off between the spatial and the temporal characterization of extreme flows can be effected through the use of regional flood frequency analysis. Regional flood frequency analysis facilitate the estimation of an extreme flow value at a location for which limited flow data exist, based on an extreme flow relationship derived using the information from basins with similar hydrologic responses.

This report describes the study of regional flood frequency analysis using peak flood series data of 34 gauging stations of Krishna basin using the following methods,

i) Index-Flood method
ii) PWM based EVI distribution
iii)PWM based GEV distribution
iv) PWM based Wakeby distribution

based on at site and regional data combined.

Out of 34 sites, 6 sites were omitted after USGS homogeneity test. From the remaining 28 sites, 26 sites were considered for analysis under 3 different sub-group i) medium catchments, ii) large catchments and iii) considering the basin as whole. In order to evaluate the fitting performance of different methods used, some of the error functions respectively their descriptive ability are computed. The results indicate that, the Index-Flood approach and PWM based EVI distribution are best suited for medium catchments for the basin as whole. However, it is recommended to include the other physiographic characteristics also for developing more rational regional flood formulae using good data base.

List of Figures

List of Tables

1.0 Introduction

Flood frequency analysis is a tool being widely used for predicting the future flood at different recurrence intervals. The reliable estimates of the magnitude and frequency of occurrence of flood are essential to the proper design of hydraulic structure across a river as well as to identify the flood risk area. Mainly there are two methods of estimating the floods; i.e., deterministic and statistical approach. In the deterministic approach, the rainfall-runoff relationships established based on the physical concepts of the various hydrological processes are used to estimated the floods. In the statistical approach, the past records of flood peaks are subjected to the statistical analysis which provides the distribution pattern for the flood peaks. The frequency analysis is a statistical technique by means of which it is possible to estimate the floods of various magnitudes and their frequencies. The flood frequency analysis for a river site with a long record can be based almost exclusively on the flood record at that site. The records used for the frequency analysis should satisfy certain assumptions in order to have a meaningful estimates;

a) data should be random
b) data considered for analysis should be homogeneous
c) data should be of good quality
d) data should be representative of the population
e) sample of data should be long enough to provide reliable estimates of the parameters.

Generally, the flood frequency analysis is carried out in the following steps;
i) Process the annual peak flood series from the frequency analysis point of view
ii) Select the theoretical frequency distribution
iii) Fit the selected frequency distribution to the annual peak flood series and estimate the parameters of the distribution using a suitable parameter estimation techniques
iv) Choose some goodness of fit criteria and select a best fit distribution based on those criteria
v) Estimate the floods for different recurrence intervals using the estimated parameters of best fit distribution.

There are various distributions and methods of parameter estimation available in literature for flood frequency analysis. Correct inference about the distribution which fits the peak flood series of a site is a crucial in the frequency analysis, as various distributions fitted to the same data result in different estimated values in the extrapolation range. The reason being that the hydrologists try to infer about the population distribution from the sample data which is subjected to sampling variability. As data arises from various situations form their own distributions, the procedure of transforming the data to a particular distribution has been suggested by some hydrologists without adopting a prior distribution for fitting the sample.

The inference about the best fit distribution for a sample data observed at a site is made based on some goodness of fit criteria. Inspite of number of attempts it has not been possible to develop uniform goodness of fit criteria for selecting the best distribution. In order to avoid such subjectivity, hydrologists are always in search of a robust frequency distribution for fitting the peak flood series. A distribution or a method of parameter estimation is termed as 'robust', if it estimates medium and high return period flood with low bias, coefficient of variation (CV) and root mean square error (RMSE).

The flood frequency analysis for those gauging sites, where the recorded peak discharges over number of years are available, is carried out using the conventional procedure available in the literature. However, the reliability of such analysis is somewhat limited for the ungauged sites or sites with shorter record length. Such a situation can be overcome by adopting regional approaches and performing flood frequency analysis with regional data and at site data or with the at site and regional data.

There has been significant developments and studies in the area of regional flood frequency analysis in India as well as abroad. Estimation of regional flood frequency parameters is performed for a specific site for two reason: i) because of the sample variations present in the short hydrologic records, frequency estimates of rare events based on at site frequency analysis are subjected to large error and thus unreliable. This error can be reduced by combining data from many more sites. ii) there are many more sites in the same region where hydrologic data are not available but design flood estimates are needed for the design of small structures. In such a situation regional flood frequency analysis helps in transferring the knowledge arrived from gauged sites to ungauged sites.

This report describes a study carried out for the Krishna basin with annual peak flood series data available for 34 sites for varying number of years. The following methods were used for analysis considering the at site and regional data.;

i). The Index- Flood method
ii). PWM based EVI distribution
iii). PWM based GEV distribution
iv). PWM based Wakeby distribution

Out of 34 sites, 6 sites were omitted after the USGS homogeneity test since they fall outside the envelope curves of homogeneity test. From the remaining 28 sites only 26 sites were considered for the analysis under three different sub-groups, i. medium catchments, ii). large catchments and iii). comprising all the catchments of the basin. The classification was based on the measured catchment area (Wiltshire, 1985), and data of other 2 sites were used as test sites for judging the performance of the developed regional formulae. Descriptive ability of various methods is tested based on the three numerical measures of goodness of fit. The performance of different methods has been compared.

2.0 Objectives of the study

The objective of this study is to establish a regional relationship between mean annual peak flood and the catchment area based on the frequency analysis for available annual peak flood for various gauging sites of hydrologically homogeneous region of Krishna basin, and to use the same for estimating the floods for various recurrence intervals for the catchment which are not used for analysis. Also, the descriptive ability of some of the flood frequency methods, used for the analysis are compared based on the performance criteria evaluated for each gauging sites.

3.0 Description of Study Area

The Krishna basin for which sufficient annual peak flood series at number of gauging station were available was selected as the study area. The total catchment area of the basin considered for the analysis is 90,000 sq.km and is located between longitude of 73°E to 78°E and latitude of 15°N to 19°N and it comprises the part of Maharastra and Karnataka states. The fig 1, shows the river system and gauging stations with all its tributary of river Krishna. The drainage area of these gauging sites varies from 540 sq.km to 70,000 sq.km. The main tributary of river Krishna are river Bhima, Ghataprabha, Malaprabha and Tunga-Bhadra. The Tunga-Bhadra basin which forms a part of the Krishna basin has not been included in the study.

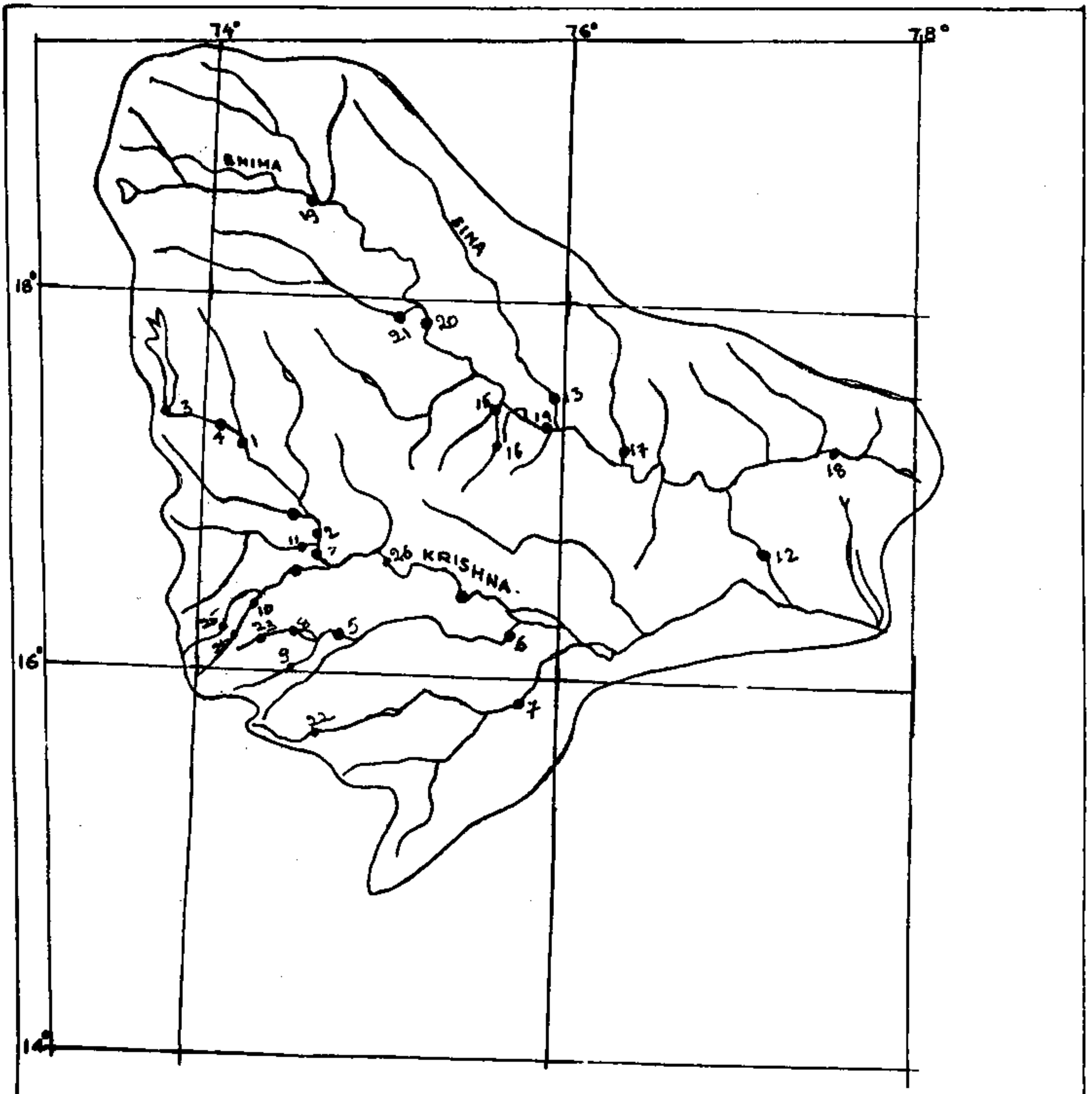

FIG. 1 GAUGING STATIONS IN STUDY AREA

4.0 Data Availability for study Area

The annual peak flood series data for 12 to 30 years varying over a period of 1969 to 1993 for 26 station of krishna basin is available for the study. The drainage area of these sites vary from 520 sq.km to 69863 sq.km. The data were collected from the record of Water Resources Development Organisation, Govt. of Karnataka and CWC annual data reports. The list of the gauging sites maintained by CWC and WRDO which are used for the study along with the data availability is given below:

Sl.no	Gauging Site	Stream	Catchment Area (km^2)	length of data available
1	Karad	Krishna	5462	1969-70 to 1990-91
2	Arjunwad	Krishna	12660	1969-70 to 1990-91
3	Koynanagar	Koyna	920	1980-81 to 1990-91
4	Warunji	Koyna	1690	1969-70 to 1990-91
5	Gokak	Ghataprabha	2776	1971-72 to 1990-91
6	Bagalkot	Ghataprabha	8610	1969-70 to 1990-91
7	Cholchgod	Malaprabha	9373	1960-70 to 1990-91
8	Gotur	Hirnya keshi	1100	1980-81 to 1990-91
9	Daddi	Ghataprabha	1150	1979-80 to 1990-91
10	Bestwad	Vedganga	640	1979-80 to 1990-91
11	Tarewad	Panchganga	2425	1979-80 to 1990-91
12	Yadgeer	Bhima	69863	1965-1992
13	Wadakbal	Sina	12092	1965-1992
14	Takali	Bhima	33916	1965-1992
15	Shirdon	Doddahalla	630	1979-80 to 1992-93

16	Konkangaon	Borinala	1640	1979-80 to 1992-93
17	Bori-omergaon	Bori	2640	1979-1993
18	Jewani	Kanga	1920	1979 -1992
19	Dhond	Bhima	11660	1969-1992
20	Narasing pur	Bhima	22856	1969-1992
21	Sarathi	Nira	7200	1969-1993
22	Khanapur	Malaprabha	540	1972-1993
23	Chichalgod	Hiranakeshi	1175	1970-1991
24	Yamagardi	Vedganga	655	1971-1993
25	Kongana halli	Dudhganga	603	1984-1993
26	Kudachi	Krishna	18417	1971-1992

5.0 Literature Review

In the recent work on regional flood frequency estimation, shown that accurate flood quantile estimates are possible when the underlying flood distributions are identical at all the sites in the region except for a scaling factor, particularly when the underlying distribution has two parameter form and regional homogeneity in moments of order higher than one. where as two parameter distributions belonging to the extreme value family perform quite well when the form of the underlying distribution is close to that of fitted distribution, large bias can result, when the distribution is misspecified. The three parameter generalised extreme value distribution, when fitted using the regional PWM method has shown to be relatively insensitive to violations of the distributional assumption and to have low variability and bias(Choudary,et al,1991). Some of the researcher shown that regional estimation method using three parameter GEV distribution are relatively insensitive to modest regional homogeneity in the coefficient of variation and to regional variation in the skewness coefficients. Following are some of excerpts from the recent research papers on regional flood frequency analysis.

5.1 Studies Abroad

Wiltshire (1985) proposed a method for grouping the basin for regional flood frequency analysis. The study was conducted using the data of the basins in United Kingdom wherein the basin were classified into three groups on the basis of soil type and the annual average rainfall. In 1986, a study was conducted by the same author for identification of homogeneous region for flood frequency analysis (Wiltshire, 1986). In this study, a procedure has been described to classify the basin into two distinct homogeneous groups using the catchment area and the average annual rainfall (AAR) as variables.

Denis et al (1993) presented a study for delineation of homogeneous region based on annual flood mechanisms. The mechanisms like rainfall and snow melt which are mainly responsible for the generation of flood were considered. The concept was applied to a river basin in New Brunswick in Canada using non parametric frequency analysis considering unimodal and bimodal distribution shapes for the basins. Finally the homogeneous regions were delineated by grouping the basins which have exhibited similar shape of density function.

Farquharson et al (1992) developed regional flood frequency curves for arid and semiarid regions. In this study, 162 catchment from 12 different countries in five continents with the drainage area varying from 1 to 357000 sq.km having an average annual rainfall of 600mm were selected. The analysis was carried out to develop dimensionless frequency curves for different countries and to study the effect of climate on the shape of the regional frequency curves.

Chowdhury et al(1991) developed critical values and formulae for computing several goodness of fit tests for the GEV distribution. These tests can check available data for a site consistent with regional GEV distribution, except for scale factor, or the consistency of the data with a regional value of shape factor k. The test employed are PWM estimator of L-moment's coefficient of variation and co-efficient of skewness. From the study it was concluded that a test based on L-cs generally has equal or greater power than probability plot correlation test of detecting L-cs differences.

Vegal et al (1993) studied the suitability of flood flow frequency models such as GEV, Generalised Pareto (GP) distribution and wakeby distribution using L-moment techniques. These methods were applied for 61 catchments in Australia. The study revealed that, the GEV distribution was the best approximation to the distribution of flood flows of winter dominated regime. Also, the ability of alternate flood frequency models were assured. Number of distributions were used as alternative distribution. However, both GP and GEV appeared to be good for flood flows for the region out side winter dominated rainfall regime. From the study it was concluded that, GEV procedures performed well for all regions considered, inspite of the fact that the L-moment diagrams did not always favour the GEV procedures.

Zrinji et al(1994) estimated extreme flow quantiles at ungauged catchment using the region of influence approach to regionalisation and explicitly incorporating a homogeneity test in the process of selecting the collection station that comprise the 'region' for ungauged sites. This method was applied to extreme flow data for sites in Newfoundland in Canada. The results obtained by new approach was compared with those obtained from the regression analysis. An improvement was observed in the estimates of extreme flow quantiles at ungauged site.

Lettenmaier et al (1987) studied the effect of the heterogeneity on flood frequency estimation. In this study, the robustness of selected regional and at site flood frequency estimation procedure was examined with respect to i) the underlying flood distribution, ii) regional heterogeneity iii) variation in record length over the region and iv) the regional flood estimation methods that provide site to site variations in the higher moments than the first moment. From the study it was concluded that, the regional index flood and PWM estimation method for the GEV distribution were relatively less sensitive to modest regional heterogeneity in the coefficient of variation when performance was measure in terms of regional RMSE.

5.2 Studies in India

Goswami (1972) carried out regional flood frequency analysis for Brahmaputra basin in North-East India using modified USGS procedure. In this study annual peak flood series data for 25 sites having catchment area ranging from 63 sq.km to 69230 sq.km were analysed. The mean annual flood Q for 2.33 year return period was graphically correlated with the catchment area.

Seth & Goswami (1974) carried out regional flood frequency analysis for ten tributaries of Brahmaputra in North-East India for the available varying length of data on annual peak flood series. The study was carried out considering: i) the annual flood series of all stations in the region having more than 10 years data, ii) extended records of some streams by developing suitable relationships with concurrent peak flood records of neighbouring stream.

Seth & Perumal (1985) carried out a study on parameter estimation of Gumble-EVI distribution using Monte-Carlo experiments. In this study, the Gumbel's method was modified by replacing the weibull plotting position formula with that of Gringorton formula recommended for EVI distribution. The estimates were compared with that obtained from the other two methods viz; i) the method of moments and ii) method of maximum likelihood. Then these methods were tested for bias, coefficient of variability and root mean square error for 1000 sample size. The study showed that after using the Gringorton plotting position formula, the Gumbel distribution using least square performed better than in comparison of the method of moments and method of maximum likelihood parameter estimation procedure.

Seth et al(1986) carried out a regional flood frequency analysis for the region of subzone 3-d of Mahanadi. In this study, the methods used for the analysis include; i) index-flood method based EVI distribution, ii) power transformation method and iii) regional wakeby distribution using James-Stein corrected mean for 18 different gauging stations in the basin for varying number of years of record. Out of 18 sites, the data of 15 sites were used to develop regional flood frequency curve and the remaining 3 sites data were used for the verification of the results obtained from the analysis.

Huq et al (1986) attempted to formulate the flood frequency formulae for country wide application using the rainfall of given frequency in the rainfall-runoff relationship. While developing the relationship, author considered 50 years flood peak values as dependent variable and the catchment size and slope of the stream as independent variables. The country was divided into the distinct regions such as alluvial plains of Indus, Ganges and Brahmaputra river system with equivalent slope upto 1.5 m/km. The area sloping above 1.5m/km upto 3.5 m/km included in the second region. The area having slope 3.5m/km and above were classified as third region. These three distinct regions are considered for the analysis. The flood formulas were developed for respective classification based on slopes.

Seth & Singh (1987) carried out the frequency analysis using wakeby distribution for three typical regions viz; i) lower Godavari basin, ii) Brahmaputra basin and iii) sub Himalayan region.

Singh et al(1991) carried out a study using the peak flood series data of hydro-meteorologically homogeneous region of Godavari basin sub zone 3f involving application of EVI (PWM) and GEV (PWM) methods based on i) at site data, ii)at site and regional data combined and iii) regional data alone. Homogeneity of the region was tested using USGS and Coefficient of variation based homogeneity test. From the study it is concludes that GEV (PWM) approach using at site and regional data in a combined form provides estimates of flood peaks for different return period with computationally less bias and comparable root mean square error.

Rakesh kumar et al (1994) carried out a study to develop regional flood frequency curves fitting the PWM based GEV distribution with the annual maximum flow data of 20 gauging station of Mahanadi basin subzone 3d. Also a relationship between the mean annual peak floods and the physiographical characteristics of the catchment area was developed. The developed regional flood formula for this region was represented in the form of Dicken's formula for different return periods estimated using the dicken's formula.

6.0 Methodology

The methods used in the present study to carry out the regional flood frequency analysis involves the USGS method and fitting of PWM based Extreme Value type-I distribution, General Extreme value distribution and Wakeby distribution. The parameters of these distribution were estimated using the method of probability weighted moments.

6.1 Modified USGS Method

The USGS method for estimating the floods of given recurrence intervals for ungauged catchments consists of following sequential steps ;

1. Select gauged catchments within region having more or less similar hydrological characteristics to that of the ungauged catchments.
2. establish flood frequency curves for each gauging station using EV-I distribution probability paper
3. estimate mean annual flood $Q_{2.33}$ at each gauging station.
4. test the homogeneity for gauged catchment.
5. rank ratios of selected return period floods to the mean annual flood at each station, and
6. compute median flood ratio for each of the selected return period of step (5), multiply by the estimated mean annual flood of the ungauged catchment and plot them against recurrence interval on Gumble probability paper.

The end result of these 6 step is a flood frequency curve for an ungauged catchment.

The gauged catchments in the vicinity of the ungauged catchments having similar characteristics are selected for the analysis. Although the similarity would include characteristics such as average elevation, geology, climate and soil structure etc, the measure of the similarity will be determined from peak flow data through the homogeneity test described by Dalrymple (1960). Since the effect of one or more combination of several characteristics of a catchment on runoff is not well defined or quantified, it is reasonable to look only at the statistics of the runoff events to determine homogeneity.

6.2. Extreme Value Type-I Distribution (EVI)

This is a two parameter distribution and it is popularly known as Gumble distribution. The

cumulative density function for EVI distribution is given by

$$F(X) = e^{-e^{-\frac{(x-u)}{\alpha}}}$$ Eq.. (1)

where F(x) is the probability of non exceedence and equal to 1-1/T ; T is the recurrence interval in years, u and α are the location and shape parameters respectively. These parameters can be estimated from the sample of annual maximum peak flood using the parameter estimation techniques available. The method of probability weighted moments(PWM) is one of such methods for estimation of the parameters and which has been successfully applied by Landerwehr et al. (1979) and Singh (1991) for estimating the parameters of EVI distribution more efficiently. The method is described below.

6.2.1. At site EVI PWM method (EVI).

Method based on probability weighted moments generally required expressing the distribution function in inverse form which is given below for EVI distribution

$$x = u - \alpha \ln(-\ln F)$$ Eq.........(2)

where, u and α, as mention earlier, are the parameters of the distribution.

Following the Landwehr et al. (1979) the r^{th} order probability weighted, M_{10r} is given by the equation:

$$M_{10r} = \frac{1}{n}\sum_{i=1}^{n} X_i (1-F_i)^r$$ Eq......... (3)

where F_i the probability of non exceedence which is computed using the plotting position formulae:

$$F_i = \frac{i-0.35}{n}$$ Eq....... (4)

where i is the rank in the arranged flood series, and n is the sample size.

Putting r= 0,1,2, ...n, M_{100}, M_{101}, M_{102} .... etc are computed from the flood series. The parameters u and α of EVI distribution and quantile Q_T are computed by this method following the steps given below,

1. Arrange the flood series and compute M_{100} and M_{101} using equations (3)& (4).
2. Standardise the computed values of M_{100} and M_{101} obtained from step (1) dividing them by at site mean,

(same as M_{100}). Hence:

$$m_0 = \frac{M_{100}}{M_{100}} = 1.0 \qquad \text{Eq.,....... (5)}$$

$$m_1 = \frac{M_{101}}{M_{100}} \qquad \text{Eq......... (6)}$$

3. Estimate the parameters u and α using the following equations (Landwehr, 1979)

$$u = m_0 - 0.5772\,\alpha \qquad \text{Eq........ (7)}$$

$$\alpha = \frac{m_0 - 2m_1}{\ln 2} \qquad \text{Eq........ (8)}$$

4. Estimate the T - year recurrence interval flood using the relation:

$$X_T = u + \alpha\,(\ln\text{-}(\ln(1\text{-}1/T))) \qquad \text{Eq.........(9)}$$

5. Scale the quantiles x_T by at site mean in order to give an estimate for the site, Q_T:

$$Q_T = M_{100}\,x_T \qquad \text{Eq..... (10)}$$

6.2.2. Using EVI PWM method on at Site and Regional Data,(SREVI).

The steps are;

i). Test for regional homogeneity of data for selected gauged catchments, using USGS homogeneity test.

ii). Rank the flood series of each gauging site and compute the at site values of PWM, $M_{100,j}$ and $M_{101,j}$ as :

$$M_{100,j} = \frac{1}{n(j)} \sum_{i=1}^{n(j)} X_{i,j} \qquad \text{Eq.... (11)}$$

$$M_{101,j} = \frac{1}{n(j)} \sum_{i=1}^{n(j)} X_{i,j}\,(1-F_{i,j}) \qquad \text{Eq......(12)}$$

where n(j) is the record length for the j[th] gauging site,

$M_{100,j}$ is the zeroth order probability weighted moment for the j[th] gauging site (same as the at site mean)

$M_{101,j}$, is the first order probability weighted moment for the j[th] gauging site.

$F_{i,j}$ is the probability of non-exceedence and computed by the following plotting position formulae:

$$F_{i,j} = \frac{i-0.95}{n(j)} \qquad \text{Eq..... (13)}$$

$x_{i,j}$, is the i[th] rank value in the sample of annual maximum peak series for the j[th] gauging site

iii). Standardize the at site values of PWM obtained from the previous step by the at site mean. Thus ;

$$m_{0,j} = \frac{M_{100,j}}{M_{100,j}} = 1.0 \qquad \text{Eq.....(14)}$$

$$m_{1,j} = \frac{M_{101,j}}{M_{100,j}} \qquad \text{Eq.....(15)}$$

where $M_{o,j}$ is the zeroth order standardised PWM, for j[th] gauging site, and

$M_{1,j}$ is the first order standardised PWM for j[th] gauging site.

iv). Compute the regional values of the standardized PWMs averaged across the number of sites in the region in the ratio of the record lengths. Hence:

$$\bar{m}_0 = \frac{1}{L}\sum_{i=1}^{M} m_{0,j}\; n_(j) = 1.0 \qquad \text{Eq..... (16)}$$

$$\bar{m}_1 = \frac{1}{L}\sum_{i=1}^{M} m_{1,j}\; n_j \qquad \text{Eq.... (17)}$$

where , $L = \sum_{j=1}^{m} n(j)$ = total record length

m_0, and m_1 are the standardized regional PWMs.

v).Compute the regional EVI parameter u and α using the relationships

$$\alpha = \frac{\bar{m}_0 - 2\bar{m}_1}{\ln 2} \qquad \text{Eq..... (18)}$$

$$u = \bar{m}_0 - 0.5772\alpha \qquad \text{Eq..... (19)}$$

vi). Estimate the regional quantiles x_T using the relation :

$$X_T = u + \alpha\,(-\ln(-\ln(1 - 1/T))) \qquad \text{Eq..... (20)}$$

vii). Scale the quantiles x_T by at site mean (as same as $M_{100,j}$) to estimate quantiles ($Q_{T,j}$) for each gauging site. Hence:

$$Q_{T,j} = M_{100j}\, X_T \qquad \text{Eq.... (21)}$$

6.3.0. General Extreme Value Distribution (GEV)

GEV is a generalised 3 parameter extreme value distribution proposed by Jenkinson (1955). The theory and the applicability of GEV are reviewed in the British flood studies report (NERC, 1975). The cumulative density function F(X) for GEV distribution is expressed as ;

$$F(X) = e^{-(1-k\frac{(X-u)}{\alpha})^{\frac{1}{k}}} \qquad \text{Eq..... (22)}$$

where u, α and k are location, scale and shape factors of GEV distribution respectively. The probability weighted moment (PWM) method has been used to estimate these parameters for 2 different cases and are described below.

6.3.1. At site GEV PWM Method

As method of probability weighted moment require the density function expressed in inverse form which is stated below,

$$X = u + \alpha (1. -(-\ln(F)^{K})/K) \quad \text{Eq.... (23)}$$

where u, α and k are the location, scale and shape parameter of the distribution. for K= 0, GEV distribution converges to the EVI distribution. if K < 0 or K > 0, it represents the EV1 and EV2 distribution respectively.

The parameters u, α and k of the distribution and the quantile Q_T are estimated using the method of probability weighted moment in the following steps :

1). Arrange the flood series and compute M_{100}, M_{101}, M_{102} using the Eq (3) and (4).
2). Standardise the computed values of M_{100}, M_{101} and M_{102} obtained from step (1) dividing them by the at site mean. Hence,

$$m_0 = \frac{M_{100}}{M_{100}} = 1.0 \quad \text{Eq......(24)}$$

$$m_1 = \frac{M_{101}}{M_{100}} \quad \text{Eq......(25)}$$

$$m_2 = \frac{M_{102}}{M_{100}} \quad \text{Eq.....(26)}$$

3). From normalised values of m_o, m_1 and m_2, estimate M_{110} and M_{120} using equations :

$$M_{110} = m_0 - m_1 \quad \text{Eq...(27)}$$

$$M_{120} = m_0 - 2\, m_1 + m_2 \quad \text{Eq...(28)}$$

4). Calculate a constant C

$$C = ((2\, M_{110} - m_o) / (3\, M_{120} - m_o)) - (\ln_2 - \ln_3) \quad \text{Eq...(29)}$$

5). Calculate the shape parameter K using the relation :

$K = 7.8590\ C - 2.9554\ c^2$ Eq...(30)

6). Calculate the scale parameter, α, using the relation :

$$\alpha = \frac{((2M_{110} - m_0) \cdot K)}{\gamma(1+K) \cdot (1.0 - 2^{-k})} \quad \text{Eq....(31)}$$

7). Calculate the location parameter, u using the relation :

$$u = m_0 + \alpha \frac{\gamma(1+k) - 1}{K} \quad \text{Eq....(32)}$$

where, Gamma(γ) $(1+K)^{1/2}$ is the value of Gamma(γ) of (1+K) computed from the Gamma function subroutine.

8). Estimate the quantile x_T using the relation :

$$x_T = u + \alpha(1 - (-\ln(1. - 1/T)^k)/k \quad \text{Eq....(33)}$$

9). Scale the quantiles x_T by the at site mean for the at site estimates of quantiles Q_T:

$$Q_T = x_T * M_{100} \quad \text{Eq.....(34)}$$

6.3.2. FFA of GEV based on at Site and Regional data (SRGEV)

Following are the steps to be followed to estimate the regional parameters and the quantiles for GEV at the site using the regional data.

1). Test for regional homogeneity test of data for selected gauged catchment using USGS homogeneity test.
2). Estimate at site values of PWM $M_{100,j}$, $M_{101,j}$, $M_{102,j}$ for each site putting r = 0,1,2,3,...n in the following equation.

$$M_{10r,j} = \frac{1}{n(j)} \sum_{i=1}^{n(j)} X_{i,j} (1 - F_{i,j})^r \quad \text{Eq.....(35)}$$

3). Standardised the at site mean values of PWMs obtained from step (2) by the at site mean:

$$m_{r,j} = \frac{M_{10r,j}}{M_{100,j}}$$ Eq.....(36)

where r = 0, 1 and 2 respectively

4). Compute the regional values of standardised PWMs averaged across the number of sites in the region in the ratio of record lengths. Hence :

$$\bar{m}_r = \frac{1}{L} \sum_{j=1}^{n(j)} m_{r,j} \; n(j)$$ Eq.....(37)

where L is record length

5). Estimate the regional parameters K, u and α of the GEV distribution using the procedure described for at site GEV PWM method where in place of at site standardized PWMs regional standardized PWMs are used.

6). Estimate the regional quantiles x_T using the relation :

$$X_T = u + \alpha\ (1. -(-\ln(1-1/T))^K)/ K$$ Eq....(38)

7). Scale the quantiles X_T by at site mean for the estimation of quantiles $Q_{T,j}$ at any gauging site :

$$Q_{T,j} = M_{100,j}\, X_T$$ Eq..... (39)

6.4. PWM based Wakeby Distribution

The wakeby distribution method is used for regional flood frequency analysis. The average value of normalised probability weighted moments are estimated from the normalised probability weighted moments computed from the annual peak flood series of different gauging sites. The regional parameters are estimated using the algorithm suggested by Landwehr et al(1979) based on these averaged normalised values of probability weighted moments.

6.4.1. Estimation of regional parameters of wakeby distribution.

A random variable, say flood Q_T is wakeby distributed, then the relationship is expressed as follows,

$$\frac{Q_T}{\bar{Q}} = m + a\,[1-(1-F)^{b}] - c\,[1-(1-F)^{-d}] \qquad \text{Eq...... (40)}$$

where, $F = F(Q) = P\,(Q \le Q_T)$, and a, b, c, d and m are the parameter of the wakeby distribution.

The regional parameter of the wakeby distribution are estimated based on the concept of probability weighted moments which is defined as,

$$M_{j,k} = \frac{1}{N(j)} \sum_{i=1}^{N(j)} Q_{i,j}\,(1-F_{i,j})^{k} \qquad \text{Eq.....(41)}$$

where $j = 1,2,....NS$

$K = 0,1,2,3,4$

$M_{j,k}$ = k^{th} order probability weighted moments for the j^{th} gauging site.

NS = Number of gauging station.

$N(j)$ = Number of annual maximum peak flood at j^{th} gauging site

$Q_{i,j}$ = i^{th} item in the sample of annual peak flows at j^{th} gauging station.

$F_{i,j}$ = probability of non-exceedence for the i^{th} item in the sample of annual maximum peak flows at the j^{th} gauging site and it is evaluated using the plotting position formulae,

$F = 1-1/T$

$$F_{i,j} = \frac{i-0.35}{N(j)} \qquad \text{Eq.....(42)}$$

The probability weighted moments expressed as Eq (41). are normalised after dividing them by zeroth order probability weighted moments which is the sample mean. Therefore, the normalised probability weighted moments may be expressed as

$$M_{j,k}=\frac{\sum_{i=1}^{N(j)} Q_{i,j}(1-f_{i,j})^k}{\sum_{i=1}^{N(j)} Q_{i,j}}$$ Eq.....(43)

The average values of normalised probability weighted moments may be estimated using the equations

$$AM_K=\frac{1}{NS}\sum_{i=1}^{NS} M_{j,K}$$ Eq......(44)

where AM_K is the average value of normalised probability weighted moments of the order K

A special algorithm suggested by Landwehr et al (1979) is followed for estimation of the regional parameters of the wakeby distribution using the average values of normalise probability weighted moments obtained form Eq (44).

6.5. USGS Homogeneity Test

The USGS homogeneity test has been widely used for testing the homogeneity of data in a region. The steps involved in USGS homogeneity test are,

1. Compute the EVI reduced variate corresponding to 10 year return period flood using Y_{10} the relation

$$Y_T = [\,-\ln(-\ln(1-1/T))]$$ Eq......(45)

example $Y_{10} = [\,-\ln(-\ln(1-1/10))] = 2.25$

2. Compute the 10 year flood putting $Y_{10} = 2.25$ in the following equation developed for different catchments using least square approach

$$X_{10} = u + \alpha\ Y_{10}$$ Eq.......(46)

$$X_{10} = u + 2.25\alpha$$ Eq.......(47)

3. Repeat step (1) and (2) to compute 2.33 year flood, which is the annual mean flood for EVI distribution for different catchments.

4. Compute the ratio of 10 year flood to annual mean flood at each gauging sites. The ratio is known as the 10 year frequency ratio.

5. Average the 10 year frequency ratios of all the gauging sites to obtain the mean 10 year frequency ratio

as a whole.

6. Determine the EVI reduced variate corresponding to the products of annual mean flood and the average 10 year frequency ratio from the linear regression equation developed for each catchment. Thus;

$$Y_T = (X_T - u)/\alpha \quad \text{Eq...... (48)}$$

7. Plot the EVI reduced variate obtained from step (6) against the effective length of record for that station on a test graph where upper and lower regional limits of 95% confidence are already plotted using the following coordinates

Sl.no	Sample Size (n)	Lower limit (Y)	Upper limit (y)
1	5	-0.59	5.09
2	10	0.25	4.25
3	20	0.83	3.67
4	50	1.35	3.15
5	100	1.52	2.88
6	200	1.80	2.70
7	500	1.97	2.53
8	1000	2.05	2.45

If the plotted points for all stations under consideration falls within the upper and lower regional confidence limit(as given in the above table) developed by USGS then the data are regionally homogeneous and applicable for analysis. Any station for which the plotted points lies outside the envelope curve is to be excluded from homogeneous region and hence from the analysis.

The upper and lower limit as listed in table above, have been computed for a return period of 10 years. The reduced variate (y) for T=10 years in the Gumble distribution is 2.55 and the limits are given as

$$Y \pm 2\, e^{y} / [N\,(T-1)]^{1/2} \quad \text{Eq.......(49)}$$

$$2.25 \pm 6.33 / [N]^{1/2} \quad \text{Eq.......(50)}$$

where N is the length of record.

6.6. Flood Frequency Curves

The process of developing the regional flood frequency curves uses a sample data comprising the station year data of standardised values of annual maximum peak flood i.e., Q/ Q for different catchment of the basin. Then the frequency analysis is carried out using Q/Q values. In the present study, Extreme Value - Type I distribution is used. The cumulative density function of EVI is expressed as

$$F(X) = e^{-e^{-\frac{(x-u)}{\alpha}}} \qquad \text{Eq...... (51)}$$

here, u and α are location and scale parameters of the EVI distribution. The parameter u & α were estimated using index-flood method. The form of the regional frequency relationship can be written as

$$X_T = Q_T/Q = u + \alpha\ Y_T \qquad \text{Eq......(52)}$$

where Q_T is the T-year return period flood.

Q is the mean of the annual peak flood

Y_T is the EVI reduced variate corresponding to T- year return period.

The EVI reduced variate can be expressed as a function of return period

$$Y_T = [\ -\ln(-\ln(1-1/T))] \qquad \text{Eq......(53)}$$

6.7.Relationship of Mean annual flood and Catchment Area

The mean annual flood of an ungauged catchment can be determined from a plot of the log of the drainage area versus the log of the mean annual flood estimated from the observed sequences on Gumble probability paper.

The relationship can be written as

$$\log Q = \log c + a \log A \qquad \text{Eq....(54)}$$

where Q is the mean annual flood (Cumecs)

A is the drainage area

c & a are the constants of regression

The equation can be written in its natural form

$$Q = c\,A^{a} \qquad \text{Eq....(55)}$$

Following are the some of the distributions used for analysing the frequency of the annual peak flow series and in developing the relationship between mean annual flood and catchment area.

6.8. Development of Regional Flood Formulae

The regional flood formula may be developed using the frequency curves developed for different methods and the relation established between the mean annual flood flows and the catchment area. The regional flood formulae developed using the equation (52) & (55) is shown as below

$$Q_T = C\,A^{b} \qquad \text{Eq......(56)}$$

where C is the coefficient of regional flood formulae

$$C = (uc + \alpha c)$$

where Q_T is the flood estimated for T year return period ;

C is the regional coefficient of T year return period flood to be estimated from regional frequency curves.

From the above equation, it is evident that the flood estimated for return period T is a function of regional flood curves developed using the different methods. This equation can be used to compute the flood for desired return periods of various un-gauged catchment in the region.

6.9.Evaluation Criteria for Selecting a Suitable Frequency Analysis Method

Evaluation criteria for selecting an appropriate frequency analysis procedure can be divided into two categories: 1). Descriptive ability, and 2).Predictive ability.

Descriptive ability criteria relate to ability of a chosen model to describe/reproduce chosen aspects of observed flood peak hydrology. Predictive ability criteria relate to statistical ability of procedure to achieve its assigned task, with minimum bias and maximum efficiency and robustness. However, for this study, only descriptive ability criteria are considered for the evaluation of the different frequency analysis methods. The descriptive ability criteria used in the study are :

a).Avergae of the relative deviation between computed and observed values of annual maximum discharge peak (ADF)

b). Efficiency (EFF)

c). Standard error (SE)

a). Computation of ADF Values:

For computation of ADF values the following relationship is used:

$$ADF=\frac{1}{n}\sum_{i=1}^{n}\frac{(QO_i-QC_i)}{QO_i} \qquad \text{Eq......(57)}$$

b). Computation of EFF values :

EFF values are computed using the relations :

$$EFF=(IV-MV)/IV \qquad \text{Eq.....(58)}$$

where

$$IV=\sum_{i=1}^{n}(QO_i-\bar{Q})^2$$

$$MV=\sum_{i=1}^{n}(QO_i-QC_i)^2$$

$\bar{Q}$ = Mean of the observed peak discharge series of QO_i

QC_i = i^{th} values of computed peak discharge series

n = sample size

c) Computation of SE values

SE values are computed, in non dimensional form using the following relationships

$$SE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(QRO_i-QRC_i)^2} \qquad \text{Eq..... (59)}$$

where, $QRO_i = QO_i$

$QRC_i = QC_i/Q$

7.0 Analysis

The annual maximum peak flood series of 34 gauging station are considered for the USGS homogeneity test. The record of 6 stations are omitted after the USGS homogeneity test since they are falling out of the USGS homogeneity envelop curves. Then the remaining 26 and 2 gauging station data are used to develop and test the regional flood frequency curve respectively using the methods discussed in the previous chapter. These gauging stations data then classified under three groups, i) medium catchments (catchment area less than 5000 Km^2), ii) large catchments (which are above 5000 Km^2) and iii) considering all the catchments together as one region. The initial statistical parameters of the data used for analysis are given in the table. 1.

The data of the following 2 gauging site are used to verify the developed regional relationship.

Sl. no	Stream	Gauging site	Drainage Area
1	Tunga	Shimoga	2381
2	Varad	Marol	4901

7.1. USGS Homogeneity Test

The USGS homogeneity test is carried out using the data of all the stations. The homogeneity plot for all 34 station is shown in fig.2. The computational details to arrive at this plot is given in table 2. The data of each of the 34 sites considered for the analysis were plotted on the Gumble EVI probability paper. From the plot it is noticed that, there are 6 sites which falls outside the envelop curves, and these stations are considered as statistically non- homogeneous. Therefore these 6 sites were excluded from the present analysis.

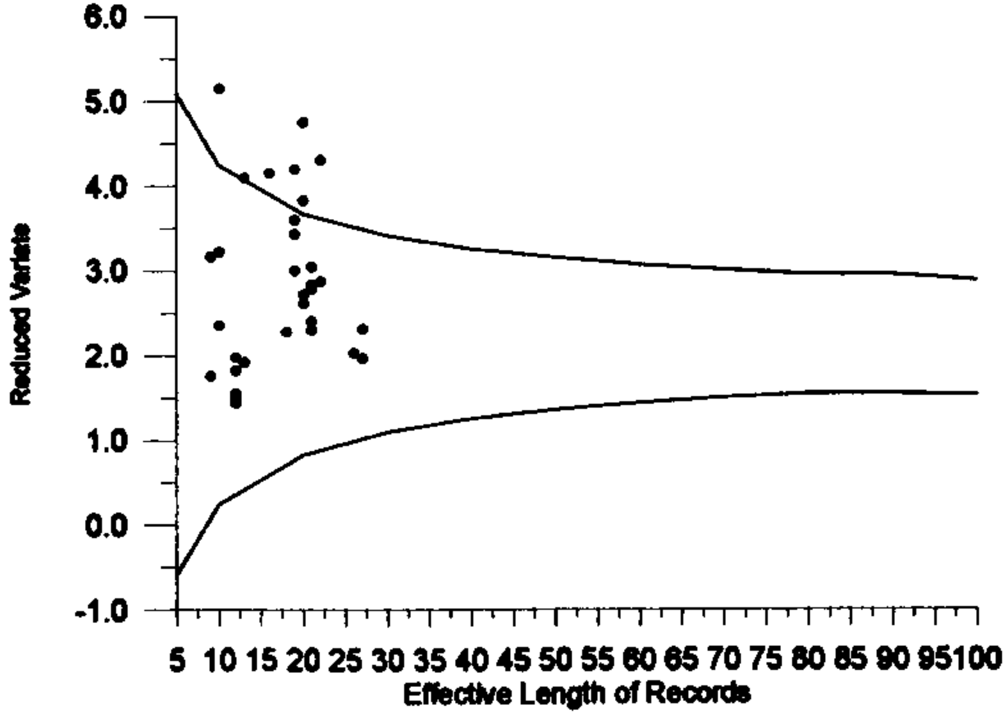

Fig.2. USGS Homogeneity Test

Table.1. Preliminary statistics of the data used for study.

Slno	Gauging Site	Stream	Catchment area (km^2)	Mean M^3/sec	Standard deviation (M^3/sec	Coefficient of Variation	Coefficient of Skewness
1	Karad	Krishna	5462	2649.8	911.2	0.3438	0.332
2	Arjunwad	Krishna	12660	3956.5	1213.7	0.3667	0.3213
3	Koynanagar	Koyna	920	987.05	712.58	0.7219	0.5634
4	Warunji	Koyna	1690	1586.1	438.13	0.276	1.1835
5	Gokak	Ghataprabha	2776	1537.3	737.19	0.479	0.275
6	Bagalkot	Ghataprabha	8610	1282.8	527.20	0.410	0.1218
7	Cholchgod	Malaprabha	9373	911.70	447.06	0.490	0.294
8	Gotur	Himya keshi	1100	786.20	253.4	0.322	0.5208
9	Daddi	Ghataprabha	1150	1089.0	379.37	0.348	0.7912
10	Bestwad	Vedganga	640	469.05	118.30	0.2522	0.174
11	Tarewad	Panchganga	2425	2196.6	1529.2	0.698	3.892
12	Yadgeer	Bhima	69863	4595	2325	0.566	0.8327
13	Wadakbal	Sina	12092	1148.1	729.79	0.6356	0.8862
14	Takali	Bhima	33916	3657.1	1858.7	0.508	1.175
15	Shirdon	Doddahalla	630	112.25	123.29	1.09	2.093
16	Konkangaon	Borinala	1640	420.65	549.72	1.306	2.713
17	Bori-omergaon	Bori	2640	449.27	314.33	0.699	0.9102
18	Jewani	Kanga	1920	678.4	603.02	0.888	1.218
19	Dhond	Bhima	11660	3551.8	1283.3	0.3613	0.0867
20	Narasingpur	Bhima	22856	4023.0	1816.3	0.4515	0.973
21	Sarathi	Nira	7200	1427.4	704.15	0.4932	0.908
22	Khanapur	Malaprabha	540	470.5	180.41	0.383	0.845
23	Chichalgod	Himakeshi	1175	570.9	226.97	0.397	2.302
24	Yamagardi	Vedganga	655	773.36	311.74	0.403	1.021
25	Kongana halli	Dudhganga	603	735.74	421.57	0.572	2.502
26	Kudachi	Krishna	18417	6766.0	1803.4	0.266	1.131

Table.2. Computational details of Homogeneity test.

Sl.No	Q_{10}	$Q_{10}/Q_{2.33}$	Rev.Q_{10}	Reduced variate	EFF. Length of records
1	3772.64	1.492	4330.72	3.00	19
2	5640.10	1.418	6809.72	3.43	19
3	2025.38	2.009	1726.31	1.76	9
4	2191.32	1.375	2728.47	3.75	19
5	2727.63	1.701	2747.42	2.28	18
6	2004.37	1.555	2207.32	2.72	20
7	1547.47	1.586	1671.07	2.61	20
8	1158.82	1.460	1359.15	3.17	9
9	1806.94	1.449	2135.31	3.23	10
10	1006.07	1.669	1032.26	2.36	10
11	4038.80	1.888	3662.93	1.92	13
12	7798.14	1.687	7916.83	2.31	27
13	2145.35	1.864	1970.47	1.96	27
14	7544.48	1.826	7072.77	2.02	26
15	297.68	2.337	218.14	1.47	12
16	912.89	2.381	656.43	1.44	12
17	895.16	1.960	782.06	1.82	12
18	1546.27	2.231	1186.64	1.55	12
19	5301.04	1.484	6115.59	3.04	21
20	6220.29	1.692	6294.38	2.30	21
21	2421.31	1.653	2507.74	2.40	21
22	723.56	1.529	810.51	2.83	21
23	872.14	1.519	983.36	2.87	22
24	1199.42	1.541	1332.50	2.78	21
25	1182.11	1.847	1095.83	1.98	12
26	9285.79	1.366	11635.96	3.83	20

The EVI probability plots for all the 26 sites considered for analysis along with lower and upper 95% confidence band are shown in fig 3 to 28.

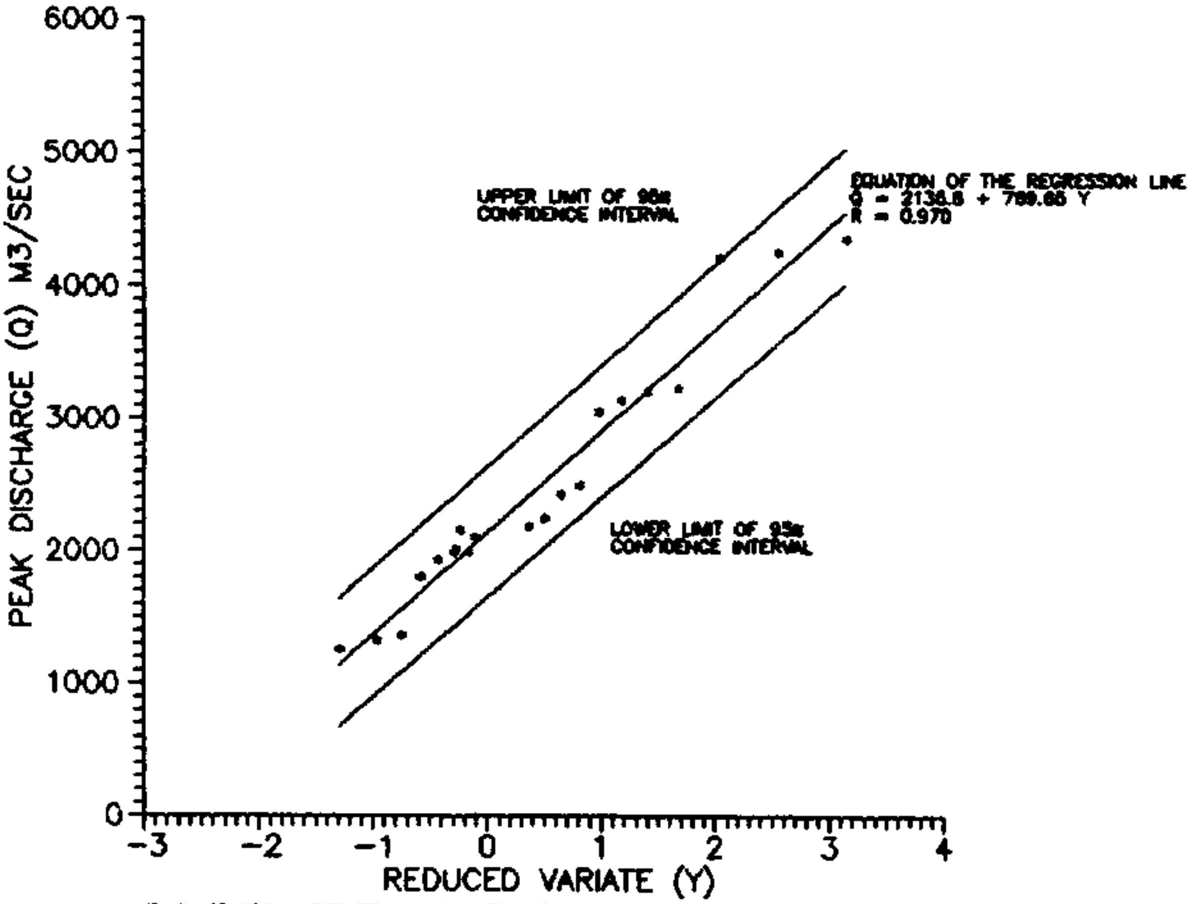

Fig.3. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION KARAD

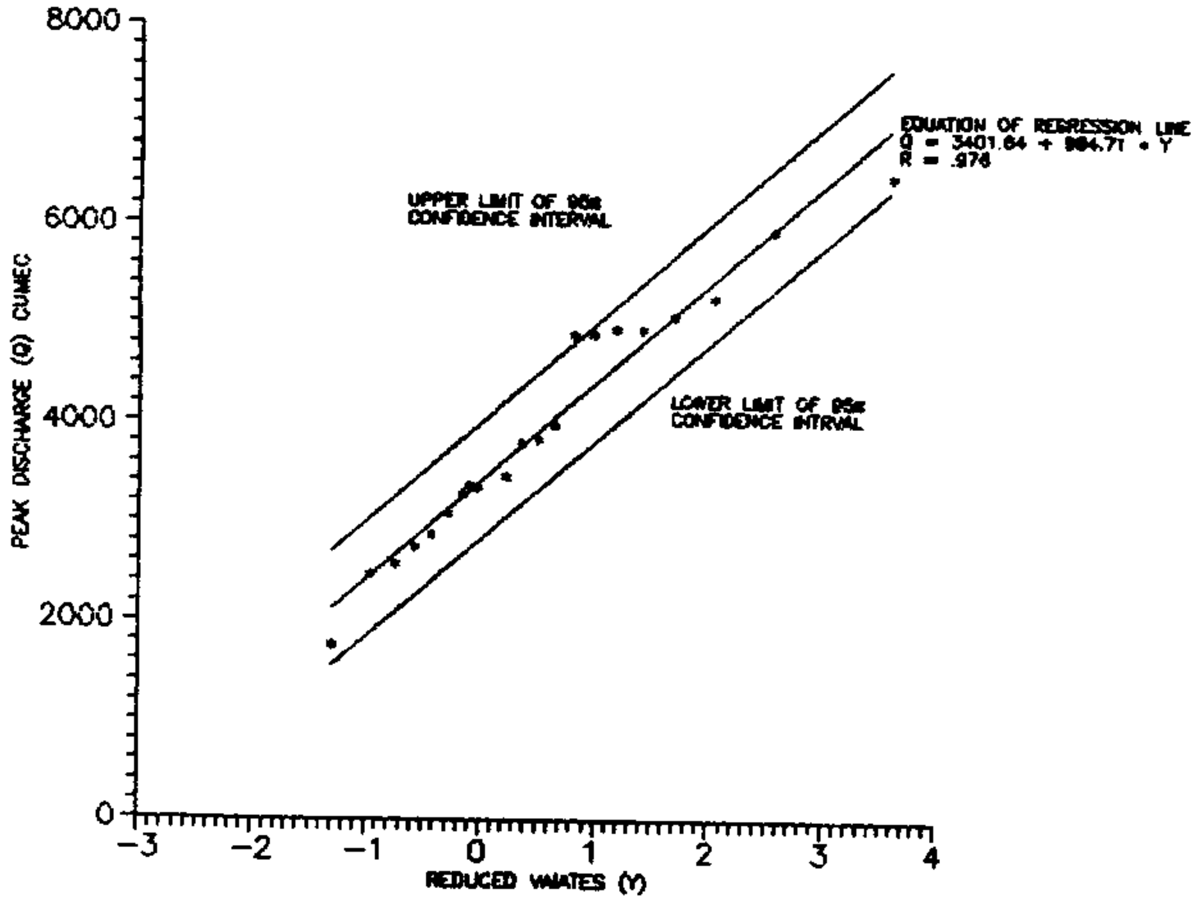

Fig.4. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT ARJUNWAD GAUGING STATION.

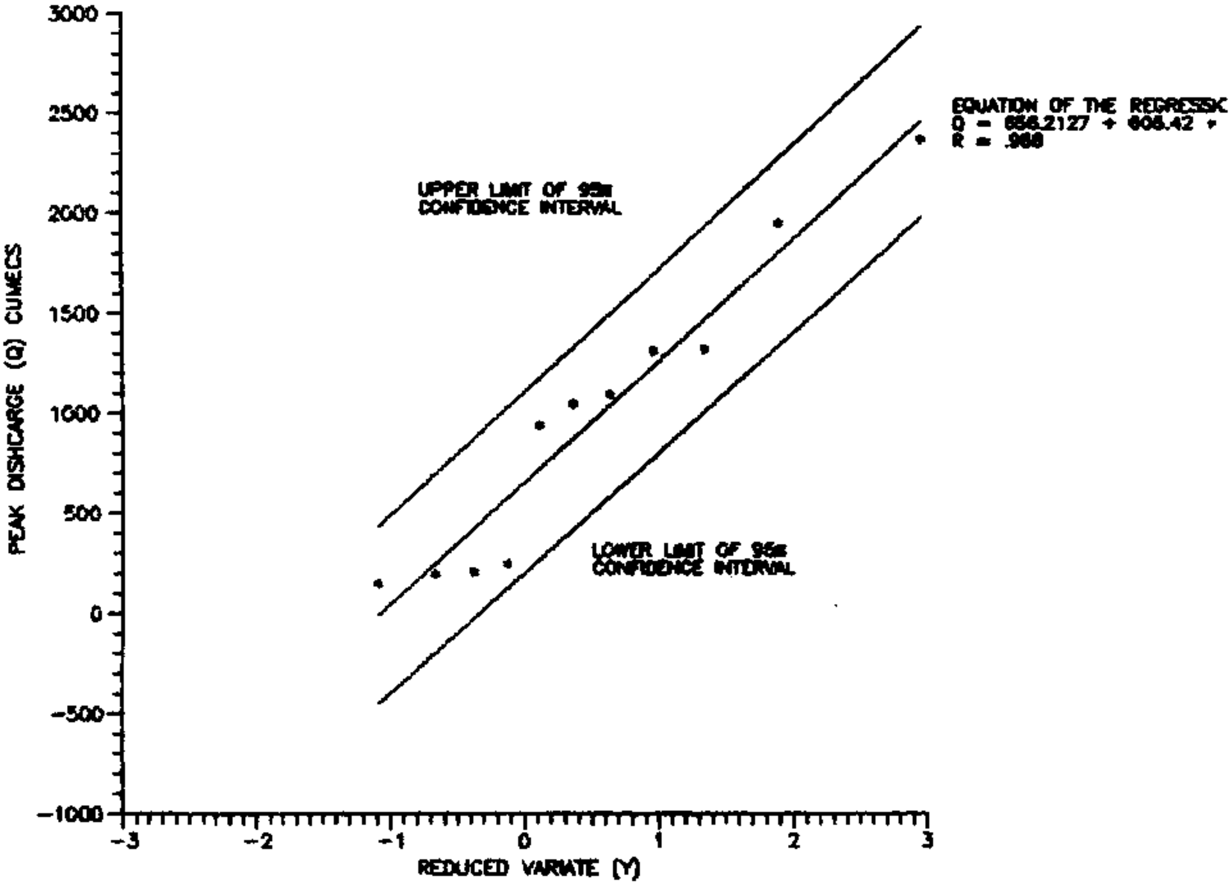

Fig.5. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EV1 REDUCED VARIATES AT GAUGING STATION KOYNA NAGAR

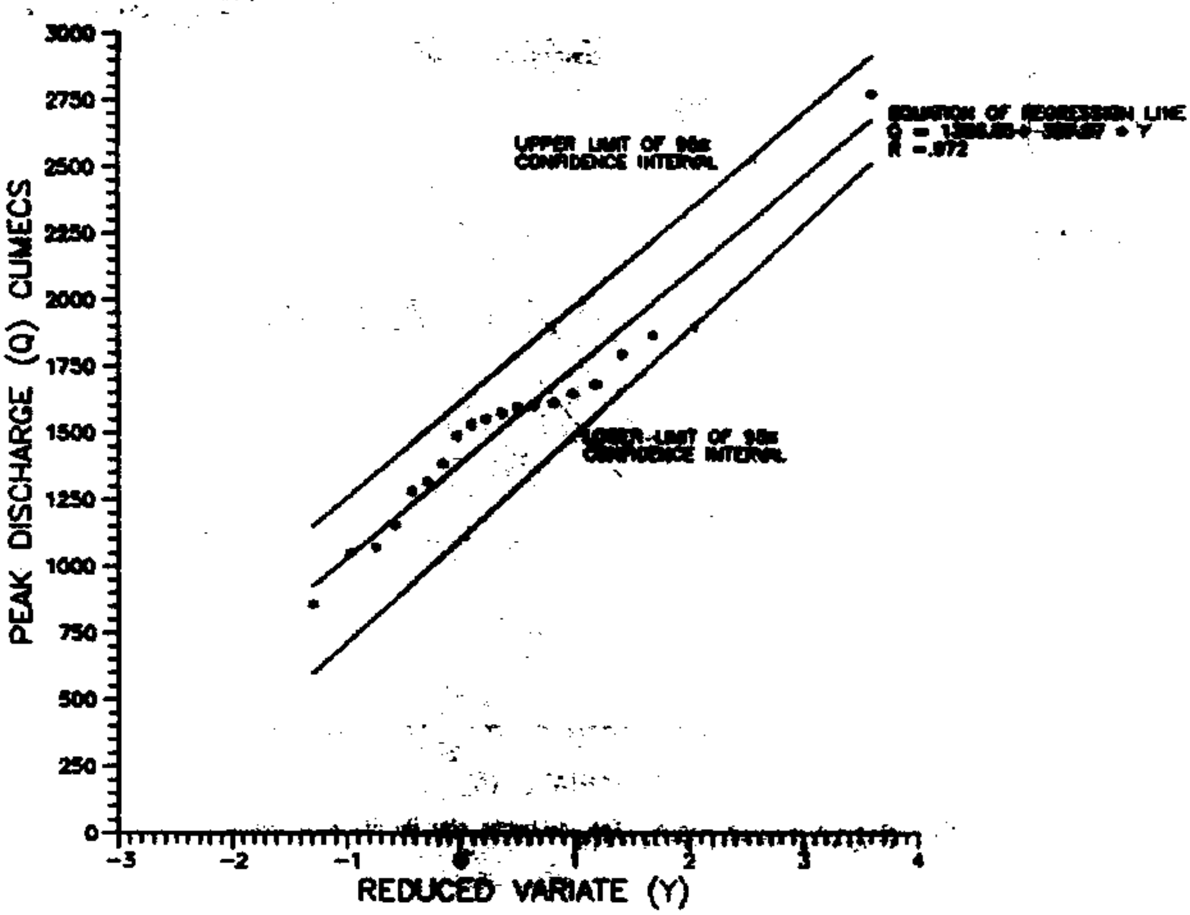

Fig.8 RELATION BETWEEN ANNUAL PEAKS AND REDUCED VARIATES AT GAUGING STATION [illegible]

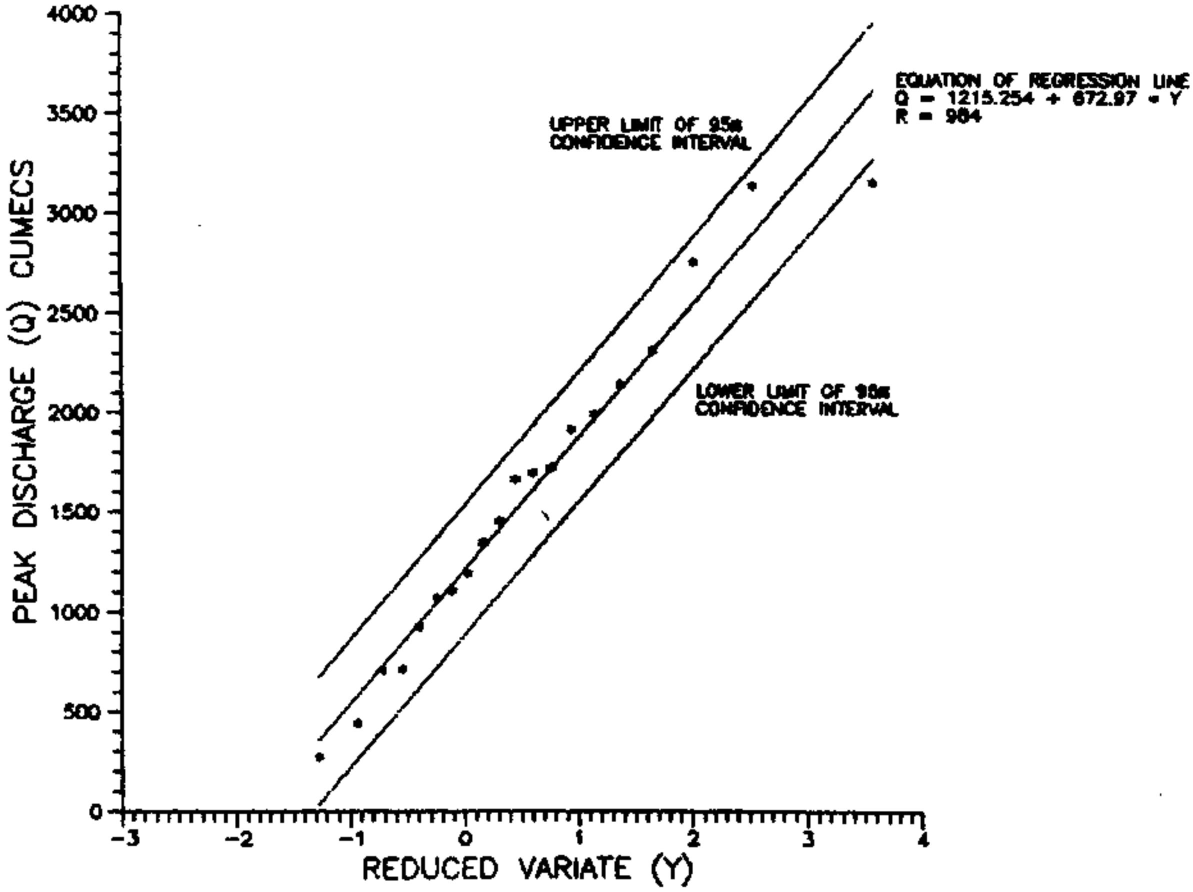

Fig.7. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION GOKAK FALLS

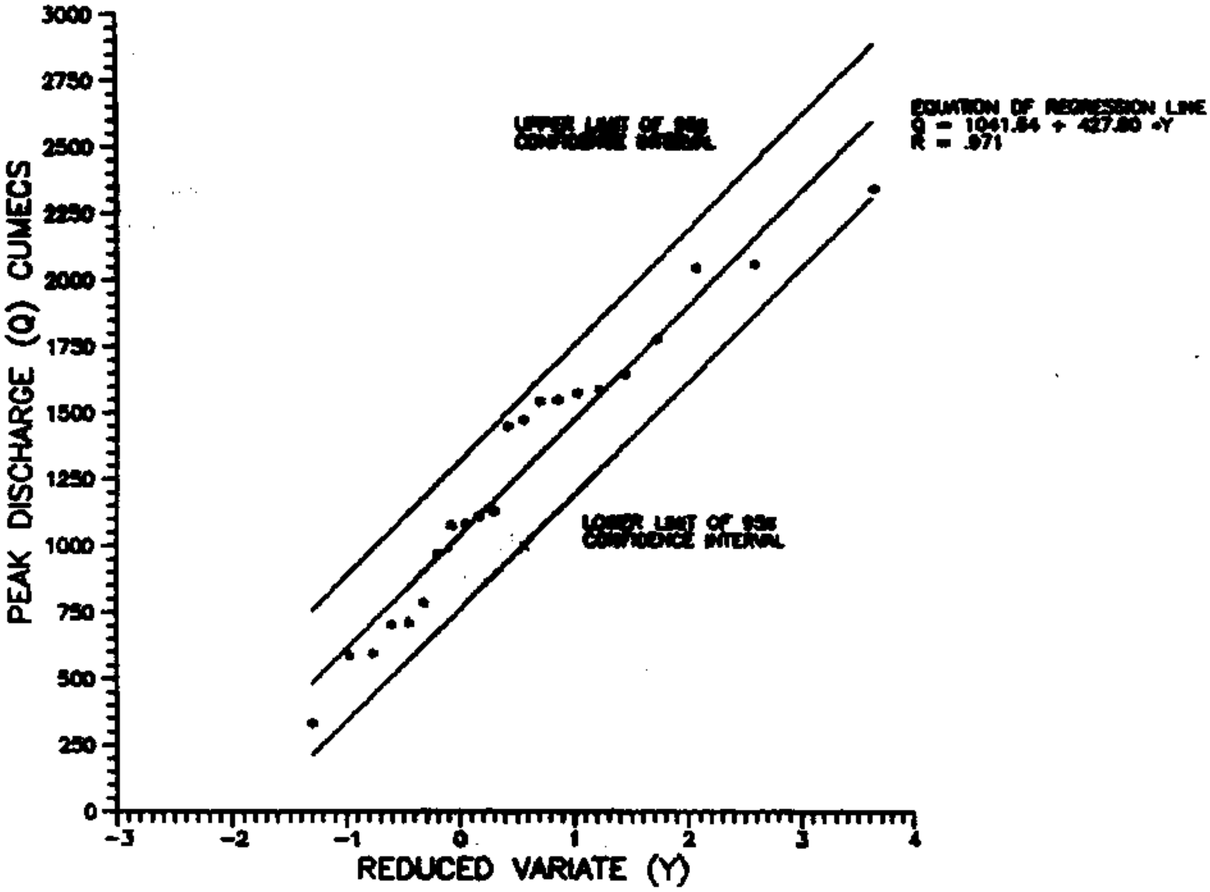

Fig.8. RELATION BETWEEN [illegible] PEAK [illegible] AND [illegible] REDUCED [illegible] AT GAUGING STATION [illegible].

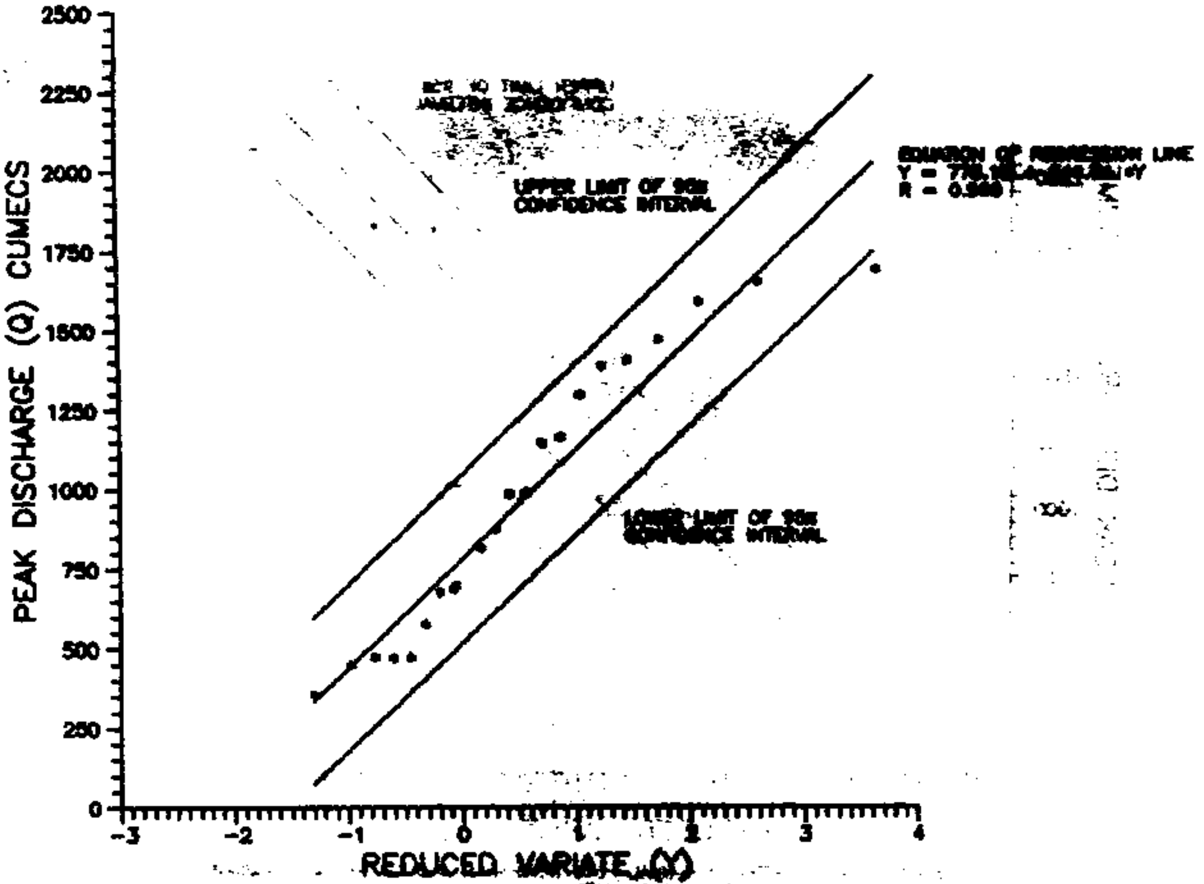

Fig.9. RELATION BETWEEN ANNUAL [illegible] REDUCED VARIATES AT GAUGING STATION CHOLACH[illegible]

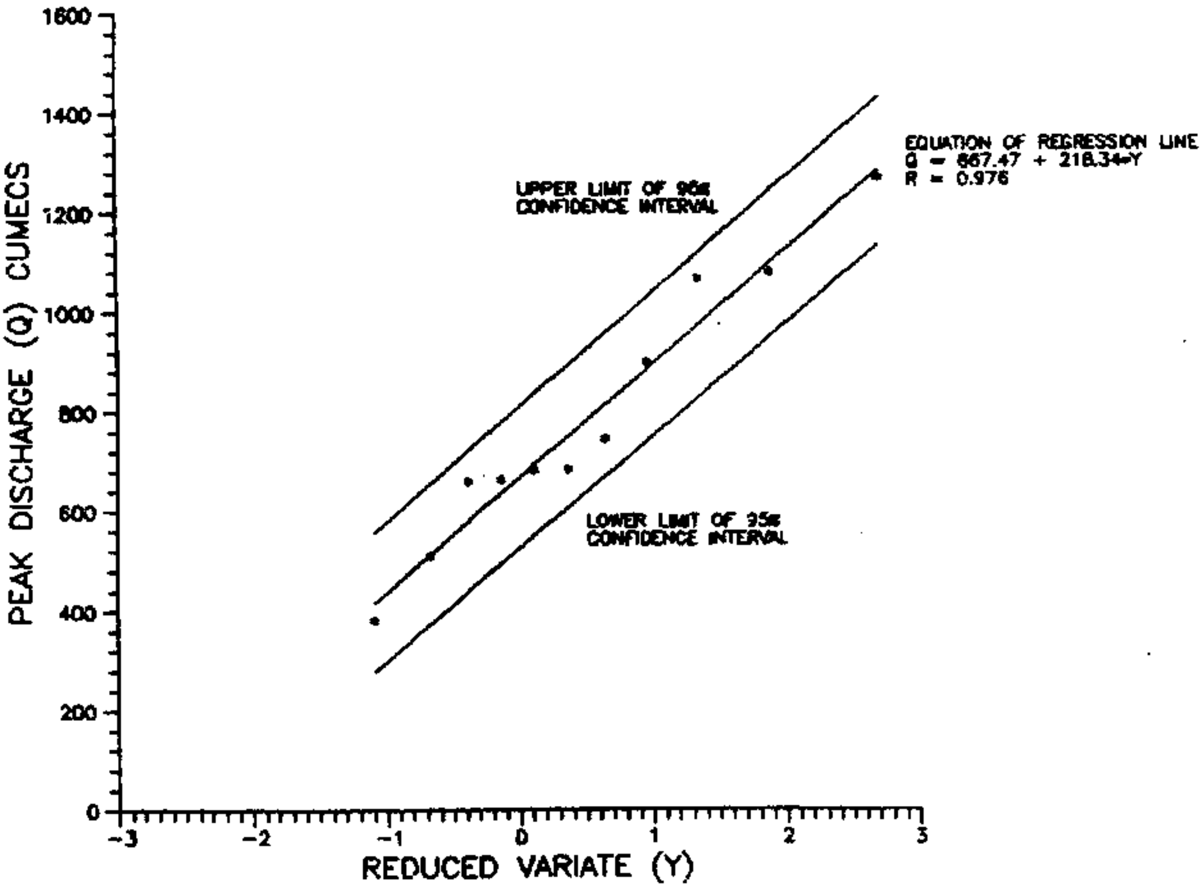

Fig.10. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION GOTUR.

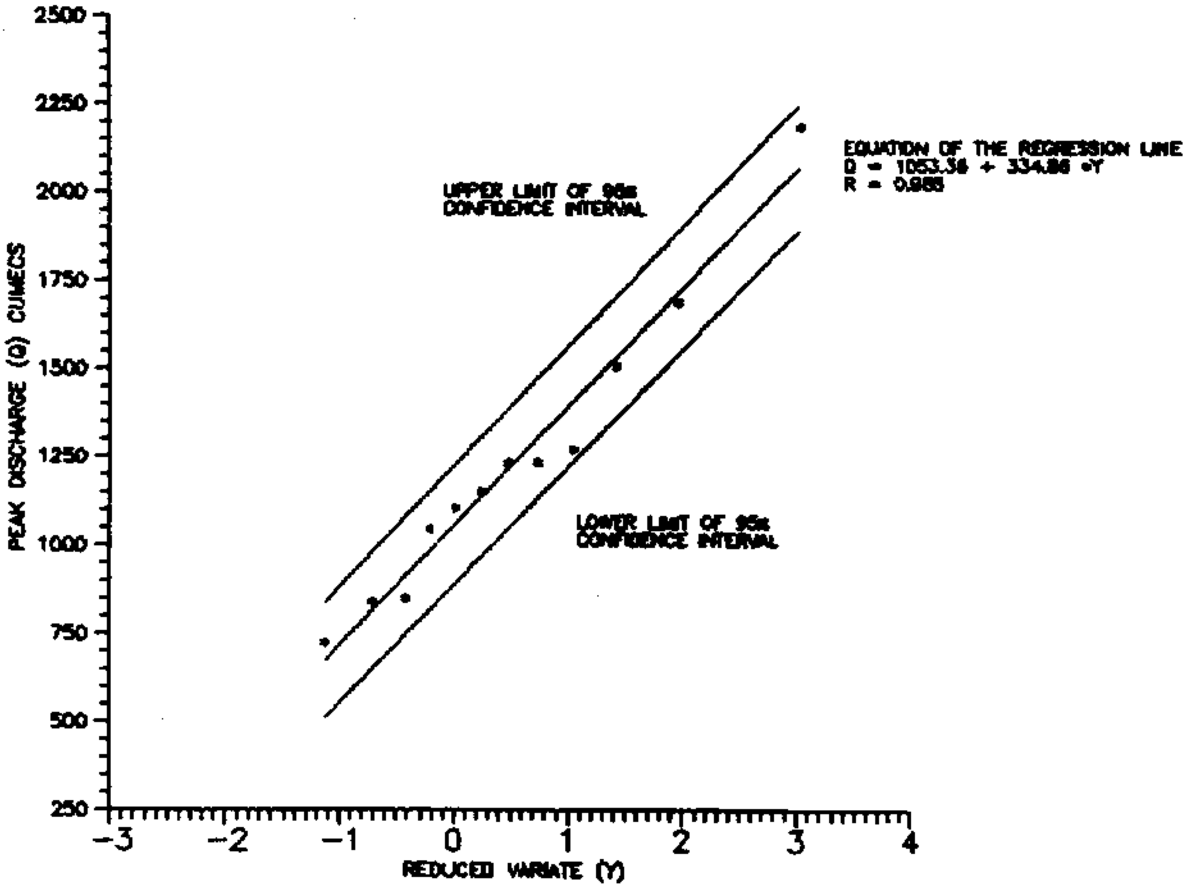

Fig.11. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION DADOI.

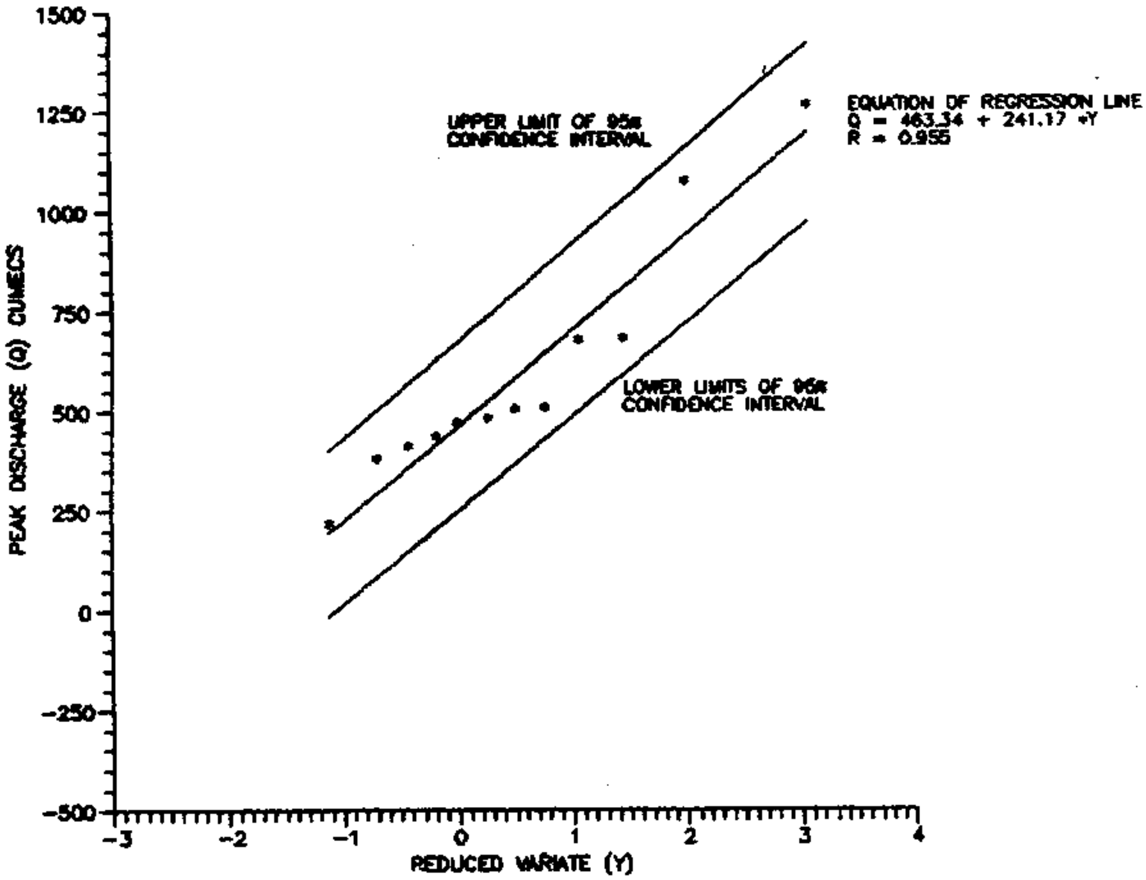

Fig.12. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES FOR THE GAUGING STATION BESTWAD.

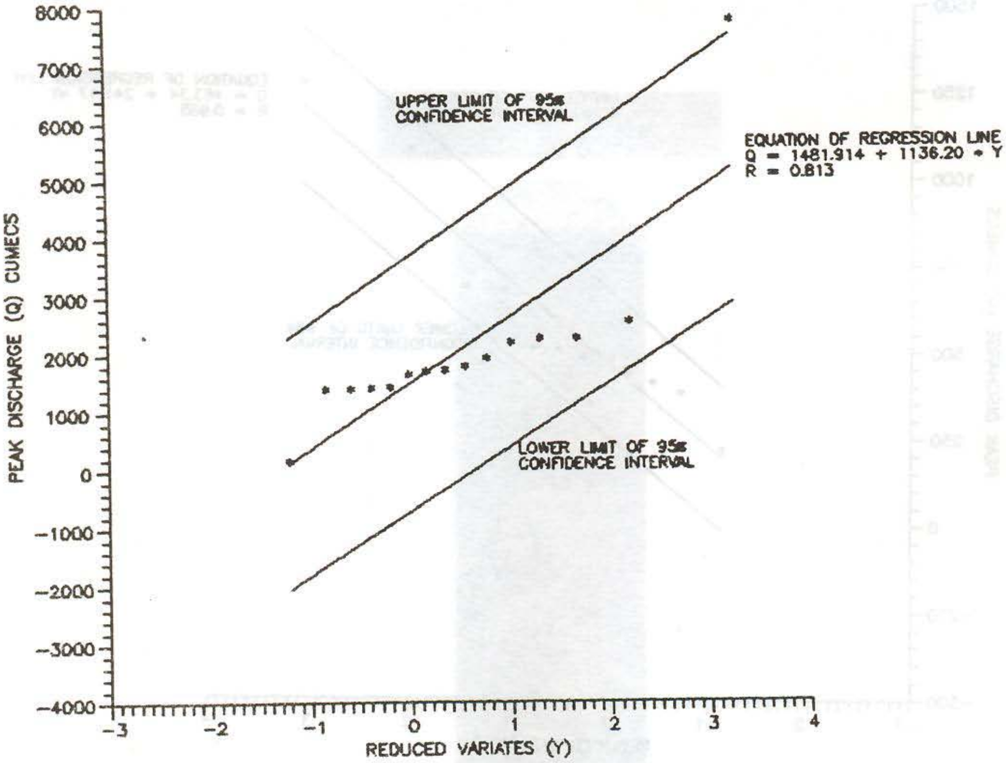

Fig.13. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION TAREWAD.

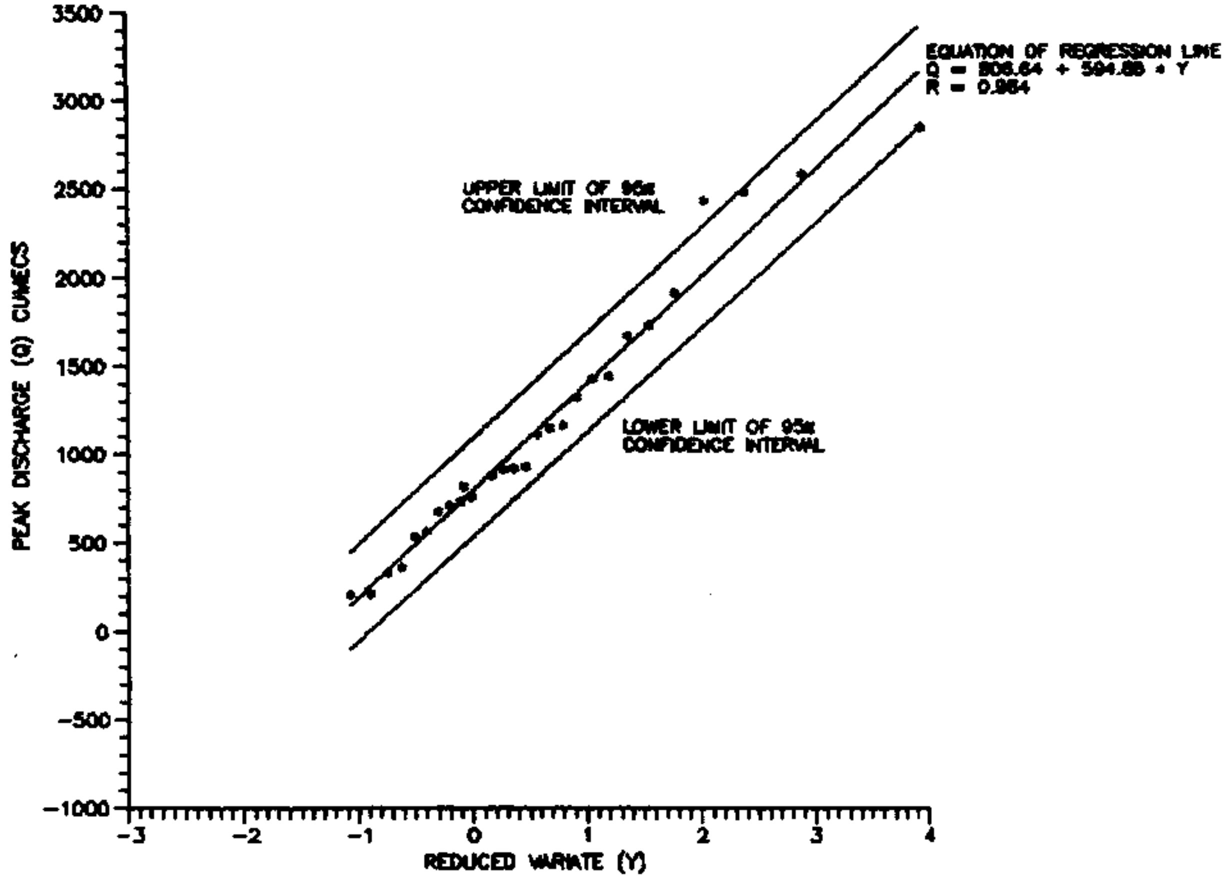

Fig.14. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION WADAKBAL.

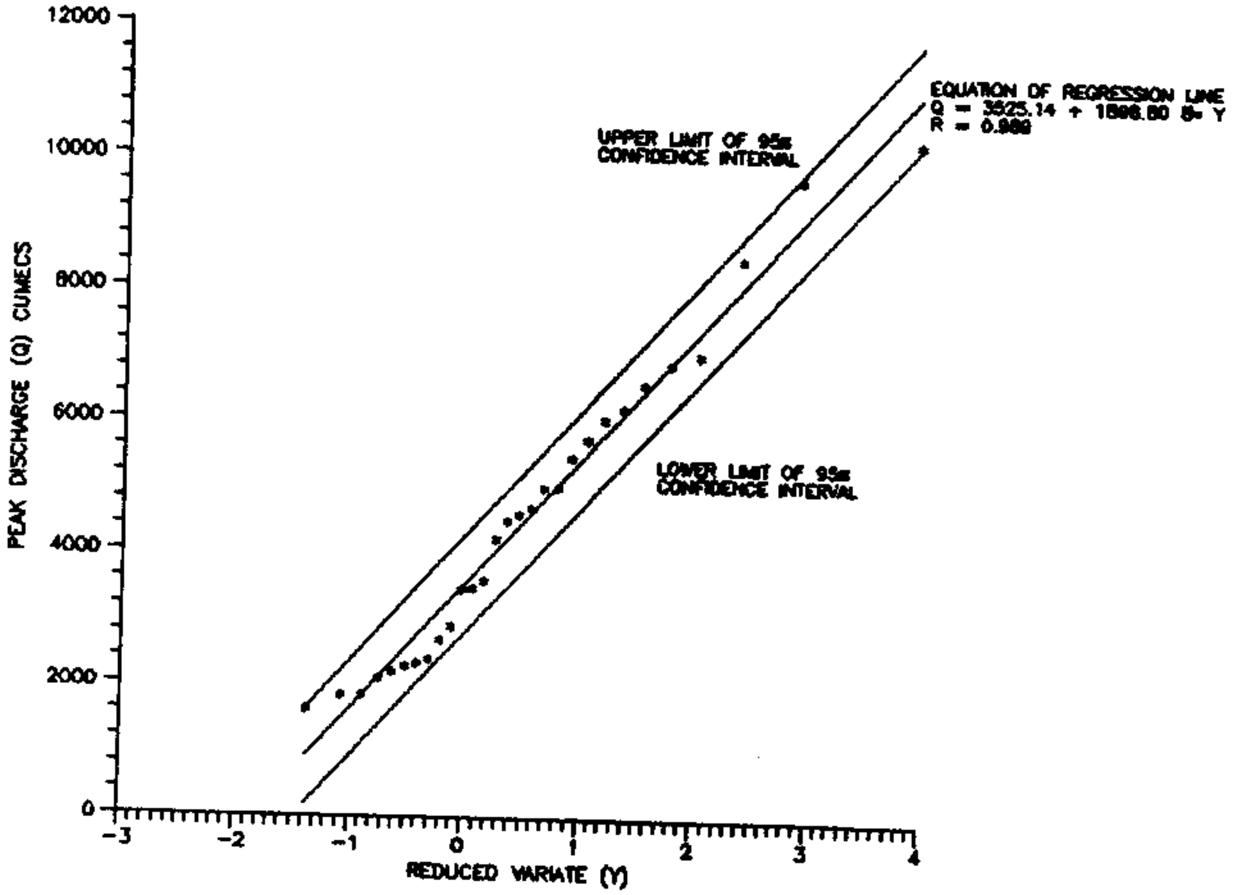

Fig.15. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION YADGEER.

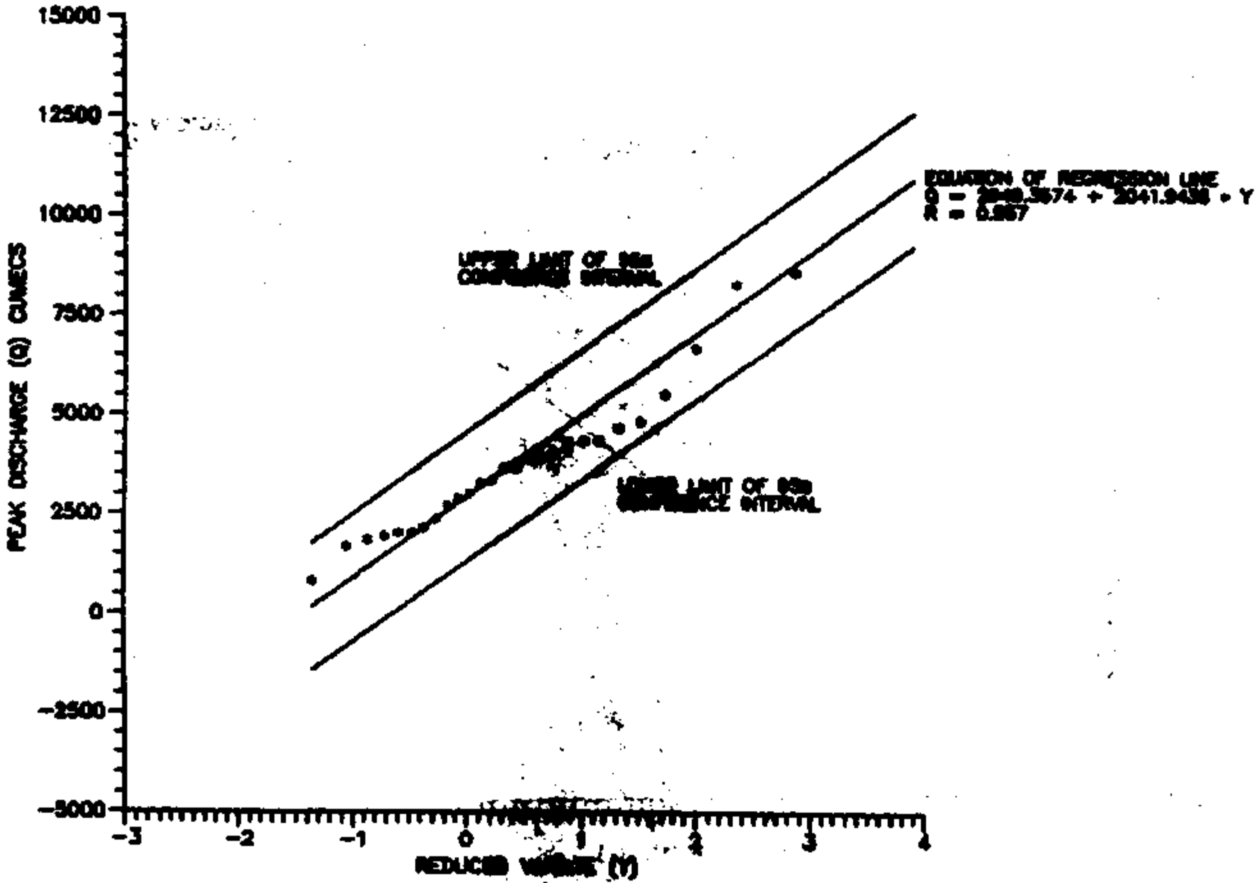

Fig.16. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EV1 REDUCED VARIATES AT GAUGING STATION [illegible]

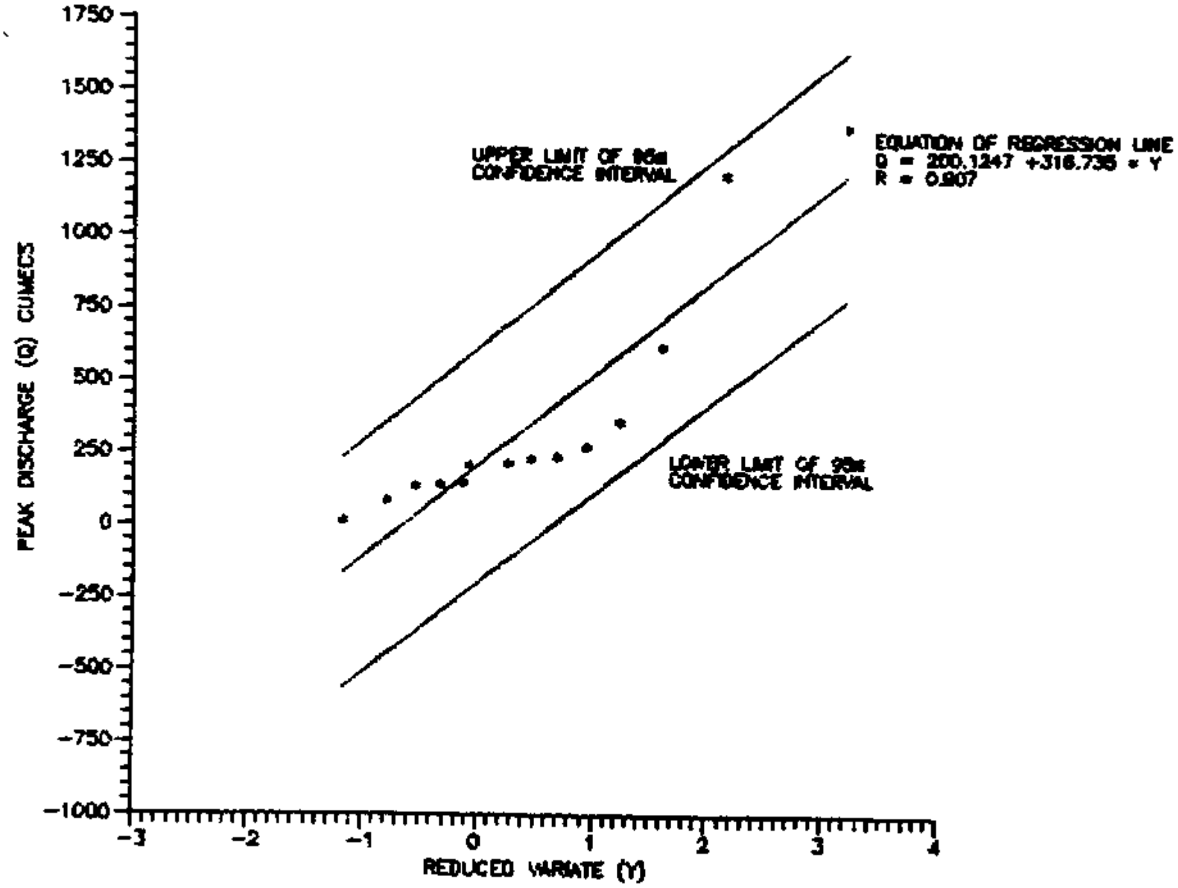

Fig.17. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARITES OF GAUGING STATION KONKANGAON

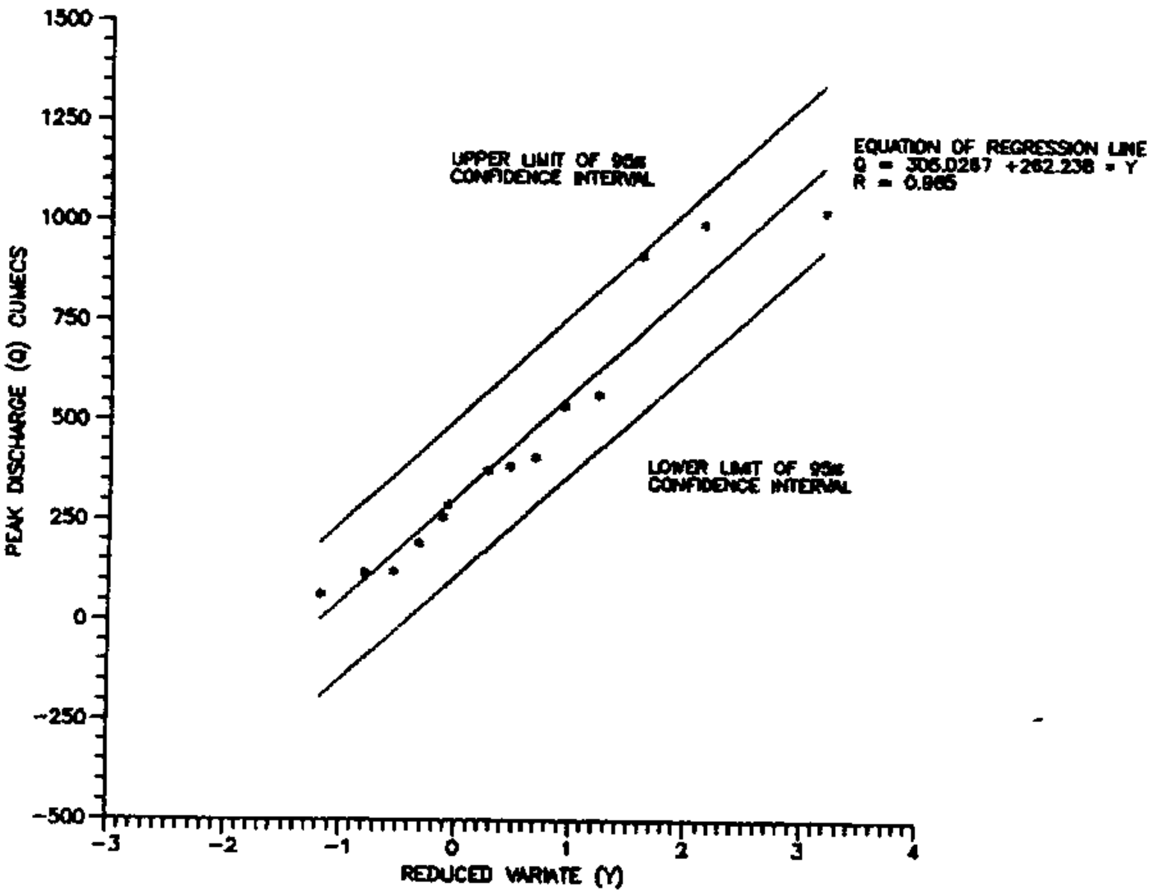

Fig.18. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARITES OF GAUGING STATION BORI OMERGAON

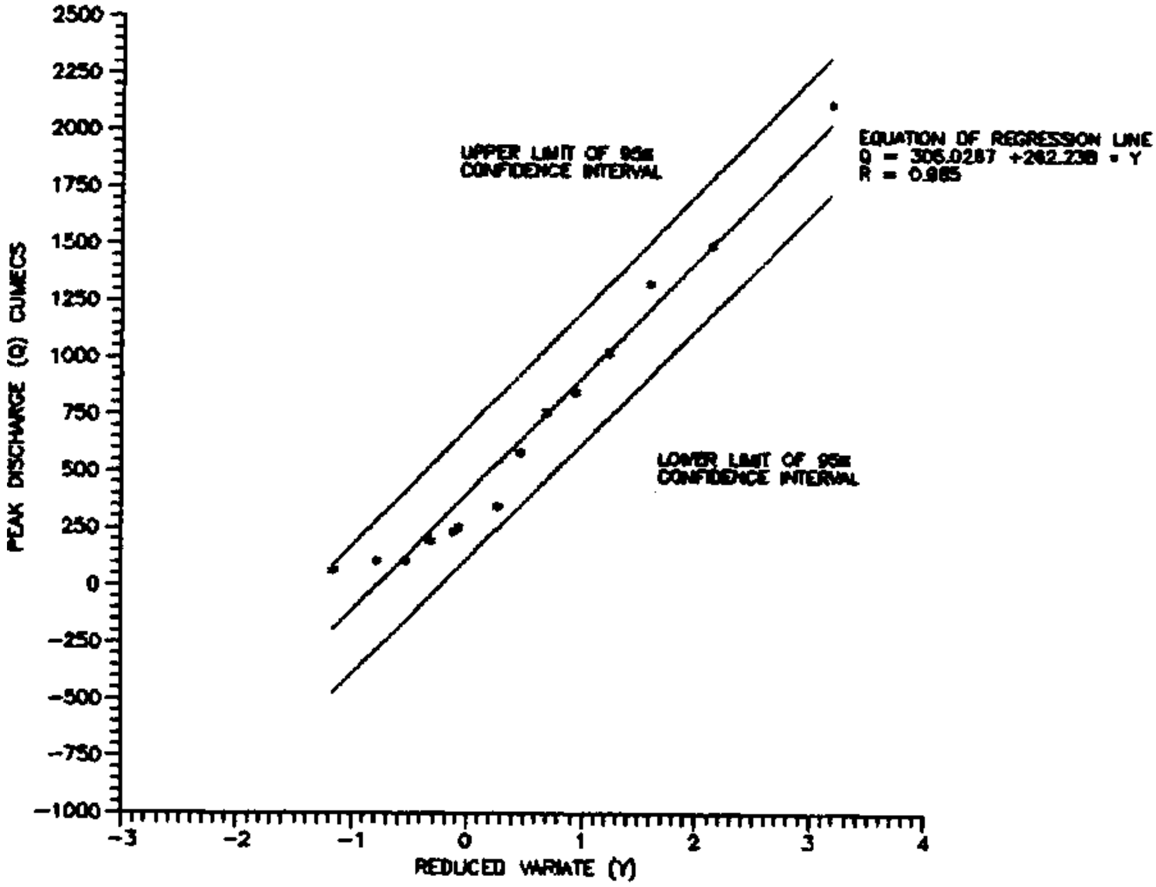

Fig.19. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARITES OF GAUGING STATION JEWANI

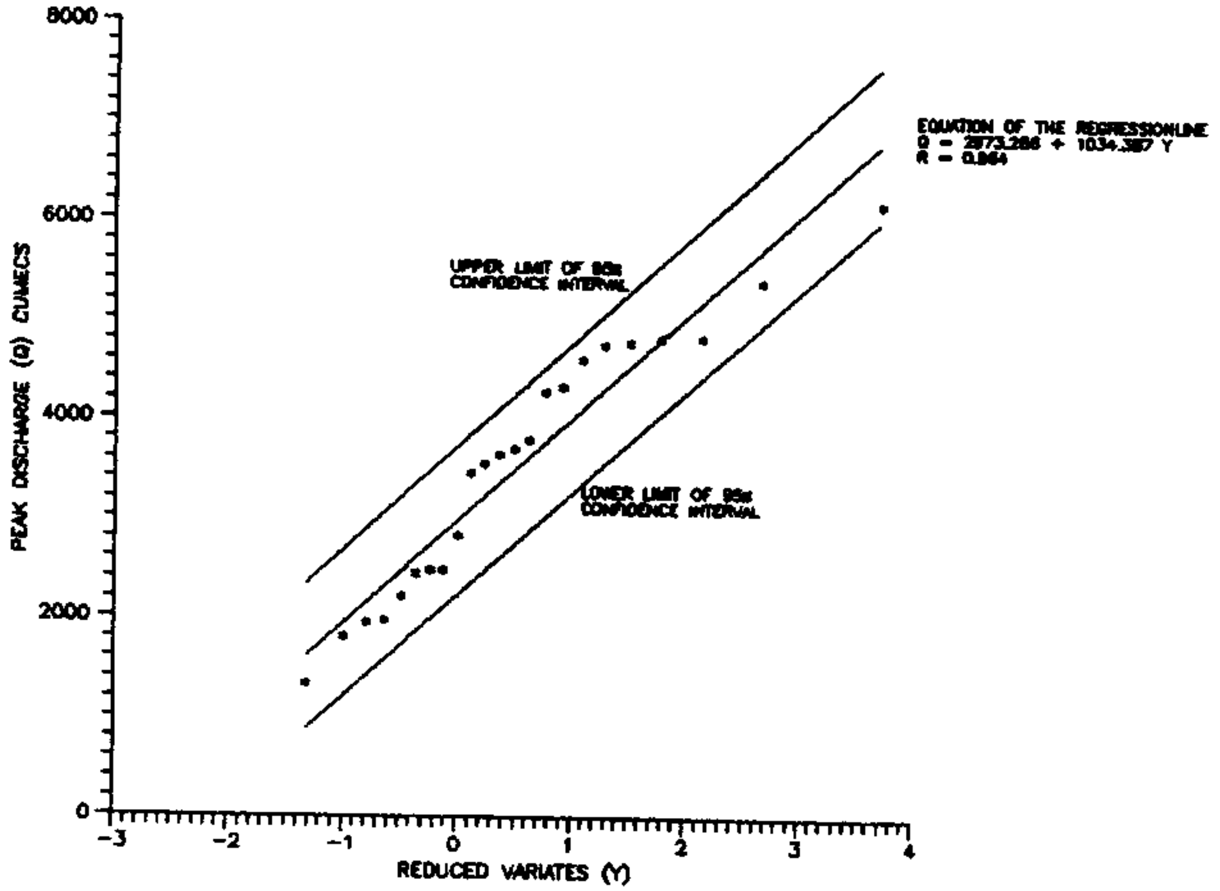

Fig.20. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EM REDUCED VARIATES AT GAUGING STATION DHOND

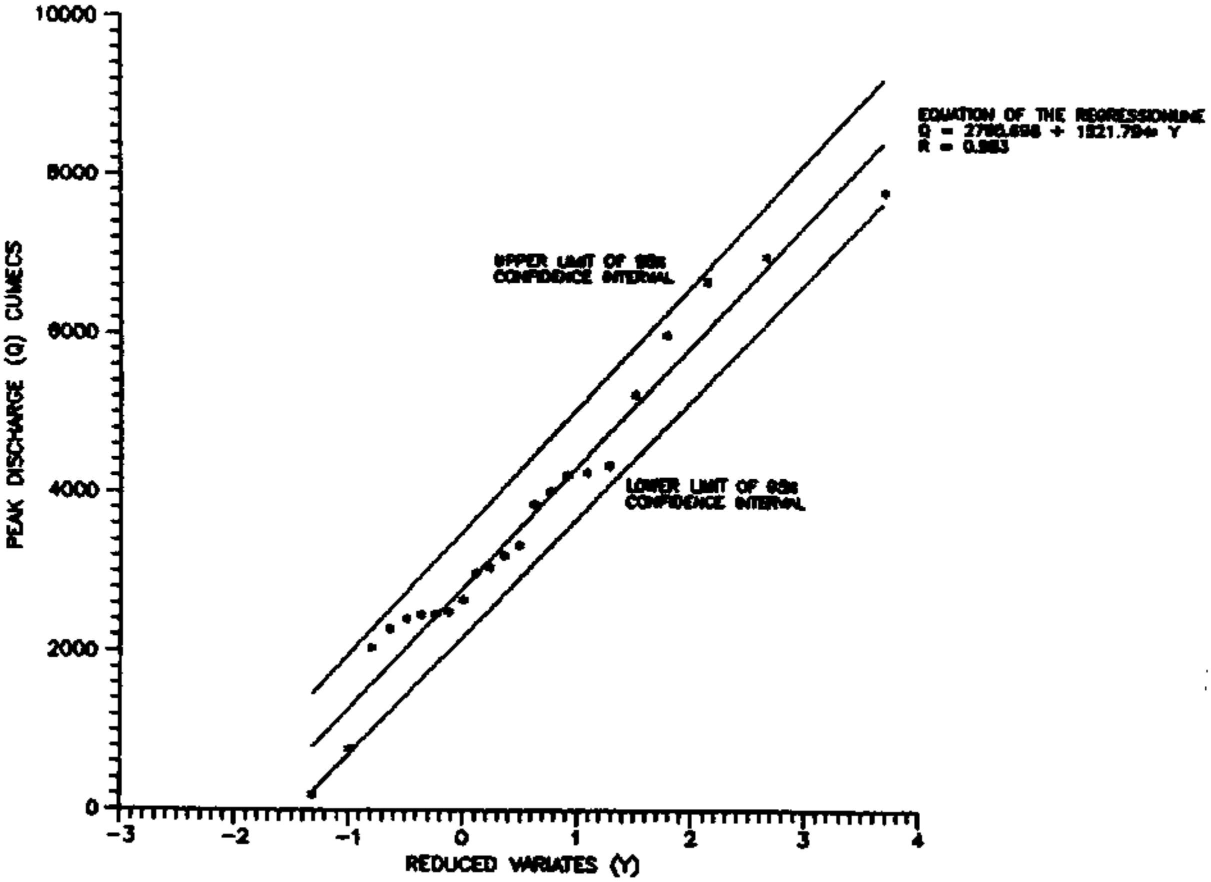

Fig.21. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EM REDUCED VARIATES AT GAUGING STATION NARASINGPUR

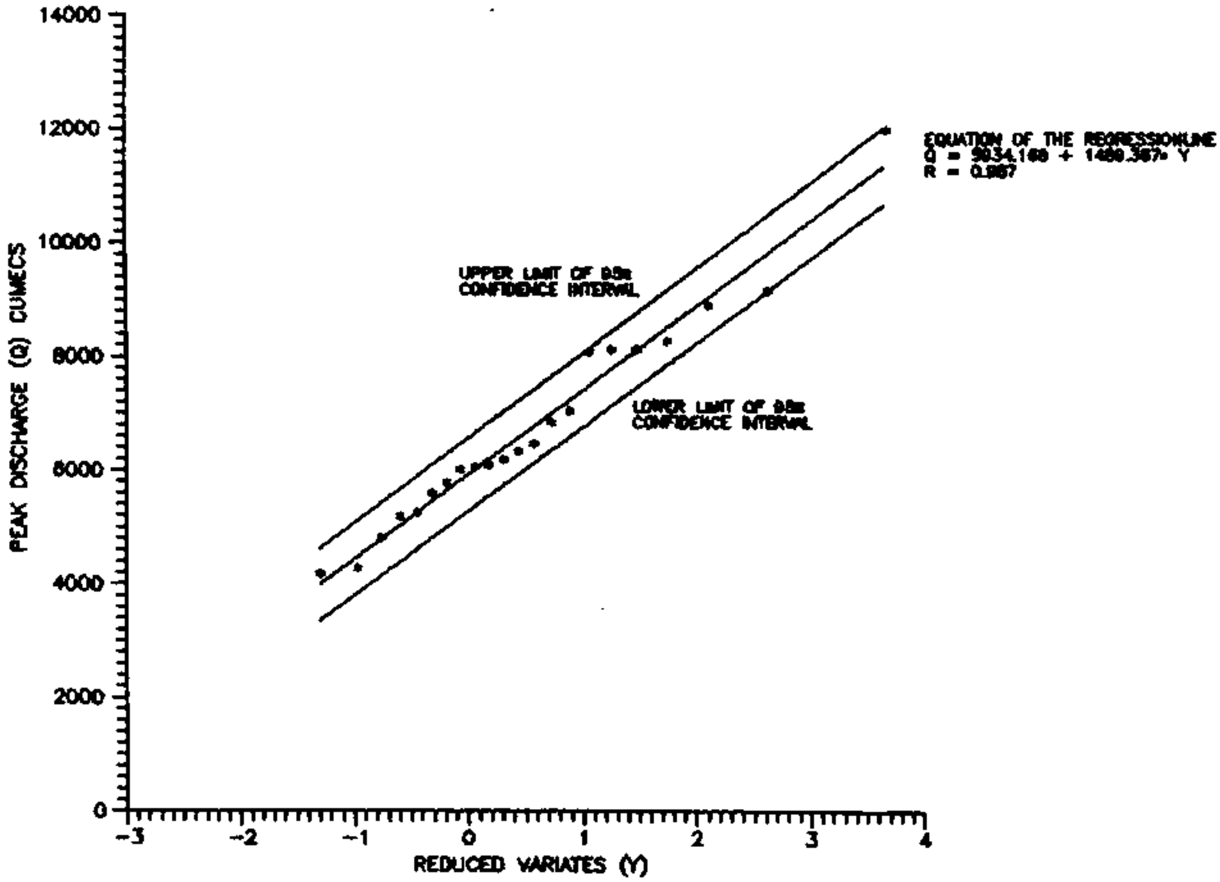

Fig.22. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION KUDACHI

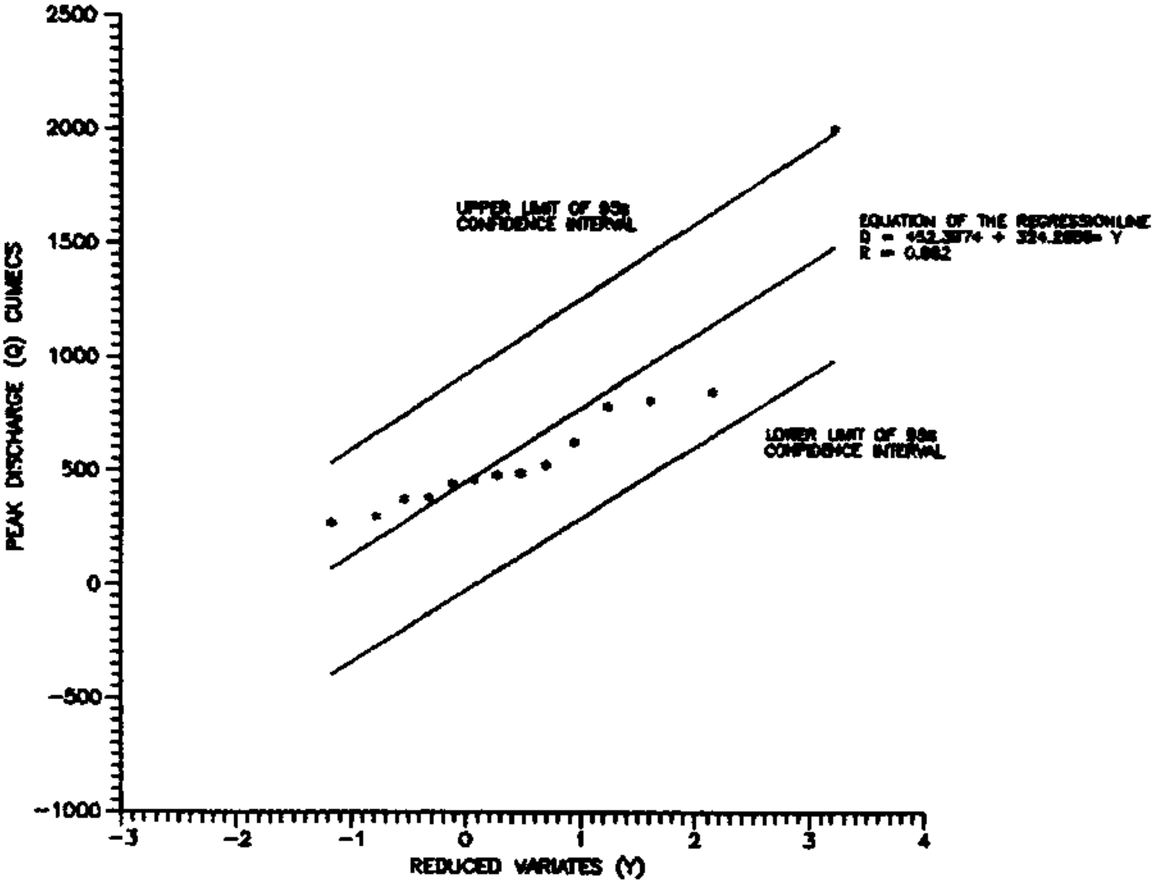

Fig.23. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION KONGANAHALLI

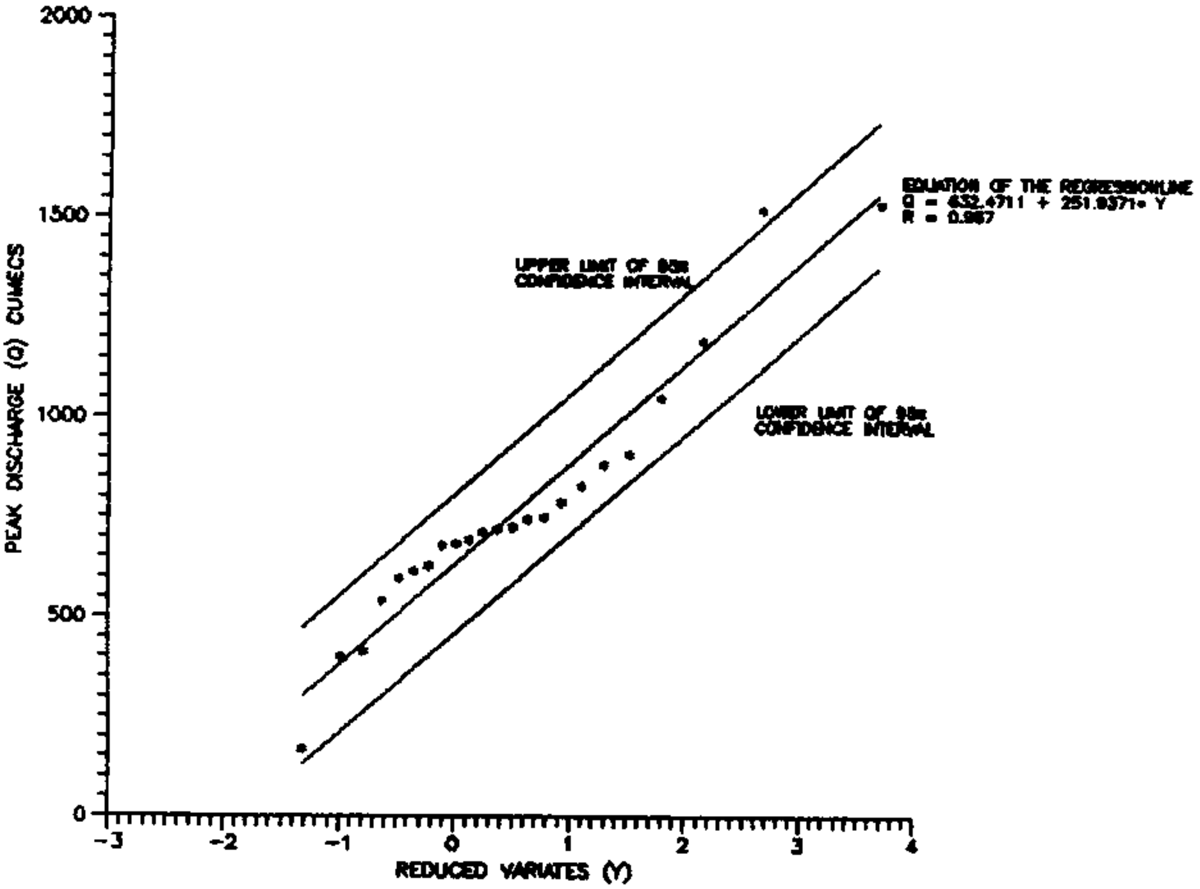

Fig.24. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARIATES AT GAUGING STATION YAMAGAREI

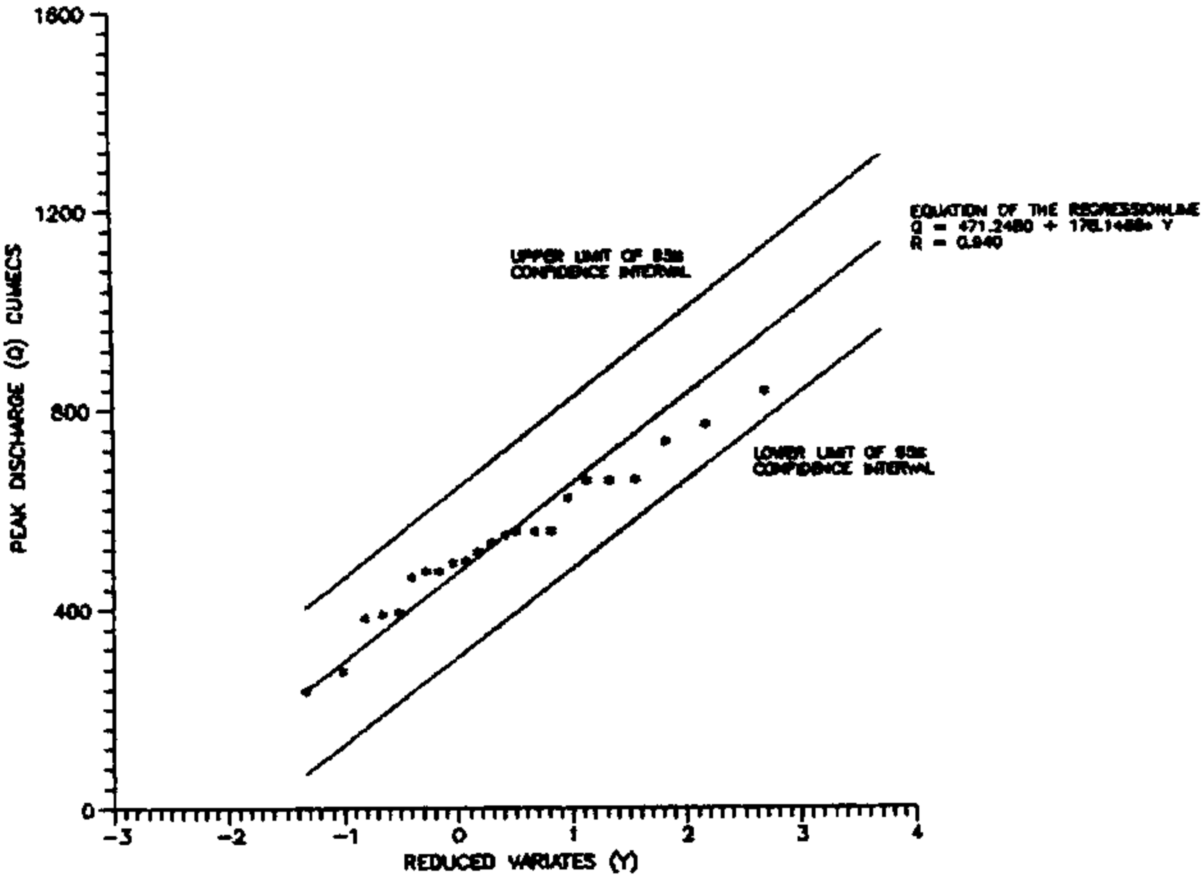

Fig.25. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EV1 REDUCED VARIATES AT GAUGING STATION CHICKALGOUDO

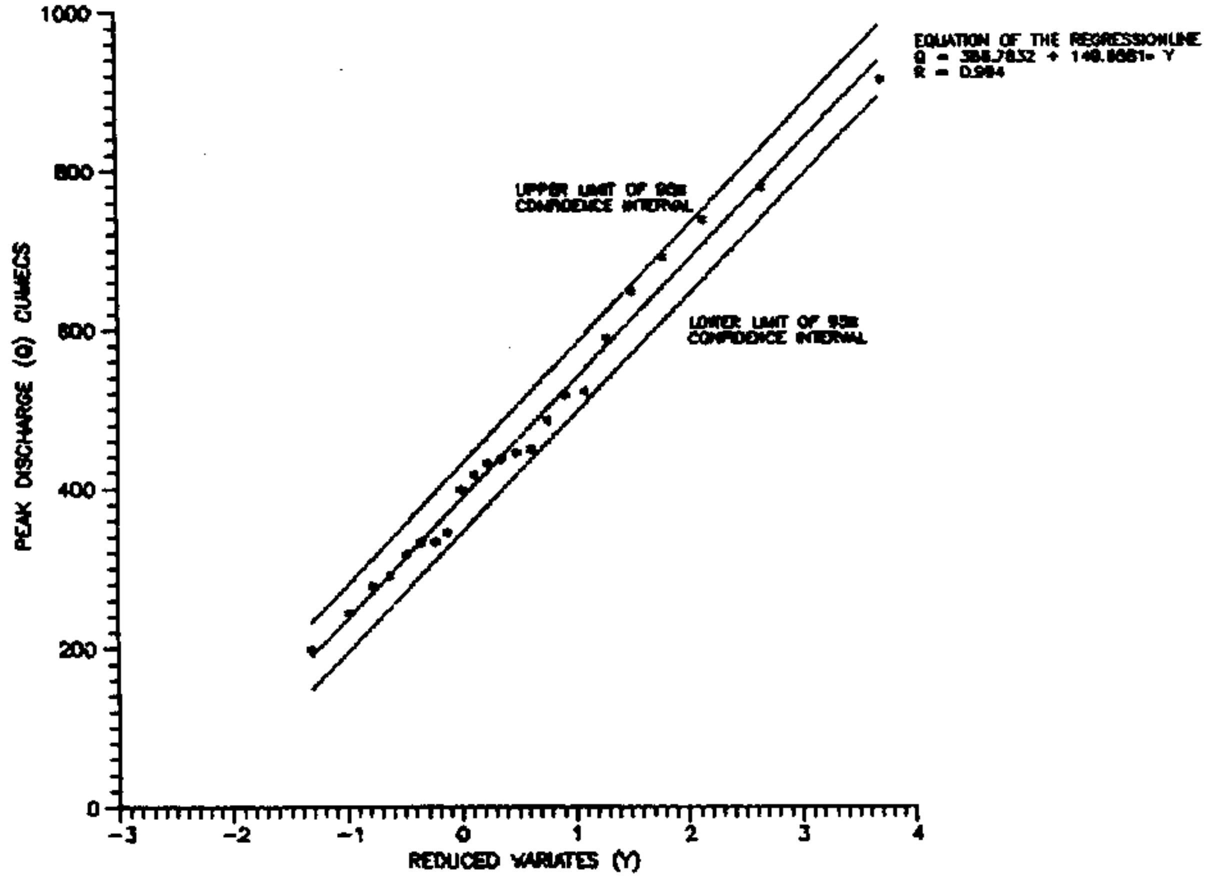

Fig.26. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EV1 REDUCED VARIATES AT GAUGING STATION KHANPUR

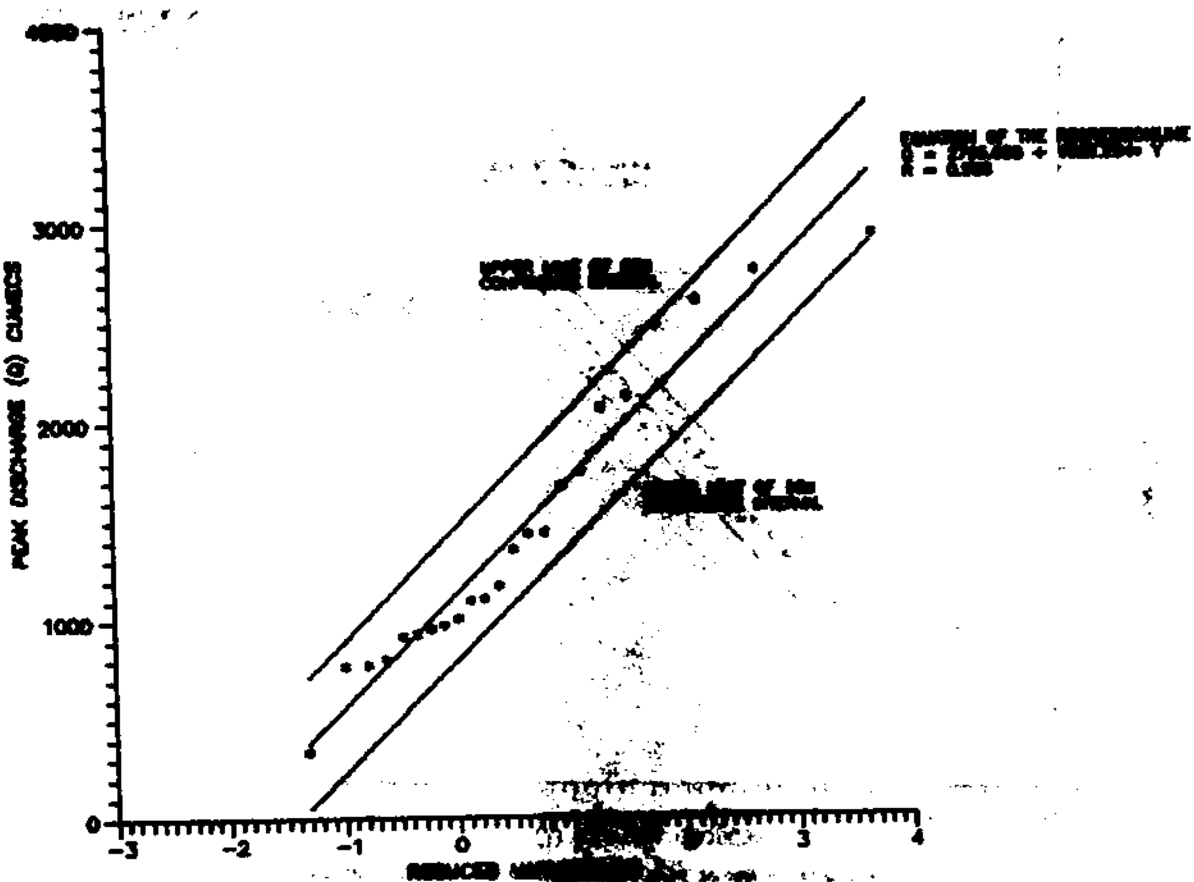

Fig.37. RELATION BETWEEN ANNUAL PEAK [illegible] VARIATES
[illegible]

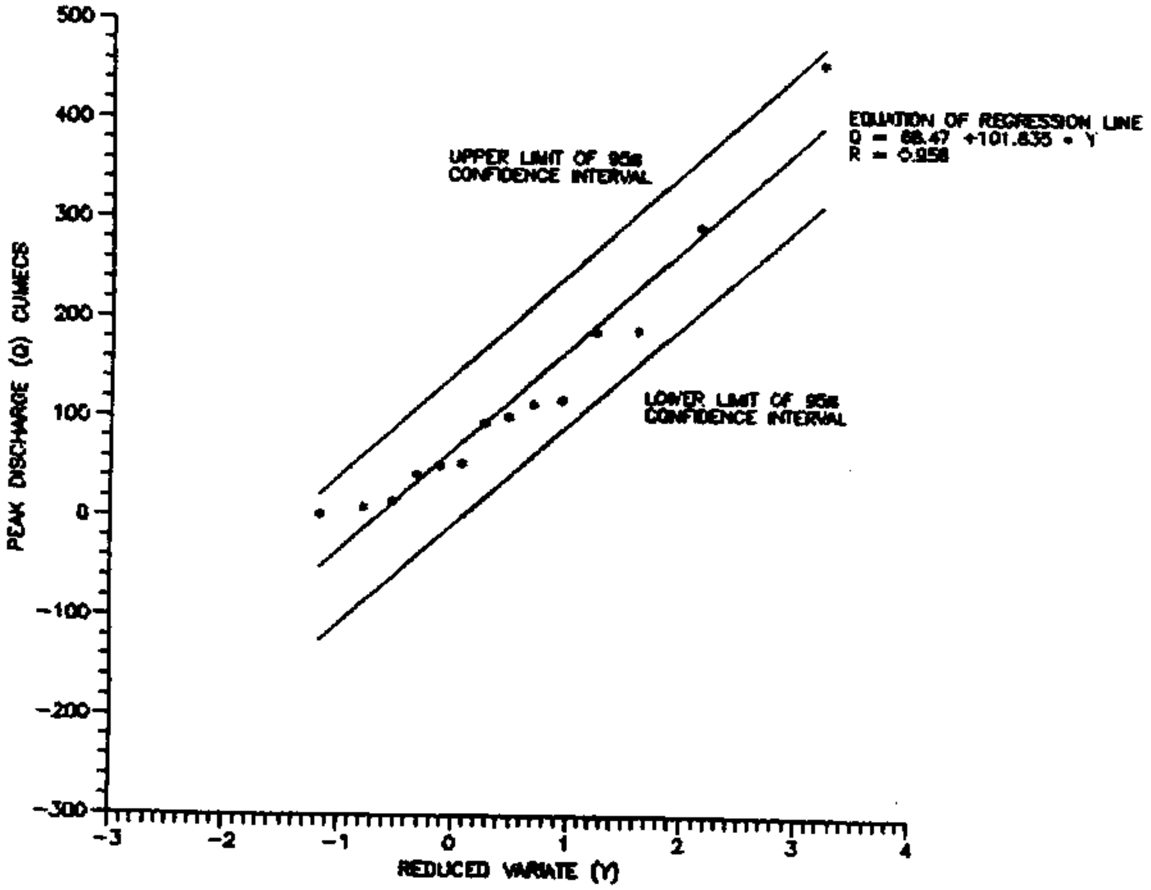

Fig.28. RELATION BETWEEN ANNUAL PEAK DISCHARGE AND EVI REDUCED VARITES OF GAUGING STATION SHIRDON

7.2. Development of Regional Frequency Curves

The annual maximum peak flood data were used for development of regional frequency curves of Krishna basin based on the fittings of different methods to the sample of Q_T/Q values.

i) Index flood method

The probability density function used in this method is

$$\frac{Q_T}{Q} = u + \alpha\left(-\ln\left(-\ln\left(1-\frac{1}{T}\right)\right)\right) \qquad \text{Eq...... (60)}$$

the parameter u and α were estimated using the index-flood procedure.

ii) Extreme Value - I distribution

The probability density function of the EVI distribution is

$$\frac{Q_T}{Q} = u + \alpha\left(-\ln\left(\ln\left(1-\frac{1}{T}\right)\right)\right) \qquad \text{Eq...... (61)}$$

The parameters of the density function were estimated using the method of probability weighted moments.

iii)General Extreme Value Distribution

The parameters in the probability density function of general extreme value distribution were estimated using the method of probability weighted moments(Rakesh Kumar and Singh 1994).

iv) Wakeby Distribution

The method of probability weighted moments has been used to estimate the regional parameters of the wakeby distribution. The probability density function of wakeby distribution is given below

$$\frac{Q_T}{Q} = m + a\left(1-(1-F)^{b}\right) - c\left(1-(1-F)^{-d}\right) \qquad \text{Eq.....(62)}$$

where Q_T is the flood estimated for T year return period, m, a, b, c and d are the wakeby parameters.

7.2.1. Medium catchments

In this case, 15 catchments having catchment area less than 5000 sq.km are considered for developing a relation of Q_T/Q interms of the regional parameters of the respective methods. The growth factors (median ratio) were estimated for different methods are given below ;

Index-Flood method

$$\frac{Q_T}{Q}=0.7685+0.40Y_T \qquad \text{Eq.......(63)}$$

Return period	2	5	10	20	50	100	200	500	1000
Q_T/Q	0.9166	1.3676	1.67	1.958	2.3304	2.616	2.888	3.2552	3.532

PWM Based EVI distribution

Using the probability weighted moments approach, the parameters of EVI distribution were estimated. The regional relationship for the evaluation of growth factor using this method is developed and given as

$$\frac{Q_T}{Q}=0.749+0.435Y_T \qquad \text{Eq......(64)}$$

The growth factors evaluated for different return period using Eq (64) is tabulated below

Return period	2	5	10	20	50	100	200	500	1000
Q_T/Q	0.908	1.401	1.727	2.041	2.446	2.750	3.072	3.4519	3.753

PWM based GEV Distribution

The regional parameters for the GEV distribution were estimated using PWM method and the

equation for the growth factors is given as

$$\frac{Q_T}{Q} = 2.38\left(-\ln\left(1-\frac{1}{T}\right)\right)^{-0.155} - 1.659 \qquad \text{Eq.......(65)}$$

The growth factors evaluated for different return periods using Eq (65) are given below

Return period	2	5	10	20	50	100	200	500	1000
Q_T/Q	0.869	1.343	1.714	2.112	2.6985	3.196	3.749	4.576	5.283

PWM based Wakeby distribution

The regional relationship developed for growth factors using PWM based wakeby distribution is given below,

$$\frac{Q_T}{Q} = 0.045 + 0.439\left(1-(1-F)^{16.095}\right) - 9.279\left(1-(1-F)^{-0.055}\right) \qquad \text{Eq.....(66)}$$

Eq (66) is used to estimate the growth factors corresponding to different return periods which are tabulated below

Return period	2	5	10	20	50	100	200	500	1000
Growthfactor	0.8445	1.344	1.736	2.146	2.7115	3.158	3.623	4.265	4.772

7.2.2. Large catchments

In this case annual peak flood series of 11 catchments having catchment area more than 5000 sq.km were considered for regional frequency analysis. The relationships developed using different methods along with growth factors for some specific return periods are given below;

Index-Flood method

$$\frac{Q_T}{\bar{Q}}=0.780+0.382Y$$

Eq.......(67)

Return period	2	5	10	20	50	100	200	500	1000
$Q_T/\bar{Q}$	0.925	1.323	1.586	1.838	2.164	2.408	2.652	2.973	3.2169

PWM Based EVI distribution

$$\frac{Q_T}{\bar{Q}}=0.780+0.382Y$$

Eq.......(68)

Return period	2	5	10	20	50	100	200	500	1000
$Q_T/\bar{Q}$	0.92	1.352	1.639	1.916	2.270	2.537	2.803	3.153	3.418

PWM based GEV Distribution

$$\frac{Q_T}{\bar{Q}}=9.972(-\ln(1-\frac{1}{T})^{-0.037})-9.199$$

Eq.......(69)

Return period	2	5	10	20	50	100	200	500	1000
$Q_T/\bar{Q}$	0.909	1.342	1.638	1.9318	2.321	2.623	2.9315	3.35	3.676

PWM based Wakeby distribution

$$\frac{Q_T}{\bar{Q}}=0.255+0.328(1-(-F)^{5.25}+9.538(1-(1-F)^{0.052}$$

Eq.......(70)

Return period	2	5	10	20	50	100	200	500	1000
Q/Q_{bar}	0.912	1.348	1.659	1.958	2.338	2.614	2.879	3.216	3.459

7.2.3.Considering all the catchment as a single region

Index Flood Method

In this case, all the catchment of varying catchment area were considered for the analysis. The relation of Q_T/Q is obtained for Index-Flood approach with the correlation coefficient of 1.0

$$\frac{Q_T}{Q}=0.7712+0.3954Y \qquad \text{Eq.......(71)}$$

The growth factors for various return period for the region are given below.

Return period	2	5	10	20	50	100	200	500	1000
Growth factor	0.999	1.364	1.661	1.946	2.314	2.590	2.865	3.2280	3.5023

PWM Based EVI distribution

$$\frac{Q_T}{Q}=0.764+0.408Y \qquad \text{Eq......(72)}$$

Return period	2	5	10	20	50	100	200	500	1000
Growth factor	0.9135	1.375	1.682	1.978	2.355	2.64	2.924	3.299	3.582

PWM based GEV Distribution

$$\frac{Q_T}{Q}=3.69\left(-\ln\left(1-\frac{1}{T}\right)^{-0.10}\right)-2.943 \qquad \text{Eq..... (73)}$$

Return period	2	5	10	20	50	100	200	500	1000
Growth factor	0.884	1.344	1.678	2.023	2.508	2.902	3.323	3.925	4.419

$$\frac{Q_T}{\bar{Q}}=0.178+0.348(1-(1-F)^{9.155}-236.878(1-(1-F)^{-0.002}$$

Eq.......(74)

Return period	2	5	10	20	50	100	200	500	1000
Growth factor	0.854	1.289	1.619	1.949	2.386	2.717	3.049	3.488	3.821

7.3.Development of Relationship between Mean Annual Peak Flood and Catchment Area.

The relation between mean annual peak flood (Q) and the catchment area (A) has been developed using linear regression approach; wherein the mean annual flood and the catchment area were plotted(Fig.29,30,31) taking the log of catchment area on X-axis and log of mean annual peak flood on Y-axis.

7.3.1. Medium catchments

The relation between at site mean annual peak flood (Q) and the catchment area (A) for the medium catchment area is given below. The correlation coefficient for the equation is 0.60

$\log\bar{Q}=3.898+0.386\log A$ or the equation in its natural form is

Eq......(75)

$$\bar{Q}=49.33A^{0.386}$$

The regression coefficients, absolute T values and standard error for the equation is given below

Regression coefficients	Value of coefficient	T values	Std. error
ln a	3.898	1.696	2.289
b	0.386	1.193	0.324

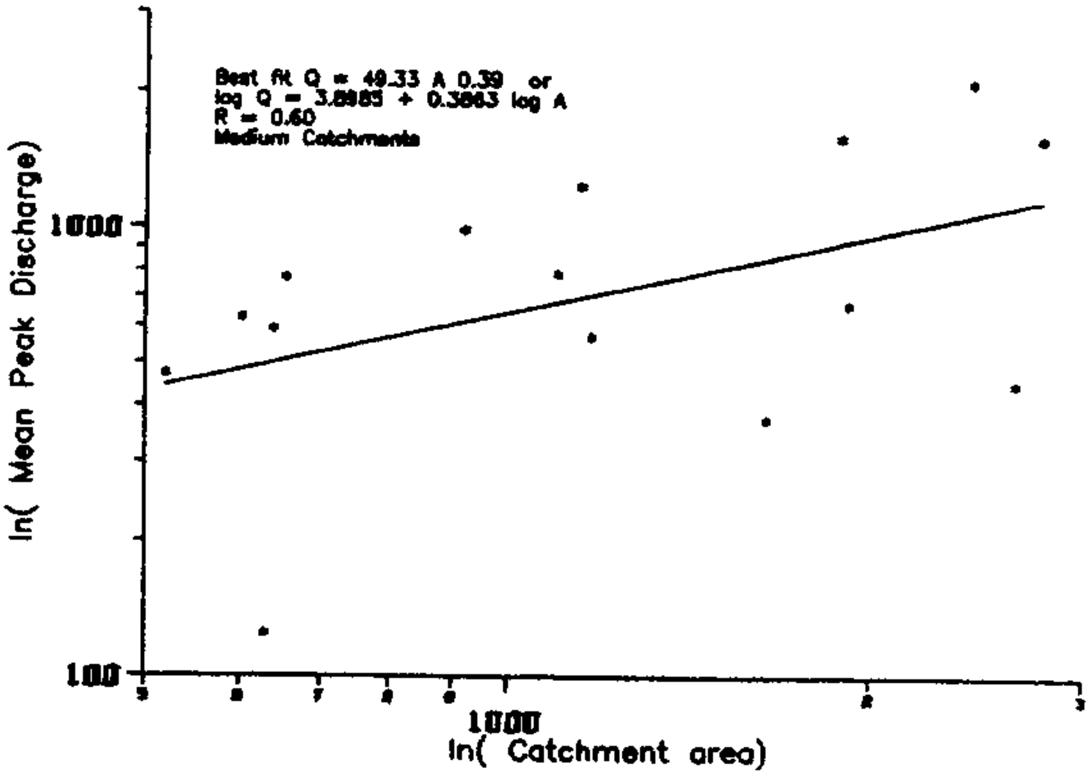

Fig.29. Relation Between Mean peak discharge and Catchment

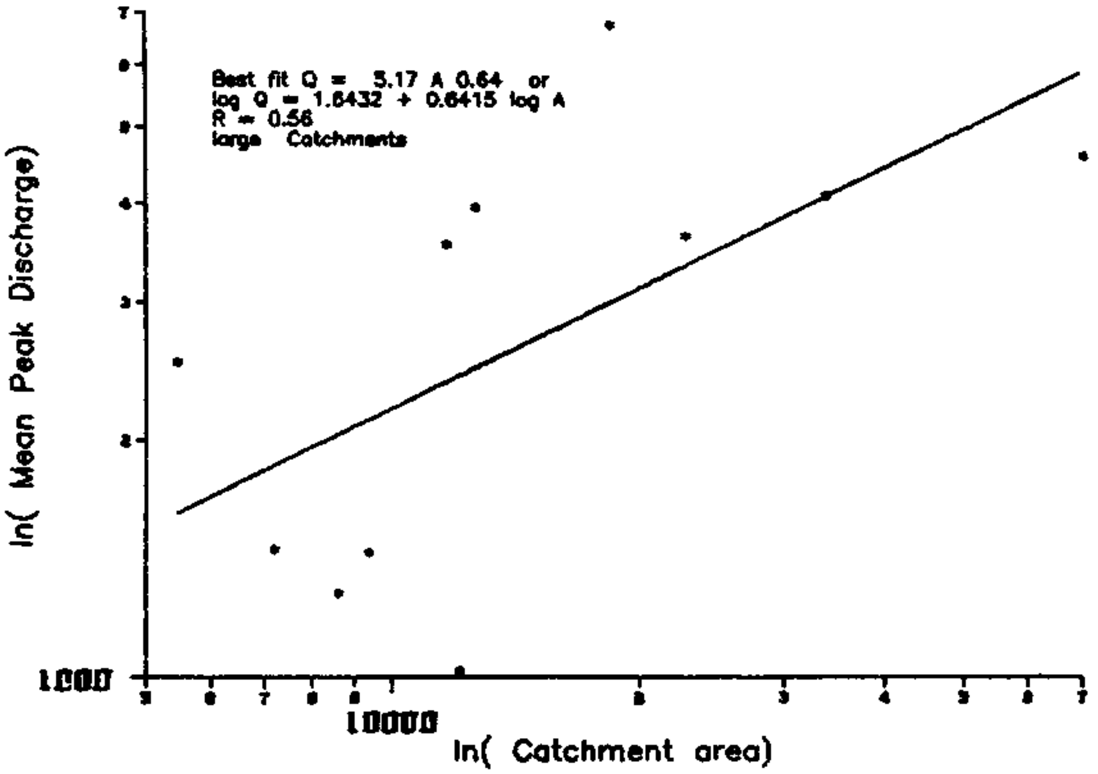

Fig.30. Relation Between Mean peak discharge and Catchment

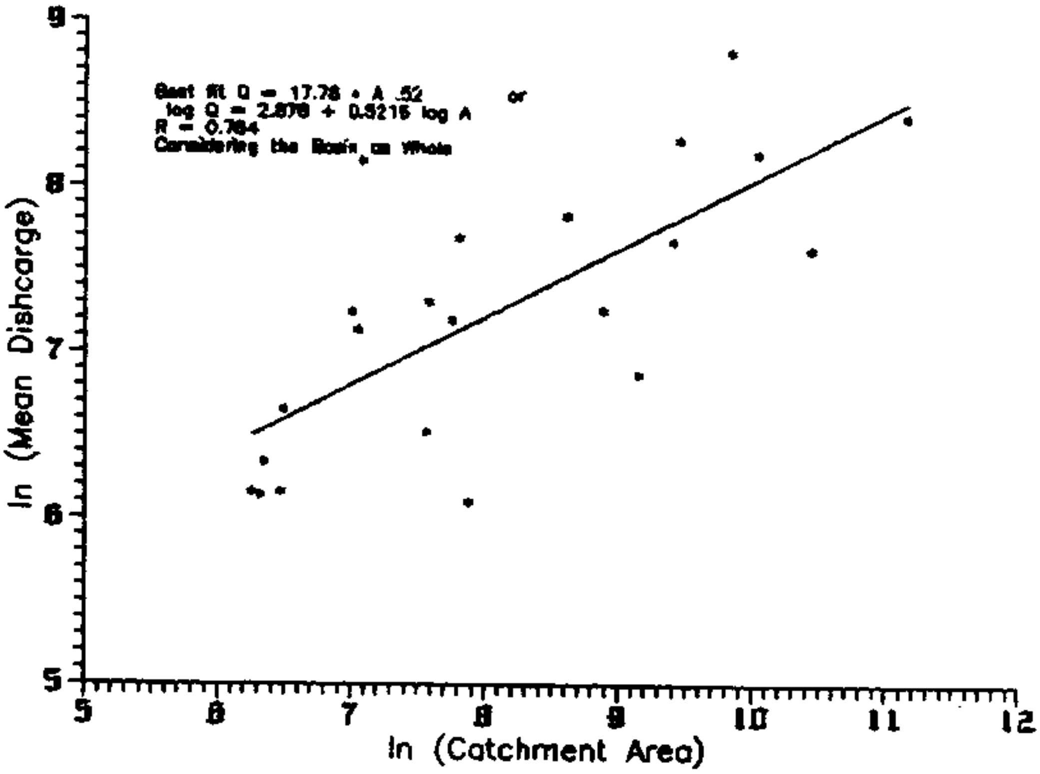

Fig.31. Relation Between Mean Discharge and Catchment

7.3.2. Large catchments

The relationship between the mean annual peak flow (Q) and the catchment area considering the large catchments is developed as

$$\log\bar{Q} = 1.6432 + 0.6415 \log A \qquad \text{Eq.......(76)}$$

the above equation in its natural form can be written as

$$\bar{Q} = 5.17A^{0.64} \qquad \text{Eq......(77)}$$

The correlation coefficient of the equation is 0.56

Regression Coefficients	Value of coefficient	T vales	Std. Error
ln a	1.6432	0.623	2.613
b	0.6415	2.357	0.272

7.3.3. considering basin as whole

The equation obtained for at site mean annual peak flow and catchment area with the correlation coefficient of 0.784 is given below

$$\log\bar{Q} = 2.878 + 0.5216 \log A \qquad \text{Eq......(78)}$$

or the equation in its natural form

$$\bar{Q} = 17.78A^{0.52} \qquad \text{Eq.......(79)}$$

The regression coefficients, standard error and the absolute T values of the equation are given below.

Reg. Coefficient	Value of Coefficient	T value	Std. Error
ln a	2.8780	4.279	0.673
b	0.5216	6.339	0.082

The correlation coefficient of 0.784 implies that only 78.4% of the initial variance has been accounted by considering the catchment as independent variable.

The mean flood for all the station were computed using regional formula for the mean flood. The floods for different recurrence intervals are estimated using the regional mean. These are tabulated in tables 3,4,5, respectively for medium catchments, large catchment and considering the basin as whole. A plot of the mean value of the observed annual peak flood series versus mean flood value estimated using the relation mentioned above is shown in fig 32,33,34. The plots show the more scatteredness of the estimated mean values. It indicates that, the estimated mean flood values not only depend on the catchment area but on other physiographical parameters as well.

Table.3.Mean Flood flow estimated using regional flood formula (Eq.75) for medium catchments.

Sl.No	Gauging station	Catchment Area KM^2	Observed Mean flow cumec	Computed mean flow cumec
1	Koyna nagar	920	987.05	706.29
2	Warunji	1890	1586.11	935.25
3	Gokakfalls	2776	1590.09	1086.53
4	Gotur	1100	786.2	757.27
5	Daddi	1150	1236.24	770.51
6	Bastwad	640	595.05	613.08
7	Tarewad	2425	2108.45	1030.73
8	Shidron	630	124.46	609.33
9	Konkangaon	1640	374.28	884.91
10	Bori- Omerga	2640	449.22	1065.45
11	Jewani	1920	674.11	941.01
12	Khanapur	520	470.48	565.39
13	Chickalgudd	1175	570.91	777.00
14	Yamagardi	655	773.36	618.65
15	Konganahalli	603	630.65	599.11

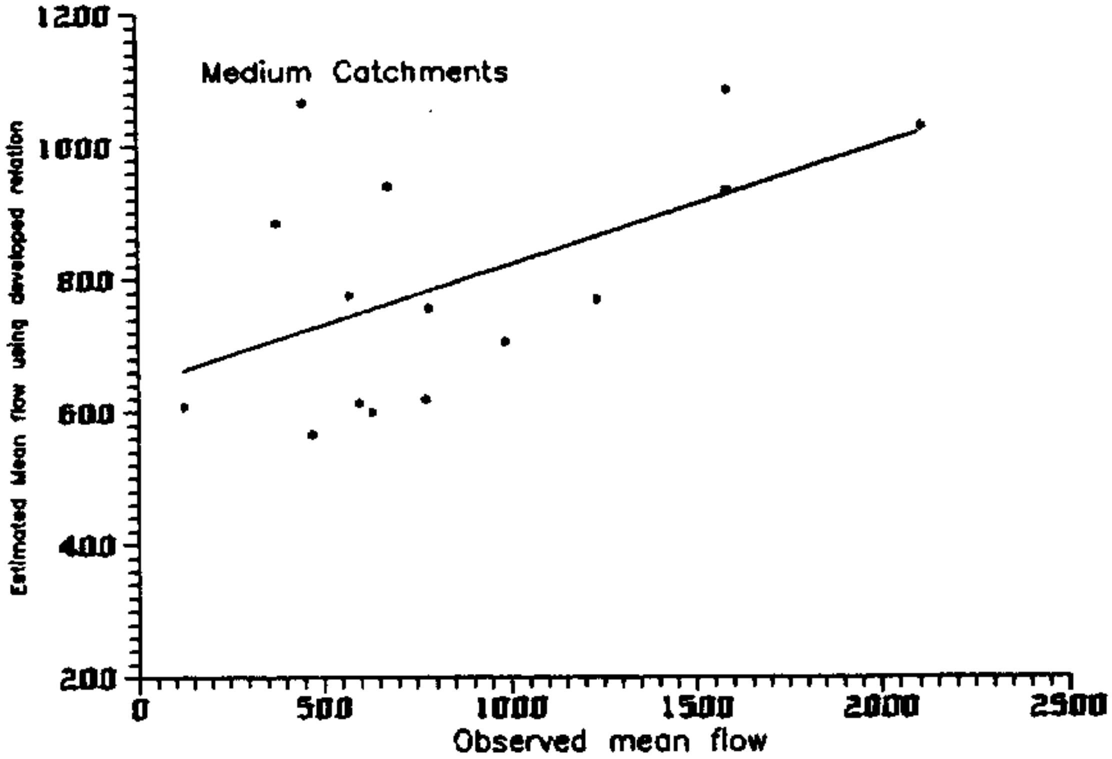

Fig.32. Comparision of observed and computed mean peak flows

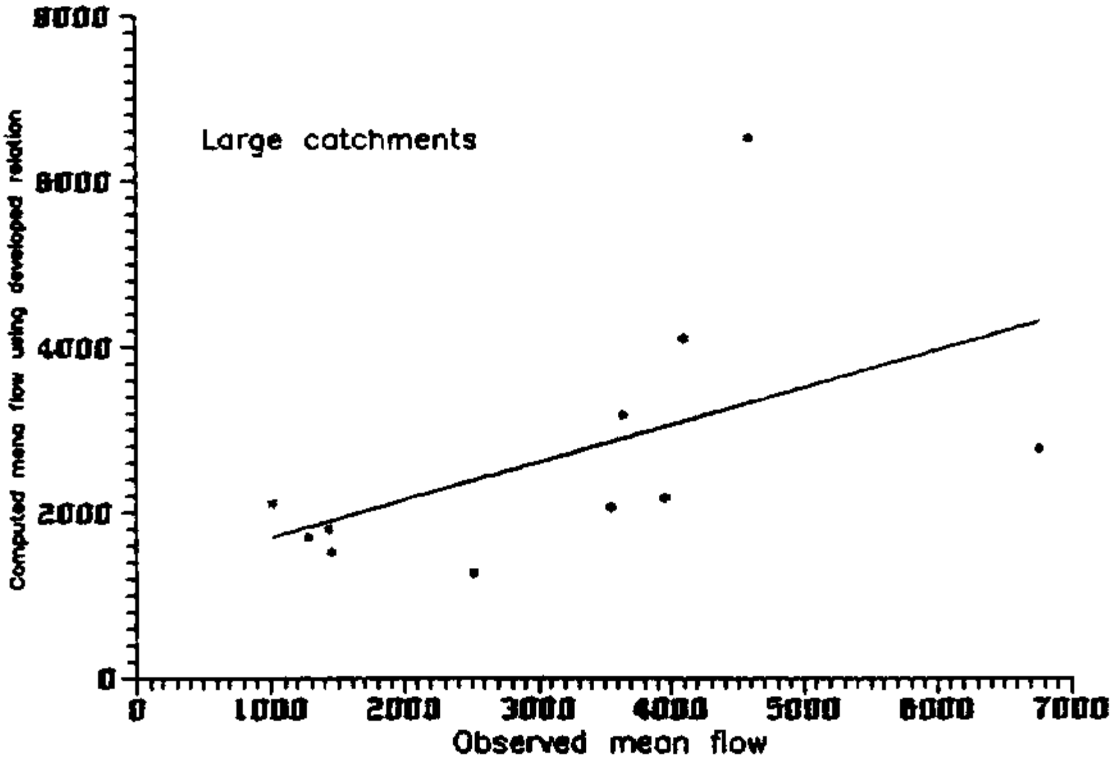

Fig.33. Comparision of observed and Computed mean peak flows

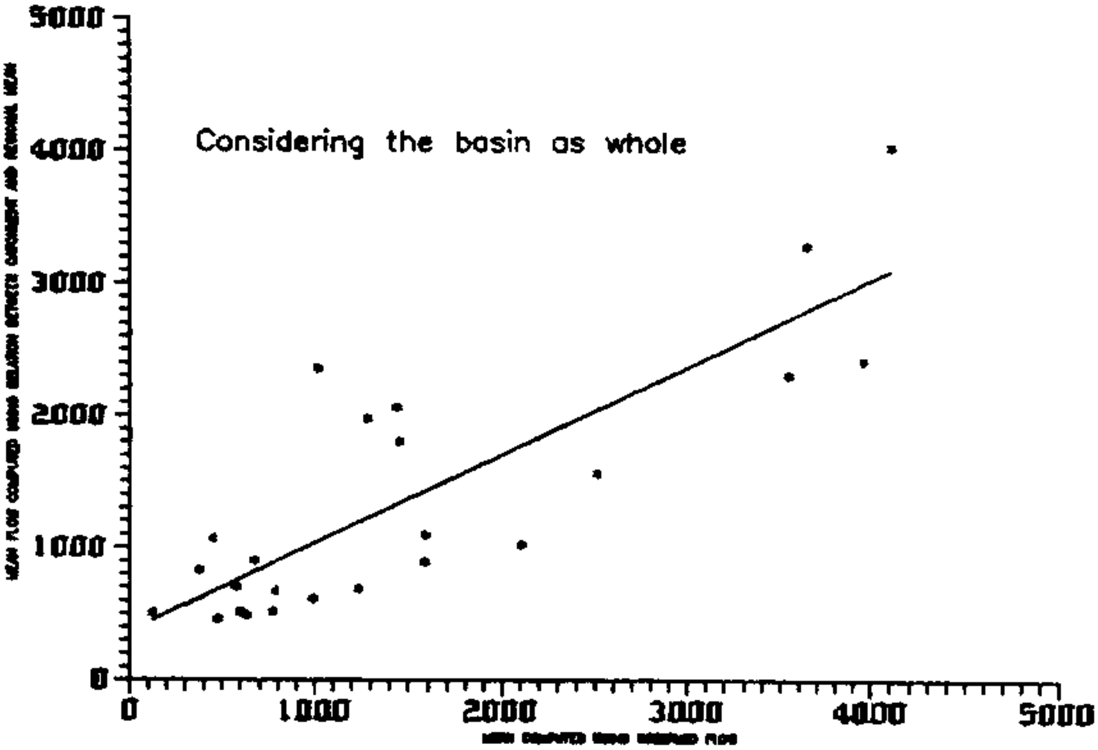

Fig.34. Comparision of observed and computed mean peak flows

Table.4. Mean Flood flow estimated using regional flood formula (Eq.77) for Large catchments.

Sl.No	Gauging station	Catchment Area KM^2	Observed Mean flow cumec	Computed mean flow cumec
1	Karad	5462	2513.88	1274.66
2	Arjunwad	12660	3956.51	2182.97
3	Bagalkot	8610	1280.60	1705.66
4	Cholchgod	9373	1436.93	1800.19
5	Yadgeer	69863	4593.24	6513.41
6	Wadakbal	12092	1016.54	2119.77
7	Takali	33916	4097.05	4101.56
8	Dhond	11660	3551.79	2070.98
9	Narasingpur	22856	3646.80	3186.03
10	Sarathi	7200	1453.57	1521.18
11	Kudachi	18417	6766.09	2774.79

Table.5. Mean Flood flow estimated using regional flood formula (Eq.79) for Considering the basin as whole.

Sl.No	Gauging station	Catchment Area KM^2	Observed Mean flow cumec	Computed mean flow cumec
1	Koyna nagar	920	987.05	1562.82
2	Warunji	1890	1586.11	2416.58
3	Gokakfalls	2776	1590.09	618.16
4	Gotur	1100	786.2	1413.44
5	Daddi	1150	1236.24	1766.50
6	Bestwad	640	595.05	3405.90
7	Tarewad	2425	2108.45	3577.84
8	Shidron	630	124.46	1032.61
9	Konkangaon	1640	374.28	1059.58
10	Bori- Omerga	2640	449.22	754.25
11	Jewani	1920	674.11	1633.29
12	Khanapur	520	470.48	11470.00
13	Chickalgudd	1175	570.91	4147.44
14	Yamagardi	655	773.36	7543.38
15	Konganahalli	603	630.63	747.39
16	Karad	5462	2513.88	1301.79

17	Arjunwad	12660	3956.51	1715.78
18	Bagalkot	8610	1280.6	1426.41
19	Cholchgod	9373	1436.97	4060.84
20	Yadgeer	69863	4593.24	6000.00
21	Wadakbal	12092	1016.54	3070.32
22	Takali	33916	4097.05	668.67
23	Dhond	11660	3551.79	1072.88
24	Narsingpur	22856	3646.8	764.45
25	Sarati	7200	1453.57	728.64
26	Kudachi	18417	6766.09	5293.69

7.4.0. Development of Regional Flood Formula

The forms of the regional flood formula developed for Krishna basin are given below.

7.4.1. Medium catchments

i)Based on Index-Flood Method

The formula for estimating the flood at different recurring interval using the catchment area is

$$Q_T = (37.93 + 19.73 (-\ln(-\ln(1-1/T)))) A^{0.39} \qquad \text{Eq......(80)}$$

ii) Based on PWM EVI distribution

The formula for estimating the flood at different return period using the catchment area and the estimated EVI parameter is

$$Q_T = (36.94 + 21.45 (-\ln(-\ln(1-1/T)))) A^{0.39} \qquad \text{Eq......(81)}$$

iii) Based on PWM GEV distribution

The coefficient of the GEV estimated using PWM are

k	u	α
-0.155	0.721	0.369

Using these estimated parameters together with the coefficients of a and b of the regional relationship between mean annual peak flow and catchment area then the relation for Q_T is obtained as

$$Q_T = (117.43(-\ln(1-1/T))^{-0.155} - 81.87)A^{0.39} \qquad \text{Eq......(82)}$$

iv) Based on PWM Wakeby Distribution

The estimated regional parameters of wakeby distribution are

a	b	c	d	m
0.439	16.095	9.279	0.055	0.045

The relationship established between Q_T and catchment area for medium catchment is given below

$$Q_T = \{ 2.219 + 21.65 (1-(1-F)^{16.095} - 457.7 (1-(1-F)^{-0.055})\} A^{0.39} \qquad \text{Eq......(83)}$$

7.4.2. Large catchments

i) Based on Index-Flood method

The relation between flood Q_T versus catchment area is as follows

$$Q_T = (4.136 + 1.8095 (-\ln(-\ln(1-1/T)))A^{0.64} \qquad \text{Eq......(84)}$$

ii) Based on PWM EVI distribution

The relation between Q_T and the catchment area with the estimated regional parameters is

$$Q_T = (4.032 + 1.974 (-\ln(-\ln(1-1/T)))A^{0.64} \qquad \text{Eq......(85)}$$

iii) Based on PWM GEV Distribution

The regional parameters of GEV distribution is estimated using the method of probability weighted moments. The values of the parameters are shown below

k	u	α
-0.037	0.773	0.369

The relation between Q_T and the catchment area obtained using these regional parameters is given below

$Q_T = (51.56 (-\ln(1-1/T))^{-0.037} - 47.56) A^{0.64}$ Eq......(86)

iv) Based on PWM Wakeby Distribution

The regional parameters of the wakeby distribution were estimated using the method of probability moments and are tabulated below

a	b	c	d	m
0.328	5.525	- 9.538	-0.52	0.255

A relation was developed using these regional parameters and the catchment area to estimate the flood at different return periods. The relation is as follows,

$Q_T = \{ 1.318 + 1.695(1-(1-F)^{5.25} + 49.31(1-(1-F)^{0.55}\} A^{0.64}$ Eq.......(87)

7.4.3. considering basin as whole

i) Index-Flood Method

The equation for estimating the flood at different return period using the catchment area is

$Q_T = [7.03 (-\ln(-\ln(1-1/T))+ 13.71) A^{0.52}$ Eq......(88)

ii) Based on PWM EVI distribution

The equation for estimating the flood at different recurring interval using the catchment area and the computed regional parameters is

$Q_T = [13.58+ 7.254 (-\ln(-\ln(1-1/T))) A^{0.52}$ Eq......(89)

ii)Based on PWM GEV Distribution

The values of the regional parameters estimated for the GEV distribution and the regression coefficients are given below

β	γ	k	u	a	b	α
-52.32	65.60	-0.10	0.747	17.78	0.5216	0.369

using these values, the regional flood formula was obtained for Krishna basin as

$$Q_T = [65.60\ (-\ln(1-1/T)^{-0.1} - 52.35] * A^{0.52} \qquad \text{Eq......(90)}$$

iii) PWM based Wakeby Distribution

The estimated values of regional wakeby parameters are tabulated below

a	b	c	d	m
0.347	9.165	236.87	0.002	0.178

A regional relationship of Q_T and the catchment is established using these estimated wakeby parameter and the regression coefficients obtained by relating the mean annual peak flood and the catchment area. The regional flood formula is given below:

$$Q_T = [(3.16+6.16(1-(1-F)^{9.165}) - 4211.54(1-(1-F)^{-0.002})\ A^{0.52} \qquad \text{Eq............(91)}$$

The regional formula has been used to estimate the floods for various return period.

7.5. Evaluation of the methods used for analysis.

In order to evaluate the methods used for the present analysis, the values of ADF, EFF and RMSE have been estimated for all the methods. The values of ADF, EFF and RMSE for all the methods under different cases namely, i) medium catchments, ii) large catchments and iii) considering the basin as whole are given in table 6,7,8, respectively.

Table.6(a). ADF Values for different methods for medium catchments.

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Koynanagar	0.393	0.388	0.281	0.669	0.602	0.662	0.668
Warunji	0.052	0.451	0.040	0.204	0.246	0.236	0.237
Gokak	0.066	0.051	0.046	0.102	0.069	0.138	0.134
Gotur	0.067	0.066	0.065	0.138	0.179	0.164	0.163
Daddi	0.051	0.048	0.051	0.158	0.201	0.191	0.189

Bestwad	0.108	0.107	0.088	0.124	0.148	0.115	0.106
Tarewad	0.320	0.408	0.194	0.350	0.348	0.376	0.328
Shirdon	1.376	0.350	0.199	1.964	1.752	2.077	1.983
Konkangaon	1.062	0.302	0.399	1.074	0.971	1.111	1.048
Bori	0.195	0.143	0.097	0.338	0.289	0.332	0.335
Jewani	0.479	0.304	0.0	0.839	0.758	0.824	0.931
Khanapur	0.089	0.091	0.093	0.085	0.103	0.095	0.075
Chickalgudda	0.038	0.038	0.038	0.498	0.141	0.123	0.125
Yamagardi	0.071	0.071	0.038	0.159	0.193	0.174	0.176
Konganahalli	0.111	0.113	0.052	0.131	0.161	0.162	0.140

Table.6(b). Efficiency Values for different methods for medium catchments.

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Koynanagar	0.926	0.922	0.938	0.827	0.885	0.872	0.863
Warunji	0.946	0.946	0.946	0.378	0.820	0.329	0.374
Gokak	0.938	0.962	0.965	0.967	0.941	0.853	0.846
Gotur	0.914	0.921	0.911	0.769	0.456	0.311	0.268
Daddi	0.969	0.968	0.958	0.750	0.452	0.360	0.316
Bestwad	0.930	0.932	0.936	0.919	0.909	0.910	0.913
Tarewad	0.720	0.877	0.907	0.639	0.711	0.784	0.791
Shirdon	0.959	0.985	0.987	0.694	0.779	0.813	0.818
Konkangaon	0.854	0.883	0.897	0.603	0.681	0.719	0.730
Bori	0.916	0.885	0.925	0.843	0.889	0.868	0.867
Jewani	0.958	0.946	0.0	0.752	0.839	0.846	0.848
Khanapur	0.935	0.902	0.949	0.954	0.913	0.831	0.832
Chickalgudda	0.978	0.967	0.970	0.923	0.783	0.652	0.637
Yamagardi	0.913	0.940	0.986	0.818	0.726	0.709	0.694
Konganahalli	0.934	0.931	0.925	0.889	0.776	0.678	0.684

Table.6(c).RMSE Values for different methods for medium catchments.

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Koynanagar	193.0	198.9	177.7	295.6	240.6	254.7	263.2
Warunji	102.0	101.9	101.9	345.4	455.7	505.6	513.5
Gokak	201.5	158.2	153.1	147.8	197.8	311.4	319.0
Gotur	74.29	71.41	75.59	121.7	186.8	210.4	216.8
Daddi	68.83	70.05	79.29	194.3	287.8	310.7	321.5
Bostwad	76.25	79.02	72.65	81.75	87.04	86.34	84.79
Tarewad	847.4	561.0	487.7	961.4	861.2	749.4	729.6
Shirdon	24.77	14.71	14.01	67.47	57.31	52.56	51.95
Konkangaon	153.4	137.5	129.1	253.1	227.1	213.1	208.8
Bori	91.37	106.5	86.03	124.4	104.8	114.0	114.6
Jewani	108.6	140.4	0.0	300.1	248.9	236.7	235.4
Khanapur	179.0	219.9	158.3	149.9	206.9	288.2	287.8
Chickalgudda	28.28	32.62	31.14	50.09	84.03	106.4	108.7
Yamagardi	66.94	55.14	27.20	96.90	118.7	122.5	125.5
Konganahalli	80.07	87.16	85.46	103.7	147.6	176.4	175.3

Table.7(a) ADF values for different methods for large catchments

Catchment	EV1	GEV	WD	SREV1	SRGEV	INDEX	RWD
Karad	0.069	0.068	0.069	0.114	0.110	0.085	0.113
Arjunwad	0.049	0.044	0.044	0.135	0.135	0.102	0.138
Bagalkot	0.088	0.065	0.061	0.082	0.090	0.083	0.09
Cholchgod	0.093	0.097	0.046	0.093	0.094	0.096	0.096
Yadgeer	0.078	0.076	0.048	0.090	0.091	0.109	0.089
Wadakbal	0.112	0.097	0.126	0.250	0.264	0.316	0.257
Takali	0.107	0.072	0.064	0.311	0.106	0.132	0.109
Dhond	0.083	0.068	0.041	0.101	0.102	0.078	0.107
Narsingpur	0.237	0.231	0.134	0.307	0.326	0.350	0.326
Sarathi	0.185	0.063	0.067	0.146	0.135	0.137	0.137
Kudachi	0.035	0.035	0.032	0.174	0.171	0.138	0.173

Table.7(b) Efficiency values for different methods for large catchments.

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Karad	0.920	0.903	0.924	0.912	0.797	0.776	0.774
Arjunwad	0.917	0.954	0.958	0.807	0.570	0.529	0.515
Bagalkot	0.908	0.967	0.97	0.944	0.880	0.856	0.855
Cholchgod	0.877	0.920	0.979	0.925	0.877	0.854	0.853
Yadgeer	0.966	0.958	0.98	0.956	0.971	0.966	0.968
Wadakbal	0.957	0.935	0.963	0.865	0.911	0.911	0.915
Takali	0.938	0.986	0.985	0.837	0.901	0.915	0.914
Dhond	0.981	0.960	0.984	0.895	0.767	0.733	0.726
Narsingpur	0.949	0.952	0.958	0.942	0.955	0.947	0.949
Sarathi	0.833	0.966	0.968	0.715	0.796	0.813	0.814
Kudachi	0.971	0.969	0.958	0.634	0.297	0.262	0.241

Table.7(c) RMSE values for different methods for large catchments

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Karad	258.0	284.7	250.7	270.5	416.7	431.6	433.8
Arjunwad	350.1	280.8	262.3	533.2	795.6	833.0	845.4
Bagalkot	159.4	95.7	91.27	124.2	181.9	199.2	200.8
Cholchgod	149.0	120.2	61.10	116.4	149.9	102.3	163.0
Yadgeer	425.9	477.7	272.8	488.3	395.2	429.4	417.3
Wadakbal	151.9	186.0	140.5	268.9	218.3	219.1	213.3
Takali	641.6	303.4	311.2	104.0	811.7	753.4	756.6
Dhond	424.0	257.7	159.9	416.5	620.1	683.4	671.5
Narsingpur	416.9	408.0	381.9	447.1	395.1	427.0	419.1
Sarathi	172.4	77.98	75.1	225.1	190.3	182.3	181.6
Kudachi	308.9	318.3	368.8	109.1	151.1	154.8	157.0

Table.8(a). ADF values for the methods used for analysis considering the basin as whole.

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Karad	0.069	0.068	0.069	0.123	0.137	0.128	0.127
Arjunwad	0.049	0.044	0.044	0.146	0.162	0.162	0.167
Koynanagr	0.393	0.388	0.281	0.681	0.663	0.700	0.702
Warunji	0.052	0.051	0.040	0.199	0.218	0.212	0.214
Gokak	0.066	0.051	0.046	0.108	0.099	0.140	0.134
Bagalkot	0.088	0.065	0.061	0.074	0.087	0.103	0.103
Cholchgud	0.093	0.097	0.046	0.092	0.096	0.099	0.113
Gotur	0.067	0.066	0.065	0.134	0.153	0.145	0.146
Daddi	0.051	0.048	0.051	0.153	0.174	0.109	0.170
Bestwad	0.108	0.104	0.88	0.120	0.123	0.105	0.101
Tarewad	0.320	0.408	0.194	0.335	0.365	0.385	0.354
Yadgeer	0.078	0.076	0.045	0.084	0.080	0.084	0.097
Wadakbal	0.112	0.097	0.126	0.226	0.209	0.237	0.230
Takali	0.107	0.072	0.064	0.097	0.094	0.083	0.084
Shirdon	1.376	0.350	0.199	2.007	1.199	2.188	2.080
Konkangoan	1.062	0.302	0.399	1.096	1.093	1.780	1.118
Bori-omerga	0.195	0.143	0.097	0.348	0.337	0.360	0.353
Jewani	0.479	0.304	0.0	0.854	0.839	0.878	0.869
Dhond	0.083	0.068	0.041	0.114	0.127	0.129	0.135
Narasingpur	0.237	0.231	0.134	0.264	0.259	0.319	0.283
Sarathi	0.089	0.091	0.093	0.086	0.089	0.090	0.083
Khanapur	0.038	0.035	0.038	0.093	0.111	0.100	0.101
Chckalgod	0.071	0.071	0.035	0.154	0.164	0.152	0.154
Yamagardi	0.113	0.113	0.052	0.129	0.141	0.145	0.135
Konganahalli	0.185	0.063	0.067	0.144	0.155	0.121	0.125
Kudachi	0.035	0.035	0.032	0.181	0.20	0.193	0.194

Table.8(b).Efficiency values for the methods used for analysis considering the basin as whole.

Catchment	EV1	GEV	WD	INDEX	SREV1	SRGEV	RWD
Karad	0.920	0.903	0.924	0.837	0.722	0.640	0.633
Arjunwad	0.917	0.954	0.965	0.644	0.427	0.280	0.282
Koynanagar	0.926	0.922	0.938	0.882	0.863	0.859	0.856
Warunji	0.946	0.946	0.946	0.408	0.151	0.033	0.006
Gokak	0.938	0.962	0.965	0.965	0.950	0.907	0.906
Bagalkot	0.908	0.967	0.970	0.914	0.839	0.753	0.741
Cholchgud	0.877	0.920	0.979	0.911	0.847	0.767	0.755
Gotur	0.921	0.911	0.969	0.783	0.588	0.515	0.483
Daddi	0.968	0.958	0.930	0.766	0.594	0.552	0.521
Bastwad	0.930	0.932	0.936	0.919	0.925	0.932	0.936
Tarewad	0.720	0.877	0.907	0.636	0.697	0.743	0.354
Yadgeer	0.966	0.958	0.986	0.977	0.970	0.943	0.94
Wadakbal	0.957	0.935	0.963	0.913	0.932	0.922	0.926
Takali	0.938	0.986	0.985	0.879	0.919	0.953	0.953
Shirdon	0.959	0.985	0.987	0.688	0.749	0.772	0.778
Konkangoan	0.854	0.883	0.897	0.598	0.654	0.679	0.668
Bori-Omerga	0.916	0.885	0.925	0.839	0.869	0.802	0.864
Jewani	0.968	0.946	nc	0.747	0.80	0.813	0.816
Dhond	0.891	0.960	0.984	0.814	0.687	0.568	0.546
Narsingpur	0.949	0.952	0.958	0.264	0.954	0.921	0.926
Sarathi	0.935	0.902	0.949	0.955	0.932	0.897	0.896
Khanapur	0.975	0.967	0.970	0.930	0.854	0.773	0.785
Chickalgod	0.913	0.941	0.986	0.825	0.793	0.797	0.787
Yamagardi	0.934	0.931	0.925	0.895	0.836	0.793	0.799
Konganahalli	0.833	0.966	0.968	0.356	0.814	0.858	0.862
Kudachi	0.971	0.969	0.958	0.722	0.075	0.02	0.098

Table.8(c). RMSE values for the methods used for analysis considering the basin as whole.

Catchment	EVI	GEV	WD	INDEX	SREVI	SRGEV	RWD
Karad	258.0	284.7	250.7	368.3	481.2	547.2	552.9
Arjunwad	350.1	360.8	262.3	726.9	918.8	103.0	104.9
Koynanagar	193.0	198.9	177.7	299.9	262.9	267.3	269.3
Warunji	102.0	101.9	101.9	377.0	403.8	430.8	436.9
Gokak	201.5	158.0	153.1	151.4	182.4	247.8	248.8
Bagalkot	159.4	95.76	91.2	154.3	211.1	261.1	267.4
Cholchgod	149.0	120.2	61.1	126.5	165.9	205.2	210.4
Gotur	74.29	71.41	75.59	118.0	162.6	177.0	182.1
Daddi	68.83	70.05	79.28	188.1	247.5	260.1	268.9
Beatwad	76.25	74.92	72.65	81.9	79.0	74.88	72.67
Tarewad	847.4	561.0	487.7	965.5	881.6	810.9	801.7
Yadgeer	425.9	477.7	272.8	353.6	402.2	555.9	569.9
Wadakbal	151.9	186.0	140.5	216.0	191.4	204.8	198.6
Takali	641.6	303.1	311.2	896.9	733.5	559.4	559.1
Shirdon	24.77	14.71	14.01	68.07	61.07	58.17	57.43
Konkangoan	153.4	137.6	129.1	254.6	236.4	227.6	224.4
Bori-Omergan	91.37	106.5	86.03	126.3	113.7	116.9	115.8
Jewani	108.6	140.4	nc	303.5	269.5	260.5	258.3
Dhond	424.0	257.7	159.9	55.41	717.9	843.3	864.5
Narasingpur	416.9	408.0	381.9	351.3	399.3	522.5	504.9
Sarathi	179.0	219.9	158.3	149.6	182.9	226.9	226.2
Khanapur	28.28	32.62	31.14	47.67	68.95	81.99	83.55
Chekalgoud	66.94	55.14	27.20	94.94	103.3	102.3	104.6
Yamagardi	80.07	82.16	85.46	100.9	126.3	141.8	139.8
Konganahalli	172.4	77.88	75.10	209.5	182.7	158.7	156.6
Kudachi	308.9	318.3	368.6	147.7	173.4	185.7	188.9

From the given tables it may be noticed that the index-flood and PWM based extreme value type-I distribution methods have yielded good results as compared to other two methods for most of the catchment. It shows that the flood series in Krishna basin may follow distribution similar to that of the Index-Flood and PWM based EVI distribution. The results obtained for the other two methods SRGEV and RWD are not so good, for some of the catchments. The efficiency values for each methods have increased when regional relationship developed considering only the data of large catchments instead of the catchment of different sizes.

8.0 Results and Discussion

The gauging sites at Shimoga and Marol having a catchment area of 2831 and 4901 km^2 are considered as test sites to verify the developed regional flood formulae under different cases namely,i) medium catchments, ii) large catchments and iii) considering the basin as whole. The flood estimated at test sites for desired return period using regional flood formulae are tabulated in table 9 to 16. The gauging records of the two test sites were used to compute the parameters of Index-Flood, PWM based EVI distribution, PWM based GEV distribution and PWM based Wakeby Distribution. The flood values obtained from these methods (independently applied on the data of test sites) were compared with those values computed for the test sites using the developed regional flood formulae. The comparison is made based on the ratios of absolute difference between observed and estimated flow expressed in percentage are also shown in table 9 to 16, respectively.

From these tables, it is observed that the flood estimated using the relationship developed between Q_T and catchment area (A) using Index-flood method and PWM based extreme value type-I distribution for the medium catchments and the case of considering basin as whole yielded very good result. The ratios of absolute difference between observed and estimated using the regional parameter is very low for Index-Flood and PWM based EVI approach compared to the ratios obtained by other two methods for most of the cases. It is further supported by the low values of (table 6 to 8) ADF, RMSE and higher efficiency obtained for these two methods. It is also seen that the results of other two methods considered for the analysis is not so good for some of the cases and they yielded high ratios of absolute difference between observed and estimated flood series.

From the results, it is also noted that, estimated ratios of absolute difference of the flood series computed using the relation developed for the large catchments (catchment area above 5000 km^2) are very high. This indicates that, the size of the catchment area plays an important role in estimating the regional parameters and in developing relation between Q_T and catchment area(A) apart form the other factors like flow, morphological and soil conditions of the basin.

The results obtained from the 4 methods for different cases gives a good comparison of the distributions used for analysis. However, it may be worth to mention that the relation developed between mean annual peak flow and the catchment area using Index-Flood approach and PWM based extreme value type-I distribution for medium and the case of considering the basin as whole yielded very low ratios of absolute percentage error. It clearly indicates that, the effect of catchment sizes on the form of the relationships. Here the relative performance of the methods are judged based on some descriptive ability criteria. However, the main objective of the flood frequency analysis is to predict the floods of various frequencies even on the extrapolation range. For this purpose the performance of these methods must be judged based on the predictive ability criteria before recommending a particular method. Also these result emphasize the need to study the methods based on PWM based GEV and PWM based wakeby distribution using the field data of varying flow conditions and the size of the catchment area.

Table.9. Comparision of observed and computed floods for various recurring intervals for test site at Shimoga.

INDEX Method

Return period	Estimated using actual parameter	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1220.84	1002.35	776.90	1015.87	18	38	17
10.00	2230.49	1827.31	1328.86	1841.93	18	40	17
20.00	2730.00	2142.53	1539.74	2157.57	22	44	21
50.00	3256.85	2550.55	1812.70	2566.13	24	44	21
100.00	3756.85	2856.30	2017.74	2872.29	24	46	24
200.00	4143.69	3160.94	2221.04	2146.15	24	46	24
500.00	4550.19	3571.56	2489.91	3579.78	22	45	21
1000.00	5121.13	3866.60	2693.12	3883.95	24	47	24

Table.10. Comparision of observed and computed floods for various recurring intervals for test site at Shimoga.

GEV Distribution

Return period	Estimated using actual Parameters	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1091.67	948.65	761.56	979.20	13	30	10
10.00	2330.28	1877.09	1372.38	1859.10	19	41	20
20.00	2703.98	2313.13	1617.26	2241.50	14	40	17
50.00	3503.89	2963.73	1944.06	2779.30	15	45	21
100.00	4036.89	3500.26	2196.45	3261.46	13	46	20
200.00	4994.00	4033.09	2454.48	3683.34	19	51	26
500.00	5462.77	4944.50	2805.23	4535.36	9	49	17
1000.00	5910.47	5786.00	3078.33	4898.45	2	48	17

Table.11. Comparision of observed and computed floods for various recurring intervals for test site at Shimoga.

Wakeby Distribution

Return Period	Estimated using actual parameters	Flood estimated using regional parameters			Absolute difference factor		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1326.77	924.34	761.56	945.08	30	42	29
10.00	2105.77	1899.87	1372.38	1793.87	10	34	15
20.00	2680.66	2349.36	1617.26	2159.17	12	39	19
50.00	2540.23	2968.48	1944.06	2644.72	16	45	25
100.00	4186.98	3458.00	2196.45	3011.99	17	48	28
200.00	4836.94	3966.55	2454.48	3379.80	18	50	30
500.00	5136.48	4609.27	2805.23	3866.78	10	48	25
1000.00	5989.47	5224.88	3078.33	4235.76	13	52	29

Table.12. Comparision of observed and computed floods for various recurring intervals for test site at Shimoga.

EVI Distribution

Return period	Estimated using actual parameters	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1169.91	929.51	770.05	1013.09	21	34	13
10.00	2153.40	1767.40	1371.86	1865.37	18	36	13
20.00	2305.19	2088.70	1603.71	2193.60	9	30	5
50.00	3219.05	2503.20	1900.01	2611.74	22	41	19
100.00	3720.24	2814.30	2123.50	2927.82	24	43	21
200.00	4277.25	3143.89	2346.10	3242.78	26	45	24
500.00	4997.31	3532.68	2639.10	3658.66	29	47	27
1000.00	5536.91	3840.83	2860.90	3972.51	31	48	28

Table.13. Comparision of observed and computed floods for various recurring intervals for test site at Marol.

INDEX Method

Return period	Estimated using actual parameters	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1665.05	1243.08	1100.00	1473.82	25	34	11
10.00	2820.94	2264.84	1886.14	2450.47	20	33	13
20.00	3420.94	265.42	2185.83	2870.93	22	36	16
50.00	4277.24	3160.47	2573.53	3413.84	26	40	20
100.00	4997.31	3547.80	2863.71	3821.02	29	43	24
200.00	5536.91	3916.69	3153.88	4226.72	29	43	24
500.00	6074.53	4414.68	3535.63	4762.26	27	42	22
1000.00	6783.83	4790.08	3825.69	5166.95	29	44	24

Table.14. Comparision of observed and computed floods for various recurring intervals for test site at Marol.

GEV Distribution

Return period	Estimated using actual parameter	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1805.55	1173.60	1081.02	1304.16	35	40	28
10.00	3006.36	2314.89	1947.98	2475.50	23	35	18
20.00	3806.36	2854.77	2297.39	2984.52	25	40	22
50.00	5166.01	3667.86	2760.24	3700.00	29	47	28
100.00	5740.80	4363.00	3119.30	4281.30	24	46	25
200.00	6313.50	5113.93	3486.29	4902.41	19	45	22
500.00	7069.06	6220.77	3973.98	5790.54	12	44	18
1000.00	7640.10	7164.70	4371.67	6519.34	6	43	15

Table.15. Comparision of observed and computed floods for various recurring intervals for test site at Marol.

Wakeby Distribution

Return period	Estimated using actual parameters	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1685.70	1150.73	1345.47	1259.98	32	20	25
10.00	2678.36	2354.35	2447.50	2388.50	12	9	11
20.00	3770.66	2910.39	2721.94	2875.35	23	28	24
50.00	5136.44	3677.32	3449.24	3520.06	28	33	31
100.00	5700.20	4282.80	3856.42	4008.38	25	32	30
200.00	6249.77	4913.48	4189.84	4498.18	21	33	28
500.00	6955.77	5784.17	4744.55	5145.84	17	32	26
1000.00	7473.10	6471.76	5103.05	5637.11	13	32	25

Table.16. Comparision of observed and computed floods for various recurring intervals for test site at Marol.

EVI Distribution

Return period	Estimated using actual parameter	Flood estimated using regional parameters			Absolute difference factors		
		Case I	Case II	Case III	Case I	Case II	Case III
2.00	1585.50	1178.50	1081.02	1304.16	26	31	17
10.00	2806.35	2324.50	1947.98	2475.50	17	30	11
20.00	3656.85	2864.28	2297.39	2984.52	22	37	18
50.00	5166.01	3659.69	2760.24	3700.00	29	46	28
100.00	5740.80	4334.39	3119.30	4281.30	24	45	25
200.00	6313.50	5804.37	3486.28	4902.41	8	44	22
500.00	7069.00	6205.90	3983.98	5790.54	12	43	18
1000.00	7640.10	7164.70	4371.67	6519.34	6	42	14

9.0. Conclusions and Recommendations

The regional frequency analysis carried out using annual peak discharge data of Krishna basin under three different groups yielded the following facts.

1. For the basins having catchment area below 5000 sq.kms, following equation can be used for the estimation of quantiles quite accurately (table 9 & 12)

$$Q_T = (36.94 +21.45 (-\ln(-\ln(1-1/T)))) A^{0.39}$$

2. For the case of considering the basin as whole, it is seen that the regional coefficients of the EVI distribution are different than the coefficients obtained for the medium catchments and it is shown below

$$Q_T = [13.58+ 7.254 (-\ln(-\ln(1-1/T))) A^{0.52}$$

Also the study reveals that, the size of the catchment plays (table 9 to 16) an important role in developing the regional flood formula. Therefore, a comparative study is needed to identify most robust flood frequency method not only based on the descriptive ability criteria but also on the predictive ability criteria.

3. However, for the basins having catchment area of 5000 sq.km. and above the the relation could not be established as there are only few gauging stations in the basin which falls in this category.

4. It is also seen from the study, the high standard errors associated with estimated mean flow using the equations 75 to 79, indicates that the mean flow does not only depends on the catchment area (fig. 32 to 34), but also on other physiographic characteristics. Therefore it is recommended to carry out a study to develop regional flood formulae based on the various physiographical characteristics of a catchment including the catchment area.

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