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DEVELOPMENT OF REGIONAL FLOOD FORMULA FOR MAHANADI SUBZONE - (3 D)

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PREFACE

Estimation of flood magnitudes and their frequencies for planning and design of water resources projects have been engaging attention of the engineers the world over since time immemorial. Whenever, rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable flood estimates directly. In such a situation the flood formulae developed for the region are one of the alternative methods which may be adopted for estimation of design flood specially for small catchments. Most of the flood formulae developed for different regions of the country are empirical in nature and do not provide flood estimates for the desired return period. In spite of the advancement in the techniques of design flood estimation, these empirical formulae are being used by the field engineers in their design practice, specially for flood estimation of small structures.

Based on the comparative flood frequency studies, probability weighted moment(PWM) based at site and regional general extreme value(SRGEV) method is found to be the most robust. In this study, regional flood frequency curves have been developed fitting the Probability Weighted Moment(PWM) based General Extreme Value(GEV) distribution to annual maximum peak flood data of bridge sites of the Mahanadi subzone-3(d). The relationship between the mean annual peak floods and the physiographic characteristics of the bridge catchments of subzone-3(d) has also been developed. Flood frequency curves, thus developed, have been coupled with the relationship established between mean annual peak floods and the physiographic characteristics, in order to develop the regional flood formula for the subzone-3(d). The developed regional flood formula has also been represented in the form of the Dicken's formula and the return periods of the floods estimated by the Dicken's flood formula have also been computed.

The study has been carried out by Shri Rakesh Kumar and Shri R.D. Singh, Scientists of the Institute. It is expected that the developed regional flood frequency curves together with at site mean annual peak flood will provide rational flood frequency estimates for gauged catchments of the Mahanadi subzone-3(d), while for computing the floods of various return periods for the ungauged catchments of the region the developed regional flood formula may serve as an useful alternative.

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ABSTRACT

Most of the flood formulae developed for different regions of India are empirical in nature and do not provide flood estimates for desired return period. Based on the comparative flood frequency studies carried out at the Institute for some of the typical regions of India, Probability Weighted Moment(PWM) based At Site and Regional General Extreme Value(SRGEV) method is found to be the most robust. In this study, regional flood frequency curves have been developed fitting the Probability Weighted Moment(PWM) based General Extreme Value(GEV) distribution to annual maximum peak flood data of 20 bridge sites of the Mahanadi subzone-3(d). The relationship between the mean annual peak floods and the physiographic characteristics of the bridge catchments of subzone-3(d) has also been developed. Flood frequency curves, thus developed, have been coupled with the relationship established between mean annual peak floods and the physiographic characteristics, in order to develop the regional flood formula for the subzone-3(d). The annual maximum peak flood data of 2 bridge catchments(test catchments) have been excluded while developing the regional flood frequency curves and the same have been utilized to compute the at site mean annual peak floods. These at site mean values together with the regional frequency curves have been used to compute the floods of various return periods for the 2 test catchments. Floods of various return periods have also been computed using the developed regional flood formula for these test catchments. The developed regional flood formula has also been represented in the form of the Dicken's formula and the return periods of the floods estimated by the Dicken's flood formula have also been computed. For estimation of floods of different return periods for the small catchments of the Mahanadi subzone-3(d), which are gauged the regional flood frequency curves together with at site mean annual peak flood may be used, while for the ungauged catchments the developed regional flood formula may be adopted.

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1.0 INTRODUCTION

The information on flood magnitudes and their frequencies are needed for the design of hydraulic structures such as dams spillways, road and railway bridges, culverts etc. Whenever, rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable flood estimates directly. In such a situation the flood formulae developed for the region are only alternative method to provide an estimate of design flood. Most of the flood formulae developed for different regions of the country are empirical in nature and do not provide flood estimates for the desired return period. In spite of the advancement in the techniques of design flood estimation, these empirical formulae are being widely used by the field engineers in their design practice, specially for flood estimation of small structures.

A number of studies have been carried out for estimation of design floods for different structures by various Indian organizations. Prominent among these include the studies carried out jointly by Central Water Commission(CWC), Research Designs and Standard Organization(RDSO), Ministry of Railways and India Meteorological Department(IMD) for various hydrometeorological sub-zones of India using the method based on synthetic unit hydrograph and design rainfall considering physiographic and meteorological characteristics to estimate design floods(for example CWC, 1985) and regional flood frequency studies carried out by RDSO for the various hydrometeorological sub-zones using the USGS and pooled curve methods(for example RDSO, 1991)

Based on the comparative flood frequency studies carried out for some of the typical regions of India(NIH, 1990-91; Kumar et al. 1992), probability weighted moment(PWM) based At Site and Regional General Extreme Value(SRGEV) method is found to be the most robust and the same is adopted for development of the regional flood frequency curves, in this study. The mean annual peak flood data of 2 bridge catchments are excluded while developing the regional flood frequency curves are utilized to compute the at site mean annual peak floods. These at site mean values together with the regional frequency curves of the sub-zone are used to compute the floods of various return periods for 2 test catchments. Floods for these test catchments are also estimated using the combined regional flood frequency curves and respective at site mean annual peak floods. Flood frequency curves developed by fitting the PWM based GEV distribution are coupled with the relationship between mean annual peak flood and physiographic characteristics for deriving the regional flood formula for the hydrometeorplogical homogeneous Mahanadi subzone 3(d).

2.0 REVIEW OF LITERATURE

The empirical formulae used for the estimation of the flood peak are the essentially regional formulae based on statistical correlation of the observed peak and important catchment characteristics. The catchments, considered for developing the regional formulae, must be from a hydrologically homogeneous region. Quality control of the peak discharge data is, therefore, a prerequisite to the analysis, Some of the elements to be considered in the quality analysis are given below:

(i) All peak discharges should represent virgin flow (negligible man made influences);

(ii) Peak-stage data should be complete and reliable;

(iii) Any extraneous or variable back water effects on the peak stage, such as these cause by ice, aquatic vegetation, or reservoir operation downstream, should be noted and taken into consideration when computing the peak discharge;

(iv) Methods used to measure or compute peak discharge should be examined for reliability; and

(v) The runoff distribution between flood plain and stream channels at the time of peak discharge should be determined.

2.1 Commonly Used Empirical Formulae

In order to simplify the form of the regional formulae, only a few of the many parameters affecting the flood peak are used. For example, the catchment area, considered to be an important parameter affecting the flood peak, is used in almost all formulae. However, most of the formulae neglect the flood frequency as a parameter. In view of these, the empirical formula are applicable only in the region from which they were developed and when applied to other areas they can at best give approximate values. The empirical formulae are usually based on data obtained for the larger streams because relatively few small streams are gauged in any region. Consequently, the empirical equations are usually applied in computing peak discharges for rivers having large catchment areas where stream flow data are inadequate. Some of the empirical flood formulae commonly used in India, in metric units along with the values of constants used in the formulae and the limitations of these formulae are given in Appendix-I.

2.2 Envelope Curves

In regions having same climatological characteristics, if the available flood data are scanty, the enveloping curve technique can be used to develop a relationship between the maximum flood flow and catchment area. In this method the available flood peak data are collected from a large number of catchments which are similar in hydrometeorological characteristics. The data are then plotted on log-log paper as flood peak V/s catchment area. This would result in a plot in which the data would be scattered. If an enveloping curve that would encompass all the plotted points is drawn, the resulting curve can be used to compute maximum peak discharge for any given area. Envelope curves are very much useful in getting the rough estimate of peak values quickly. An empirical flood formulae of the type Q = f(A) can be derived if equations are fitted to these enveloping curves.

Kanwar Sain and Karpov (1967) collected the data on Indian rivers and have drawn two envelope curves which suit basins of south India and central India. Since in these curves the peak discharge has been correlated with the catchment area only and other catchment characteristics are ignored, the results obtained may not be precise. However, these can be used for preliminary guidance for determining peak flood discharge. This method is definitely better than the empirical formulae in the sense that it does not require the selection of coefficients on the basis of judgment as required in empirical formulae.

The limitation of these curves lies in the fact that they are based on past records available up to the time such curves are drawn. Such curves, should, therefore, be revised from time to time as more and more data become available.

2.3 Rational Method

If a rainfall of uniform intensity occurs over a basin beyond a time equal to time of concentration of the basin, which is defined as the time taken for a drop of water from the farthest point of the catchment to reach at the outlet, then the runoff will be constant at the peak value. The peak value of the runoff is given by the equation

$$Q_p = C\ i\ A \quad \text{for} \quad t \geq t_c$$

where C = coefficient of runoff

A = Area of the catchment, and

i = intensity of rainfall

The above equation is the basic equation of the rational method. Using the commonly used units in metric system, the equation is written for field application as :

$$Q_p = \frac{1}{3.6} C \, (i_{t_c,p}) \, A$$

Where Q_p = peak discharge in m^3/s

C = Co-efficient of runoff

$i_{t_c,p}$ = the mean intensity of precipitation (mm/hr) for a duration equal to t_c, time of concentration, and an exceedence probability p, and A = catchment area in sq. km.

The application of the method for peak flood computation require three parameters i.e. t_c, $i_{t_c,p}$ and C, which can be estimated as follows:

Time of Concentration

Time of concentration can be estimated using an empirical equation of the form :

$$t_c = C_{tL} \left(\frac{L \, Lca}{\sqrt{S}}\right)^n$$

where C_{tL} and n are constant

L is length of the main stream in km.

L_{ca} is the length along the main stream from the outlet to a point opposite the C.G. of the catchment in km.

S is the basin slope.

Another empirical equation, known as Kirpich equation, is very much in use to estimate the value of t_c. This equation is given as:

$$t_c = 0.01947 \, L^{0.77} \, S^{-0.385}$$

where t_c = time of concentration in minutes

L = maximum length of travel of water in meter and

S = Slope of the catchment = $\Delta H/L$

ΔH = difference in elevation between the most remote point on the catchment and the outlet in meter.

Rainfall Intensity ($i_{t_c,p}$):

The rainfall intensity - frequency - duration relationship for the given catchment can be used to obtain the rainfall intensity corresponding to a duration t_c and the desired probability of exceedence p (i.e. return period = 1/p)

Runoff Coefficient (C)

The coefficient C represent the integrated effect of the catchment losses and depends on the nature of the surface surface slope and rainfall intensity. Some typical values of C are given below, where the effect of rainfall intensity is not considered for the values of C.

Value of the coefficient C for different types of Areas	
A. Urban area (P = 0.05 to 00.10)	
Lawns sandy - soil, flat, 2%	0.05 - 0.10
sandy - soil, steep, 7%	0.15 - 0.20
Heavy - soil, average, 2-7%	0.18 - 0.22
Residential Areas	
Single family areas	0.30 - 0.50
Multi units, attached	0.60 - 0.75
Industrial	
Light	0.50 - 0.80
Heavy	0.60 - 0.90
Streets	0.70 - 0.95
B. Agricultural Area	
Flat : Tight clay, cultivated	0.50
woodland	0.40
Sandy loam, cultivated	0.20
woodland	0.10
Hilly : Tight clay, cultivated	0.70
woodland	0.60
Sandy loam, cultivated	0.40
woodland	0.30

The rational method is commonly used for peak flow prediction in small catchments up to 50 Km^2 in area. This method has found considerable application in design of Urban drainage, small culverts and bridges.

2.4 Application of Empirical Formulae for Design Flood Estimation

Whenever the hydrological records are inadequate for frequency analysis or unit hydrograph analysis, the empirical formulae developed for the region are only alternative method to provide an estimate of flood at project site. Many empirical formulae have been devised as discussed above. These formulae are essentially the regional formulae based on statistical correlation of the observed peaks and important catchment properties. Most of the empirical formulae involve only one or two physical characteristics for the estimation of the flood peak. Since the flood peaks not only depend on one or two physical characteristics involved in those empirical formulae but also on many other factors , therefore those formulae can not be expected to give generalized precise results. In view of these, the empirical formulae are applicable only in the region from which they were developed. Also its applicability is limited for estimating the flood peaks up to the range of values considered in developing the formula. Care has to be taken while using these formula in extrapolation range of peak values and catchments sizes.

The empirical formulae developed for a specific region based on past available records should be revised from time to time as more and more data becomes available. Those catchments, which have been affected by various land use changes, should be excluded while revising the empirical formulae unless the factors reflecting those changes are already included in the empirical formulae. In general, it can be stated that the empirical formulae must be used with great prudence and must never be used unless their origin has been investigated.

3.0 PROBLEM DEFINITION

For design of various types of hydraulic structures such as road and railway bridges, culverts, weirs, barrages, cross drainage works etc. the information on flood magnitudes and their frequencies is needed. Whenever, rainfall or river flow records are not available at or near the site of interest, it is difficult for histologists or engineers to derive reliable flood estimates directly. In such a situation, the flood formulae developed for the region are the alternative method for estimation of design flood. Most of the flood formulae developed for different regions of the country are empirical in nature and do not provide flood estimates for the desired return period. In this study, regional flood frequency curves developed by the General Extreme Value distribution have been coupled with the relationship between mean annual peak flood and physiographic characteristics for deriving a regional flood formula for the Mahanadi subzone-(3d).

The objectives of this study are:

(a) Testing the regional homogeneity of the study area.

(b) Development of regional flood frequency curves using GEV distribution.

(c) Development of relationship between mean annual peak floods and physiographic characteristics for estimating the mean annual peak flood for the ungauged catchments.

(d) Coupling the relationship between mean annual peak flood and physiographic characteristics for developing the regional flood formula for the study area.

4.0 DESCRIPTION OF THE STUDY AREA

Mahanadi sub-zone 3(d) comprises of Mahanadi, Brahmani and Baitarani basins. The Mahanadi, Brahmani and Baitarani are peninsular rivers which fall into the Bay of Bengal. Important tributaries of Mahanadi river are Seonath, Hasdo, Mand and Ib joining from north, and Jonk, ong and Tel joining from south. The total length of Mahanadi, Brahmani, and Baitarni rivers is 850, 705 and 333 kilometers respectively. Hirakud dam the multi-purpose project in Orissa is located in the middle of the Mahanadi sub-zone. The total drainage area of this sub-zone is about 1,95,256 square kilometers. Out of which the river Mahanadi and its tributaries drain 1,40,628 square kilometers, the river Brahmani covers 35,337 square kilometers and the river Baitarani drains 19,291 square kilometers respectively.

Mahanadi sub-zone 3(d) lies between longitudes 80^{o} 25' to 87^{o} East and latitudes 19^{o} 15' to 23^{o} 35' North. Location of Mahanadi sub-zone 3(d) is shown in Fig. 1. Map of this sub-zone is shown in Fig. 2. Mahanadi basin is fan shaped up to Hirakud reservoir. The Brahmani and Baitarani are oblong catchments. The subzone comprises of parts of Maharashtra, Madhya Pradesh, Orissa and Bihar. About half of the area of this sub-zone is hilly varying in height from 300 meters to 1350 meters and rest of the area varies in height from 0 to 300 meters on both sides of the Mahanadi river. The hilly area is mostly on the North, South and Southwest of the region.

The sub-zone receives about 75% to 80% of the annual rainfall from South-West monsoon during the monsoon season from June to September. The variation of normal annual rainfall over the sub-zone is from a minimum of 1200 mm to a maximum of 1600 mm. The convergence between the Bay of Bengal branch and Arabian sea branch of the monsoon sometimes becomes significant and causes heavy precipitation.

The minimum and maximum temperatures are recorded in the months of December and April/May respectively. The temperature begins to rise from January to April/May and then falls down gradually up to December. The mean monthly minimum temperature of about 12^{o} C and mean monthly maximum temperature of 40^{o} C are recorded in this sub-zone.

The red and yellow soils cover major part of the sub-zone. The red sandy and coastal alluvial soils cover the remaining part of sub-zone. The sub-zone has an extensive area under forest.

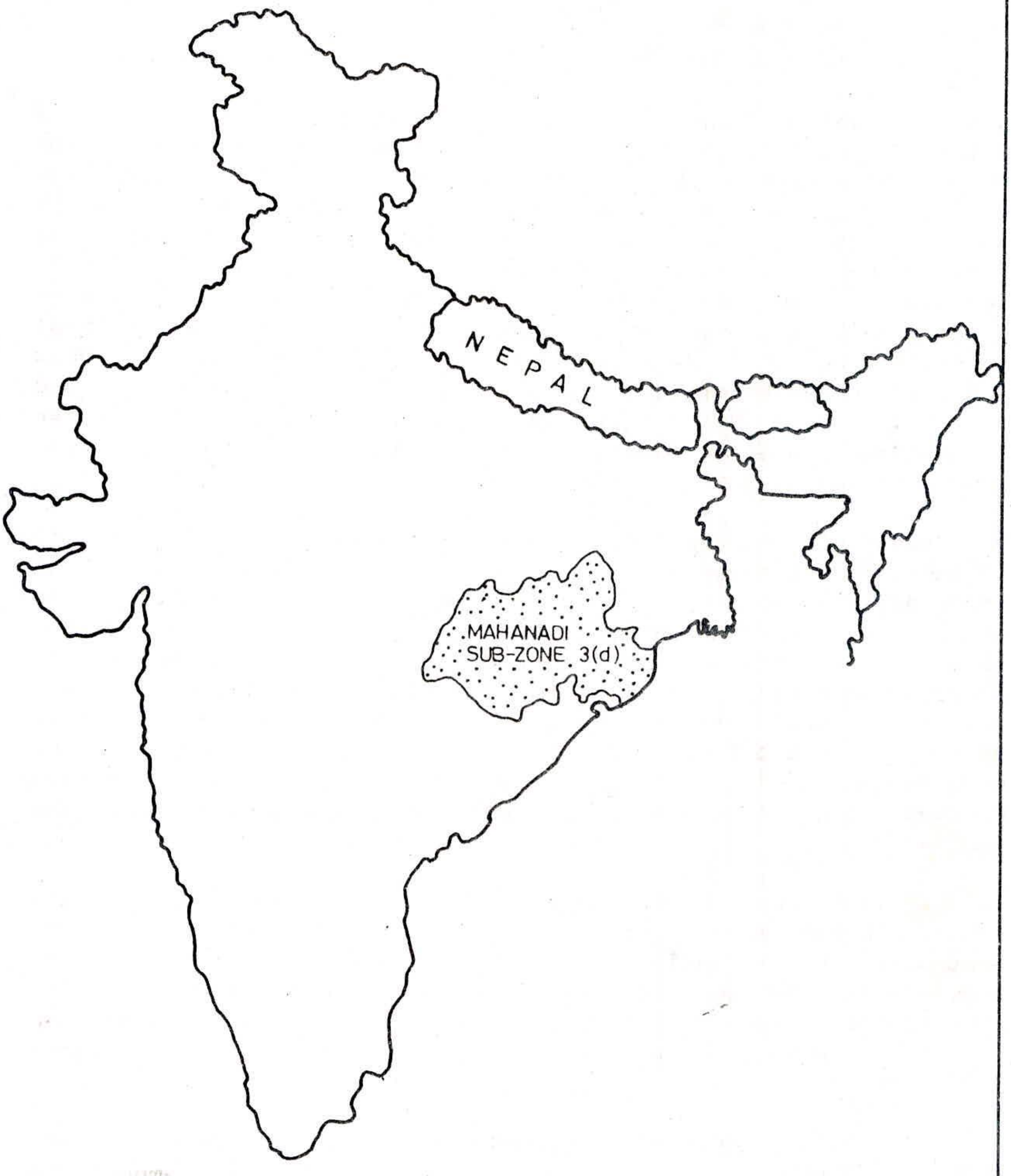

FIG.1 LOCATION MAP OF HYDROMETEOROLOGICAL
MAHANADI SUB-ZONE 3(d)

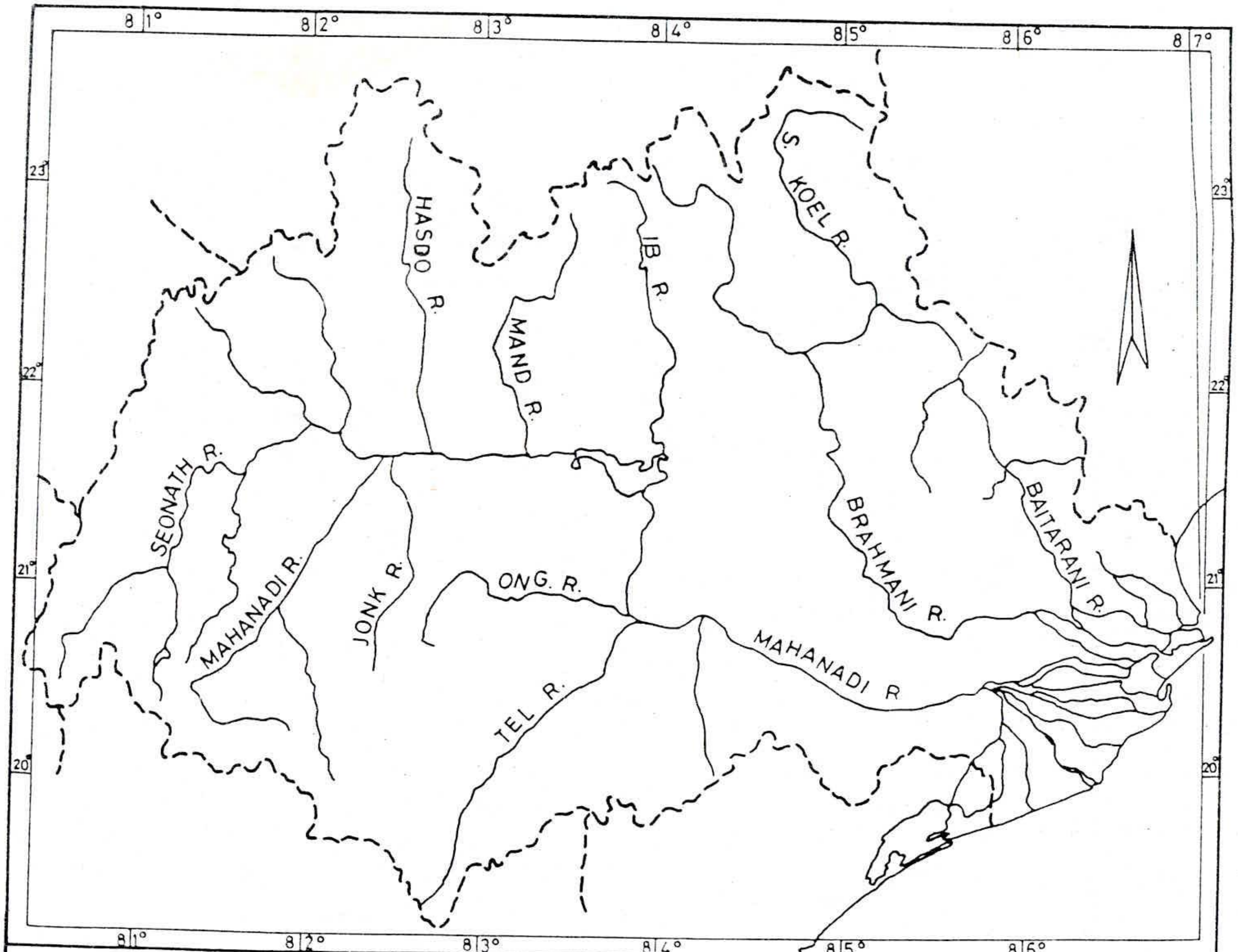

FIG. 2 INDEX MAP OF MAHANADI BASIN SUB-ZONE 3 (d)

Paddy is the main crop grown on the cultivable land. Most of the irrigated area is in Sambalpur district under the canals of Hirakud project. In the deltaic area under Cuttack, the irrigation is mostly done by inundation canals.

5.0 DATA AVAILABILITY FOR THE STUDY

The annual peak flood series data for 11 to 31 years varying over the period 1957 to 1989 for 23 gauging sites of the Mahanadi basin sub-zone 3(d) were available for this study(RDSO, 1992). The drainage area of these sites vary between 19 to 1150 square kilometers. The details of catchment area, mean annual peak flood, standard deviation, coefficient of variation, coefficient of skewness and record length of the annual peak floods for the 22 gauging sites passing the USGS homogeneity test and used in this study(discussed in the following Section) are given in Table-1.

Table-1 Catchment area, sample statistics and sample size

S.NO.	Br.No.	Catchment Area (Sq Km)	Mean Flood (Cumec)	Standard Deviation (Cumec)	Coff. of Variation	Coff. of Skewness	Sample Size (Years)
1	66K	154	260.32	201.63	.775	1.611	28
2	48	109	103.90	79.68	.767	1.527	30
3	176	66	81.48	114.36	1.403	4.369	31
4	93K	74	153.07	75.26	.492	.735	28
5	59KGP	30	72.90	55.42	.760	1.262	29
6	308	19	41.22	25.42	.617	.819	27
7	332NGP	225	188.59	99.48	.527	1.158	22
8	59BSP	136	196.23	154.32	.786	1.560	22
9	698	113	247.00	198.48	.804	1.404	25
10	37	64	25.09	20.61	.822	1.054	23
11	121	1150	1003.86	466.53	.465	.521	19
12	385	194	115.40	70.67	.612	.387	21
13	332KGP	175	71.83	39.44	.549	.695	20
14	40K	115	260.67	165.51	.635	1.220	24
15	154	58	160.16	146.75	.916	2.405	21
16	42	49	53.50	20.36	.381	.028	19
17	69	173	238.89	147.75	.618	.916	21
18	90	190	130.73	80.74	.618	.458	20
19	195	615	963.77	385.71	.400	.335	19
20	235	312	176.14	96.65	.549	.764	11
21	325	26	50.00	42.81	.856	.953	13
22	489	823	1071.95	1171.58	1.093	2.003	14

6.0 METHODOLOGY

The methodology used for testing the regional homogeneity, development of regional flood frequency curves using PWM based GEV distribution as well as regional relationship for the estimation of mean annual peak flood and deriving the regional formula is discussed here under.

6.1 U.S.G.S. Homogeneity Test

This test has widely been used for testing homogeneity of a region. The steps involved in U.S.G.S. Homogeneity Test are:

(i) Compute the EV1 reduced variate corresponding to 10 year return period flood using the relation:

$$Y_T = -\ln(-\ln(1-\frac{1}{T})) \qquad (1)$$

for example

$$Y_{10} = -\ln(-\ln(1-\frac{1}{10})) \qquad (2)$$

$$=2.25$$

(ii) Compute the 10 year flood putting $Y_{10} = 2.25$ in the following equation developed for the different catchments using least square approach :

$$X_{10} = u + \alpha Y_{10} \qquad (3)$$

$$= u + 2.25\alpha \qquad (4)$$

(iii) Repeat step (i) and (ii) to compute 2.33 year flood, which is the annual mean flood for EV1 distribution, for the different catchments.

(iv) Compute the ratio of 10 year flood to annual mean flood ($Q_{2.33}$) at each gauging sites. The ratio is known as the 10 year frequency ratio.

(v) Average the 10 year frequency ratios of all the gauging sites to obtain the mean 10 year frequency ratio for the region as a whole.

(vi)Determine the EV1 reduced variate corresponding to the product of annual mean annual flood and the average 10 year frequency ratio from the linear regression equations developed for each catchment . Thus :

$$Y_T = (X_T - u)/\alpha \tag{5}$$

(vii)Plot the EV1 reduced variates obtained from step (vi against the effective length of records for that station on a test graph where upper and lower regional limits of 95 % confidence are already plotted using the following coordinate pairs :

Sample size (n)	Lower Limit (Y)	Upper Limit (Y)
5	-0.59	5.09
10	0.25	4.25
20	0.83	3.67
50	1.35	3.15
100	1.52	2.88
200	1.80	2.70

(viii)If the plotted points for all the gauging sites lie between the 95 % confidence limits , then they are considered to be homogeneous.

6.2 Development of Regional Flood Frequency Curves

In order to develop the regional flood frequency curves a sample comprising the station-year data of standardized values of annual maximum peak floods i.e. $x/\bar{x}$ values for different catchments of the subzone-3d are considered for the analysis. Then the flood frequency analysis is performed with the sample of $x/\bar{x}$ values.

The GEV distribution is a generalized three parameter extreme value distribution proposed by Jenkinson(1955). Its theory and practical applications are reviewed in the Flood Studies report prepared by Natural Environment Research Council(NERC, 1975). The cumulative density function F(z) for GEV distribution is expressed as:

$$F(z) = e^{-\left(1-K\left(\frac{z-u}{\alpha}\right)\right)^{1/K}} \tag{6}$$

Here u, α and K are location, scale and shape parameters of the GEV distribution respectively. The parameters u, α, and K of the GEV distribution are estimated using the method of PWM(Hosking et al., 1985). The form of the regional frequency relationship is expressed as:

$$z_T = x_T / \bar{x} = Q_T / \bar{Q} = u + \alpha Y_T \qquad (7)$$

Here, z_T is T-year return period flood estimate, $\bar{z}$ is the mean annual peak flood and Y_T is GEV reduced variate corresponding to T-year return period.

The GEV reduced variate (Y_T)can be expressed as a function of return period, T as:

$$Y_T = [1 - \{-\ln(1 - \frac{1}{T})\}^K]/K \qquad (8)$$

6.3 Estimation of T Year Flood Using At-Site Mean

Once, at site estimate of mean annual peak flood($\bar{x}$) is made for the gauged catchments the T year floods are estimated using the following relationship:

$$x_T = \bar{x}\ z_T \qquad (9)$$

6.4 Development of Relationship Between Mean Annual Peak Flood and Physiographic Characteristics

For the estimation of T year return period flood at a site in the region, the estimate for the mean annual peak flood is required. For gauged catchments , such estimates can be obtained based on the at site mean of the annual maximum peak flood data. However, for ungauged catchments at site mean can not be computed in absence of the flow data. In such a situation , a relationship between the mean annual peak flood of the gauged catchments in the region and their pertinent physiographic and climatic characteristics is needed for the estimation of the mean annual peak flood. Since, catchment area, slope of the catchment, its length etc. are considered to be the most prominent physiographic characteristics and some of them such as area are readily available, a relationship of the following form is developed in terms of physiographic characteristics of the catchment for the estimation of mean annual peak flood for ungauged sites.

$$\bar{x} = a\ A^b\ S^c\ L^d\ D^e \qquad (10)$$

Here, A is the catchment area, S is slope of the catchment, L is the length of the main stream, and D is the drainage density (or any other relevant physiographic characteristics may be adopted) of the catchment and 'a', 'b', 'c', 'd' and 'e' are the coefficients to be estimated using the least square approach.

Based on the T test significance of various physiographic characteristics has been examined in the developed relationships. 95% confidence limits over the mean annual peak floods are estimated, which are used for computing the flood estimates corresponding to lower and upper 95% confidence limits(Haan, 1977).

6.5 Development of Regional Flood Formula

The following form of the regional flood formula may be developed using the Equations (7), (8), (9) and (10).

$$x_T = r_T \; A^b \; S^c \; L^d \; D^e \tag{11}$$

where,

$$r_T = [\beta + \gamma \{-\ln (1-1/T)\}^K] \tag{12}$$

$$\beta = a (\alpha/K + u) \tag{13}$$

$$\gamma = - \alpha \; a/K \tag{14}$$

Here, x_T is the flood estimate for T year return period flood, r_T is the regional coefficient for the T year return period flood to be estimated from the regional flood frequency curves.

From the above equation, it is evident that the flood estimate(x_T) for return period T is a function of regional frequency curves developed using PWM based GEV distribution, return period, the regional coefficients appearing in the Equations (11) to (14). These equations can be used to compute the floods for desired return periods for the various ungauged catchments in the region.

6.6 Representation of Revised Flood Formula in the Form of Dicken's formula

The regional flood formula may be represented in the form of the Dicken's formula using the procedure described earlier. The conventional Dicken's formula is:

$$Q = C\ A^{0.75} \tag{15}$$

There is no return period associated with the conventional Dicken's formula. If the conventional Dicken's formula is revised as:

$$Q_T = C_T\ A^{0.75} \tag{16}$$

From Equation (11) and (16) the value of C_T can be obtained as:

$$C_T = r_T\ A^{b-.75}\ S^c\ L^d\ D^e \tag{17}$$

Thus, the coefficient C_T in the Dicken's formula can be associated with the return period and it can be evaluated using the physiographic characteristics such as A, S, L and D etc. and regional coefficients appearing in Equation(17).

7.0 ANALYSIS AND DISCUSSION OF RESULTS

The homogeneity of the region has been tested by the U.S.G.S. homogeneity test as discussed in Section 6.1. The homogeneity test graph is shown in Fig. 3. It is seen from the figure that out of the 23 bridge sites the data of 22 bridge sites pass the regional homogeneity test.

7.1 Development of Regional Flood Frequency Curves

The annual maximum peak flood data for 20 catchments (out of 22) are used for developing the regional flood frequency curves for sub-zone 3(d) based on fitting the PWM based GEV distribution to the sample of $x/\bar{x}$ values. The ánnual maximum peak flood data of the 2 catchments viz. bridge number 325 and 489 are used for the purpose of testing the methodology.

For GEV distribution(K<0) probability density function(PDF), density function(DF) and the relationships for the statistical parameters are given in Appendix II. Range of the GEV parameter values along with the range of variate(z) as well as reduced variate(y) are also given in Appendix II. The estimated values of GEV parameters for the regional flood frequency curves viz. K, u, and α are:

$K = -0.14$ $u = 0.67$ $\alpha = 0.45$

Statistics of GEV variate($z = x/\bar{x}$) for the sub-zone 3(d) are given below.

z_{lb}	$\bar{z}$	z_{med}	z_{mod}	σ_z	σ_z^2	CV_z	g_z
-2.5543	1.0	.8392	.6116	.7230	.5227	.7219	2.3849

Statistics of GEV reduced variate(y) computed using the relationships mentioned in Appendix II are given here under.

$\bar{y}$	y_{med}	y_{mod}	σ_y	σ_y^2	CV_y	g_y
1.1031	1.0527	.9818	.2249	.0506	.2039	2.3849

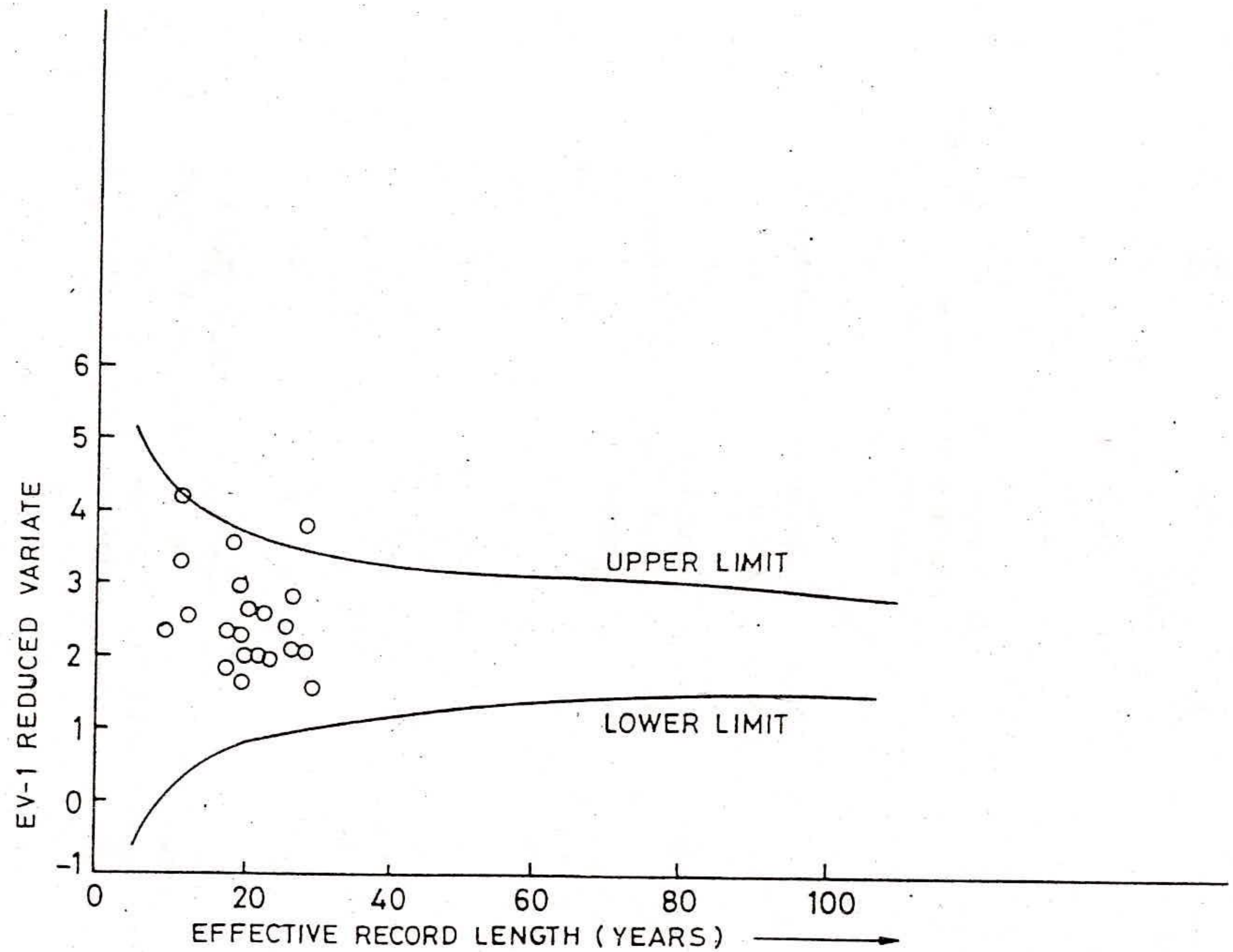

FIG. 3 HOMOGENEITY TEST GRAPH FOR SUB ZONE (3d)

The values of growth factors $(x_T/\bar{x})$ for various return periods for the subzone-3d are given below.

Return Period	2	10	20	50	100	200	500	1000
$x_T/\bar{x}$	0.838	1.852	2.316	2.991	3.559	4.185	5.108	5.890

The flood estimates for various recurrence intervals computed by using the at site mean and the above mentioned growth factors for all the 22 bridge sites of the region are given in Table-2

7.2 Development of Relationship Between Mean Annual Peak Flood and Physiographic Characteristics

For computation of flood frequency estimates for an ungauged catchment in the subzone-3d; a relationship between mean annual peak flood and physiographic characteristics for this subzone is required to be developed. Out of 22 small catchments considered in the study physiographic characteristics such as catchment area(A), length of the main stream from periphery of the catchment to the gauging site(L)and slope etc. for only 11 catchments were readily available(CWC, 1982). The various forms of relationships between mean annual peak flood and physiographic characteristics were tried. These relationships are discussed below.

7.2.1 Relationship between $\bar{x}$, A and S

The relationship between mean annual peak flood($\bar{x}$), catchment area(A) and slope(S) has been developed using multiple linear regression approach; wherein $\bar{x}$ has been considered as dependent variable and A & S have been considered as independent variables. The form of the relationship is given below.

$$\bar{x} = a\ A^b\ S^c \qquad (18)$$

The values of regression coefficients(a, b, c), their standard errors and absolute T values for Equation (18) are given as follows.

Table-2 Flood estimates for various recurrence intervals using regional frquency curves and at site mean

S.No.	Br. No.	Flood estimates for various recurrence intervals							
		2	10	20	50	100	200	500	1000
1	66K	218.	482.	603.	779.	927.	1089.	1330.	1533.
2	48	87.	192.	241.	311.	370.	435.	531.	612.
3	176	68.	151.	189.	244.	290.	341.	416.	480.
4	93K	128.	283.	355.	458.	545.	641.	782.	902.
5	59KGP	61.	135.	169.	218.	260.	305.	372.	429.
6	308	35.	76.	95.	123.	147.	172.	211.	243.
7	332NGP	158.	349.	437.	564.	671.	789.	963.	1111.
8	59BSP	165.	363.	455.	587.	699.	821.	1002.	1156.
9	698	207.	457.	572.	739.	879.	1034.	1262.	1455.
10	37	21.	46.	58.	75.	89.	105.	128.	148.
11	121	842.	1859.	2325.	3004.	3574.	4201.	5128.	5913.
12	385	97.	214.	267.	345.	411.	483.	589.	680.
13	332KGP	60.	133.	166.	215.	256.	301.	367.	423.
14	40K	219.	483.	604.	780.	928.	1091.	1332.	1535.
15	154	134.	297.	371.	479.	570.	670.	818.	943.
16	489	45.	99.	124.	160.	190.	224.	273.	315.
17	42	200.	442.	553.	715.	850.	1000.	1220.	1407.
18	90	110.	242.	303.	391.	465.	547.	668.	770.
19	195	808.	1785.	2232.	2884.	3431.	4033.	4923.	5677.
20	235	148.	326.	408.	527.	627.	737.	900.	1038.
21	325	42.	93.	116.	150.	178.	209.	255.	295.
22	489	899.	1985.	2483.	3207.	3816.	4486.	5476.	6314.

Reg. coefficient	Value of coeft.	T value	Std. error
ln a	0.64	0.356	1.8087
b	0.92	3.318	0.2774
c	0.03	0.083	0.3716

In order to test the significance of A as well as S in the Equation(18) T test has been performed. In this test null hypothesis(H_0 : C = 0) is assumed and the computed absolute values are compared with the critical T value obtained from the T table for a given degree of freedom and specific confidence interval. In this study a two tailed T distribution has been considered and the critical T value for 95% confidence interval, which corresponds to the probability of 0.975, has been derived from the T table for the given degree of freedom. From the T table critical T value corresponding to the probability of 0.975 and degree of freedom equal to 8(= 11-3) is obtained as 2.31. In case the computed absolute T value of a regression coefficient is more than the critical T value the Null hypothesis H_0 is rejected and it is considered that the associated independent variable is significant in the relationship. On the other hand, if the computed absolute T value of a regression coefficient is less than the critical T value the Null hypothesis H_0 is accepted. Which indicates that the associated independent variable is not able to explain the significant variance in the dependent variable. In the above relationship the T value associated with independent variable A(in natural log domain) is 3.318, which is more than the critical T value(2.31); whereas the absolute T value associated with average slope S (in natural log domain) is less than the critical value of T. It indicates that the catchment area may be retained as the independent variable and the variable S should not be considered as an independent variable in the above relationship. The multiple correlation coefficient is 0.811 which indicates that only 81% of the variance in the dependent variable has been accounted for by considering A & S as independent variables.

7.2.2 Relationship between $\bar{x}$, A/L^2 and S

The relationship between $\bar{x}$ as dependent variable and A/L^2 and S as independent variables in the following form has also been developed.

$$\bar{x} = a\ (A/L^2)^b\ S^c \tag{19}$$

The regression coefficients, their standard errors, and absolute T values for Equation(19) are given here under.

Reg. coefficient	Value of coeft.	T value	Std. error
ln a	0.18	0.053	3.3974
b	-0.65	-0.666	0.9686
c	-0.71	-1.497	0.4740

The computed absolute T values associated with the independent variable A/L^2 is 0.666 and for S is 1.497. These absolute T values are less than the critical T value(2.31). Thus the Null hypothesis H_o is accepted for the two independent variables. It implies that the variable A/L^2 and S should not be considered together for the developing the relationship for $\bar{x}$. Furthermore, the multiple correlation coefficient for the above relationship is 0.480 which is quite low. Hence the relationship (Equation-19) should be not considered for predicting the $\bar{x}$ values for the ungauged catchments of the subzone-3d.

7.2.3 Relationship between $\bar{x}$ and A

The relationship between $\bar{x}$ and A in the following form has also been tried.

$$\bar{x} = a\ A^b \tag{20}$$

The regression coefficients, their standard errors, and absolute T values for Equation(20) are given here under.

Reg. coefficient	Value of coeft.	T value	Std. error
ln a	0.53	0.459	1.1587
b	0.91	4.158	0.2183

The correlation coefficient for the above relationship is 0.811. The absolute computed T value associated with independent variable(in natural log domain) is 4.158, which is more the critical T value i.e. 2.26(the T value obtained from the table corresponding to the probability of 0.975 and degree of freedom equal to 9). Hence the Null hypothesis H_o is rejected and the A alone as an independent variable is significant in the above relationship.

For the Equation (18) and (20) the multiple correlation coefficients are same(0.811). However, in Equation (18) the independent variable S is insignificant based on T test. Therefore, only A has been considered as independent variable for developing the prediction equation for $\bar{x}$. Since, the catchment area were available for all the 22 sites; hence, the relationship between $\bar{x}$ and A has been developed using the data of the 20(not using data of 2 test catchments) sites. The relationship thus developed is given as:

$$\bar{x} = 3.82\ A^{0.76} \tag{21}$$

The regression coefficients, their standard errors, and absolute T values for Equation(21) are given here under.

Reg. coefficient	Value of coeft.	T value	Std. error
ln a	1.34	1.999	0.6710
b	0.76	5.543	0.1365

In the above relationship(Equation-21) the computed absolute T value is more than the critical value i.e. 2.09 (the value of T obtained from the T table corresponding to the probability of 0.975 and degree of freedom equal to 18. The multiple correlation coefficient is 0.794. It implies that only 79.4% of the initial variance has been accounted for by considering the catchment area as independent variable in Equation (21).

7.3 Development of Regional Flood Formula

The form of regional flood formula developed for the sub-zone 3(d) using the relationship between catchment area and mean annual peak flood based on the methodology discussed in Section 6 is:

$$x_T = [\beta + \gamma\ \{-\ln\ (1-1/T)\ \}^K]\ A^b \tag{22}$$

where,

$$\beta = a\ (\alpha/K + u) \tag{23}$$

$$\gamma = -\ \alpha\ a/K \tag{24}$$

x_T is flood estimate for T year return period in cubic meter per second(Cumec), A is the catchment area in square kilometers, a and b are the regional coefficients obtained from the relationship between mean annual peak flood($\bar{x}$) and catchment area(A).

The values of coefficients used in the regional flood formula and the values of regional GEV parameters are given below.

β	γ	K	u	α	a	b
- 9.512	12.080	-0.14	0.67	0.45	3.82	0.76

Using the values of the regional GEV(PWM) parameters K, u, α and the coefficients a and b for subzone-3d the regional flood formula is obtained as:

$$x_T = [12.08 \ \{(-\ln(1-\frac{1}{T}))^{-0.14}\} - 9.512] \ A^{0.76} \qquad (25)$$

It may be observed that the coefficient of the developed regional flood formula does not depend on catchment area and it is dependent on return period only. Fig. 4 shows variation of regional coefficient with return period for the subzone-3d. Using the regional flood formula, the flood frequency estimates have been computed for the various catchments of the subzone-3d. Fig. 5 shows variation of flood estimates with catchment area for return periods of 2, 10, 20, 50, 100, 200, 500 and 1000 years. This figure may be utilized for estimating the floods for ungauged catchments corresponding to the above referred return periods.

The data of 2 catchments(Bridge No. 325 and Bridge No. 489) for the subzone-3d are not considered while developing the regional flood frequency relationships as well as the relationship between mean annual peak flood and catchment area, because these catchments are treated as ungauged, and the flood frequency estimates for these catchments based on their at site and regional mean annual peak floods can be compared. The area of catchment bridge number 325 is 26 square kilometers and it is the second smallest catchment among the various catchments considered in the study. The area of catchment bridge number 489 is 823 square kilometers and it is the second largest catchment among the various catchments. Flood frequency estimates for the 2 test catchments are computed using at site mean as well as regional

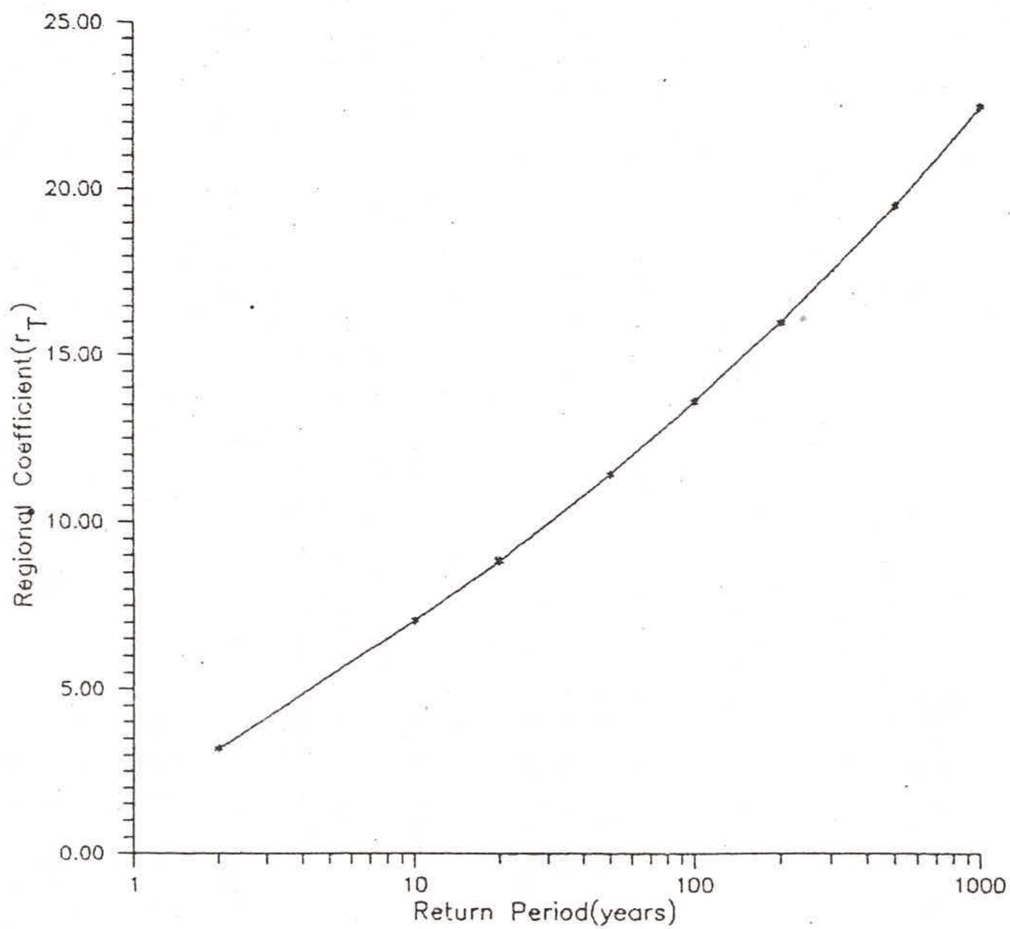

Fig 4 Variation of regional coefficient with return period for sub-zone 3(d)

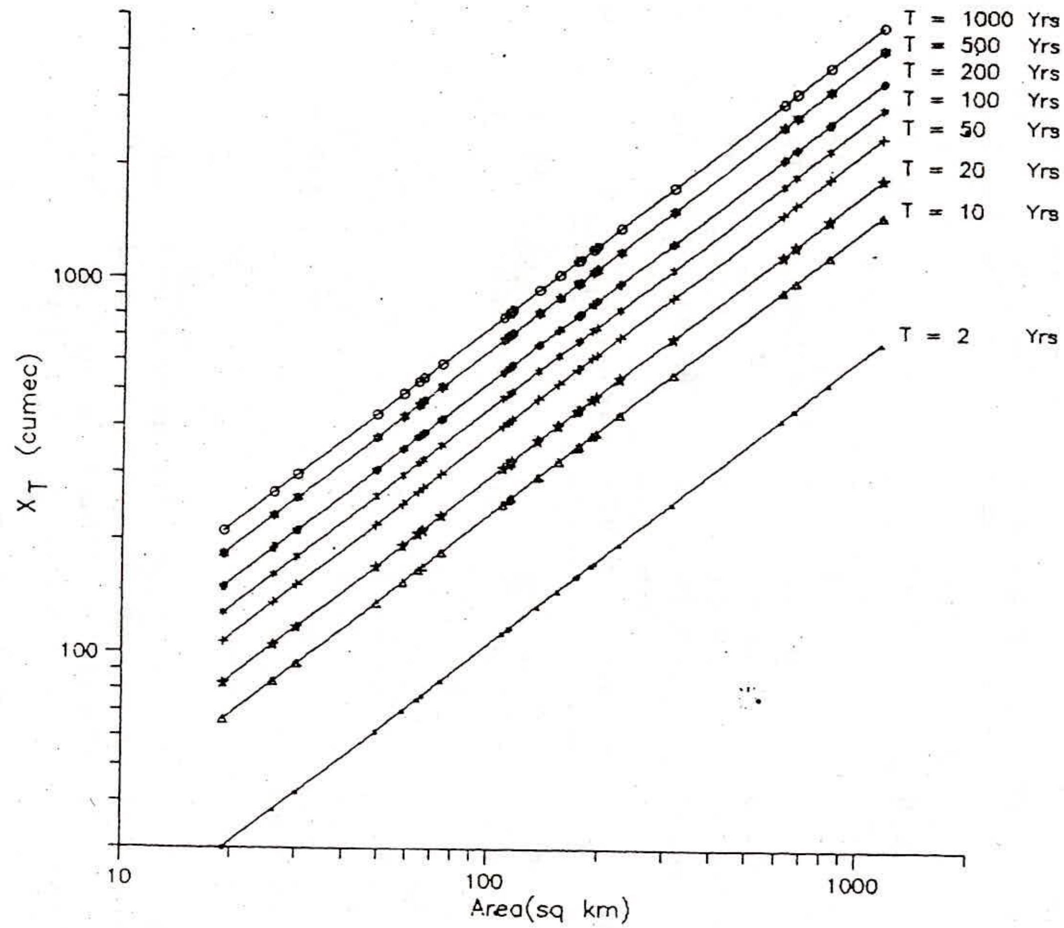

Fig 5 Variation of flood frequency estimates with catchment area for sub-zone 3(d)

mean obtained from equation(21) for the subzone-3(d), and the same are given in Table-3. Flood frequency estimates computed using the the lower and upper 95% confidence limits on mean annual peak floods for the 2 test catchments are also given in Table-3.

Table-3 The flood estimates (in cumec) computed using the at site mean ($\bar{x}_{asm}$), regional mean($\bar{x}_{rm}$) and 95% confidence limits on the regional mean for the 2 test catchments

Return Period (Years)	Using ($\bar{x}_{asm}$)	Using mean($\bar{x}_{rm}$)	Using 95% confidence limits Lower	Upper
Test catchment 1 : Br. No. 325, A = 26 sq. km., $\bar{x}_{asm}$ = 50 Cumec				
2	41.90	38.11	11.58	123.19
10	92.60	83.76	25.98	272.24
20	115.80	104.64	32.49	340.45
50	149.55	134.98	41.96	439.68
100	177.95	160.47	49.93	523.17
200	209.25	188.46	58.72	615.20
500	255.40	229.81	71.66	750.88
1000	294.50	264.79	82.64	865.83
Test catchment 2:Br. No. 489, A = 823 sq.km., $\bar{x}_{asm}$ = 1071.95 Cumec				
2	898.29	526.50	144.72	1910.97
10	1985.25	1157.11	319.84	4223.30
20	2482.64	1445.52	399.97	5281.41
50	3206.20	1864.72	516.55	6820.68
100	3815.07	2216.71	614.64	8115.95
200	4486.11	2603.36	722.75	9543.47
500	5475.52	3174.62	882.15	11648.28
1000	6313.79	3657.78	1017.20	13431.56

The ratios of these flood frequency estimates(based on regional mean and at site mean) would be same as the ratio between the respective regional mean and the at site mean. The details of catchment area(A), at site mean ($\bar{x}_{asm}$), regional mean($\bar{x}_{rm}$) and ratio of regional mean to at site mean ($\bar{x}_{asm}$)/($\bar{x}_{rm}$) for the 2 test catchments are given as follows.

Bridge Number	A (Sq.km.)	$\bar{x}_{asm}$ (Cumec)	$\bar{x}_{rm}$ (Cumec)	$\bar{x}_{asm}/\bar{x}_{rm}$
325	26.00	50.00	45.44	0.91
489	823.00	1071.95	627.72	0.58

It is seen that the ratios of regional mean to at site mean is 0.91 for the smaller test catchment and 0.58 for the larger test catchment. It indicates that there is not much variability in the flood frequency estimates obtained by at site mean and regional mean for smaller test catchment; whereas for the larger test catchment there is a considerable variation in flood estimates obtained by using the at site mean and the regional mean. The larger deviations in the flood estimates may be mainly attributed to the higher standard errors associated with the relationship between the mean annual peak flood and the catchment area.

7.4 Representation of the Developed Regional Flood Formula in the Form of Dicken's formula

The developed regional flood formula may be represented in the form of the Dicken's formula using the procedure described in Section 6.6.

The developed regional flood formula is expressed in terms of the Dicken's formula, and its coefficient C_T (Equation-16) for the subzone-(3d) is expressed as:

$$C_T = [12.080\{(-\ln(1-\frac{1}{T}))^{-0.14}\}-9.512]A^{0.01} \qquad (26)$$

Fig. 6 shows variation of revised Dicken's coefficients with return period for the 2 test catchments. The revised Dicken's coefficients for the different catchments of the subzone-3d for various return periods are given in Table-4. The flood estimates for various return periods computed by using the revised Dicken's formula are given in Table-5. It may be observed that the coefficient(C_T) of revised Dicken's formula is dependent on catchment area as well as return period, while the coefficient(r_T) used in the developed regional flood formula is dependent on return period only.

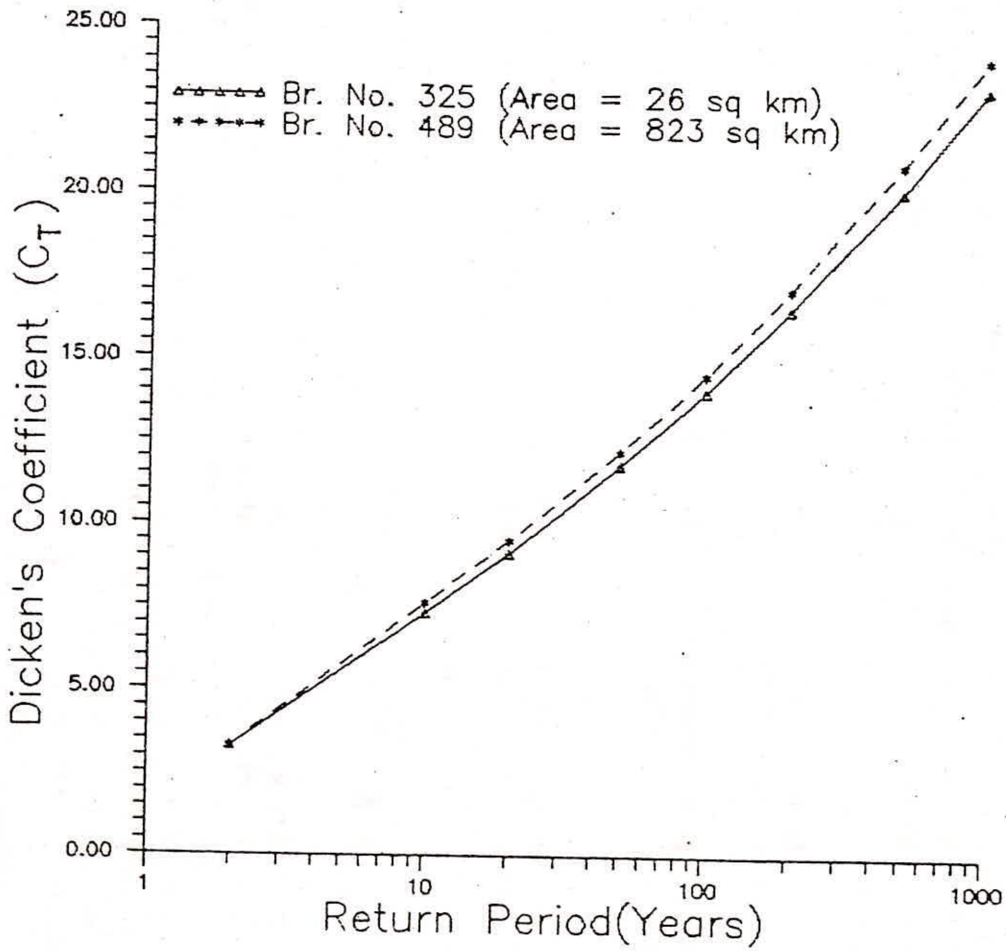

Fig.6 Variation of Dicken's coefficient with return period for 2 test catchments

Table-4 Revised Dicken's coefficients for Sub Zone 3(d) for various return periods

S.No.	Catchment Area (Sq.Km.)	Revised Dicken's coefficients for various return periods							
		2 (Yrs)	10 (Yrs)	20 (Yrs)	50 (Yrs)	100 (Yrs)	200 (Yrs)	500 (Yrs)	1000 (Yrs)
1	19.	3.3	7.3	9.1	11.8	14.0	16.4	20.1	23.1
2	26.	3.3	7.3	9.1	11.8	14.0	16.5	20.1	23.2
3	30.	3.3	7.3	9.2	11.8	14.1	16.5	20.2	23.3
4	49.	3.3	7.4	9.2	11.9	14.1	16.6	20.3	23.4
5	58.	3.3	7.4	9.2	11.9	14.2	16.6	20.3	23.4
6	64.	3.3	7.4	9.2	11.9	14.2	16.7	20.3	23.4
7	66.	3.3	7.4	9.2	11.9	14.2	16.7	20.3	23.4
8	74.	3.3	7.4	9.2	11.9	14.2	16.7	20.4	23.5
9	109.	3.4	7.4	9.3	12.0	14.2	16.7	20.4	23.6
10	113.	3.4	7.4	9.3	12.0	14.2	16.7	20.4	23.6
11	115.	3.4	7.4	9.3	12.0	14.3	16.7	20.4	23.6
12	136.	3.4	7.4	9.3	12.0	14.3	16.8	20.5	23.6
13	154.	3.4	7.4	9.3	12.0	14.3	16.8	20.5	23.6
14	173.	3.4	7.4	9.3	12.0	14.3	16.8	20.5	23.7
15	175.	3.4	7.4	9.3	12.0	14.3	16.8	20.5	23.7
16	190.	3.4	7.5	9.3	12.0	14.3	16.8	20.5	23.7
17	194.	3.4	7.5	9.3	12.0	14.3	16.8	20.5	23.7
18	225.	3.4	7.5	9.3	12.1	14.3	16.9	20.6	23.7
19	312.	3.4	7.5	9.4	12.1	14.4	16.9	20.6	23.8
20	615.	3.4	7.5	9.4	12.2	14.5	17.0	20.8	24.0
21	823.	3.4	7.6	9.5	12.2	14.5	17.1	20.8	24.0
22	1150.	3.4	7.6	9.5	12.3	14.6	17.1	20.9	24.1

Table-5 Variation of flood frequency estimates with catchment area for sub-zone 3(d)

S.No.	Catchment Area (Sq Km)	Return Period (Years)							
		2	10	20	50	100	200	500	1000
1	19.00	30.	66.	83.	107.	127.	150.	183.	211.
2	26.00	38.	84.	105.	136.	162.	190.	232.	267.
3	30.00	42.	94.	117.	152.	180.	212.	259.	298.
4	49.00	62.	136.	170.	220.	262.	308.	375.	433.
5	58.00	70.	155.	194.	250.	297.	350.	427.	492.
6	64.00	76.	167.	209.	269.	321.	377.	460.	530.
7	66.00	77.	171.	214.	276.	328.	386.	471.	543.
8	74.00	84.	186.	233.	301.	358.	421.	513.	592.
9	109.00	113.	250.	313.	404.	480.	565.	689.	795.
10	113.00	116.	257.	321.	415.	494.	580.	708.	817.
11	115.00	118.	260.	326.	421.	500.	588.	718.	828.
12	136.00	134.	296.	370.	478.	568.	668.	815.	940.
13	154.00	147.	325.	407.	525.	625.	734.	896.	1033.
14	173.00	161.	355.	444.	574.	683.	802.	979.	1129.
15	175.00	162.	358.	448.	579.	689.	809.	988.	1139.
16	190.00	173.	381.	477.	616.	733.	861.	1051.	1212.
17	194.00	176.	388.	485.	626.	745.	875.	1068.	1231.
18	225.00	196.	434.	542.	701.	833.	980.	1195.	1378.
19	312.00	252.	556.	695.	898.	1069.	1256.	1533.	1767.
20	615.00	422.	931.	1165.	1504.	1790.	2103.	2567.	2960.
21	666.00	448.	990.	1238.	1598.	1901.	2235.	2727.	3144.
22	823.00	526.	1162.	1454.	1877.	2233.	2625.	3203.	3693.
23	1150.00	679.	1499.	1874.	2421.	2880.	3384.	4131.	4762.

The design flood estimates have been computed by the conventional Dicken's formula for the 2 test catchments using the lowest(C = 22) and highest(C = 28) values of the Dicken's coefficients for the study. Return periods corresponding to these design floods have also been computed by using the Dicken's form of the developed regional flood formula as given below.

Dicken's Coefft.(C)	Design Flood (Cumec)	Estimated Return Period (Years)
Test catchment 1 : Br. No. 325(Area = 26 sq. km.)		
22	253.3	802.2
28	322.4	2754.1
Test catchment 2 : Br. No. 489(Area = 823 sq. km.)		
22	3380.4	677.2
28	4302.4	7643.3

It is observed that for the recommended range of the Dicken's coefficient for the study area the floods are estimated for the return periods of 802 and 2754 years for the lowest and the highest values of the Dicken's coefficient(C) respectively for the smaller test catchment by the conventional Dicken's formula. On the other hand for the larger test catchment, the floods are estimated for return periods of 677 and 7643 year return periods for the lowest and highest values of C for the larger catchment. Thus, it may be seen that the design floods corresponding to very high return periods are obtained for the 2 test catchments by the conventional Dicken's formula.

8.0 CONCLUSIONS

On the basis of this study the following conclusions are drawn.

(a) The conventional Dicken's and other flood formulae can not provide design flood estimates for the desired return periods. However, the developed regional flood formula is capable of providing design flood estimates corresponding to different return periods as accurate as obtained from the regional flood frequency analysis for the various catchments of the Mahanadi subzone-(3d).

(b) Regional flood frequency curves are developed by fitting PWM based GEV distribution to the station year data of $x/\bar{x}$ values for subzone-(3d). Whenever, at site mean annual peak flood estimates are available for catchments of subzone-3(d), the developed regional flood frequency curves together with at-site mean may be used to estimate the floods for different return periods.

(c) In case of ungauged catchments of the subzone-(3d), for obtaining more rational flood estimates of various return periods than those obtained from the conventional empirical formulae, the developed regional flood formula may be used. Alternatively, floods of 2, 10, 20, 50, 100, 200, 500 and 1000 year return periods may also be estimated using the graphical representation of the regional flood formula for the subzone-(3d) as shown in Fig. 5.

(d) The relationship between mean annual peak flood and catchment area developed on the basis of available data of 20 catchments in the log domain is able to explain 79.4% (correlation coefficient r = 0.794) of the initial variance. Additional physiographic characteristics which were available for only 11 catchments do not improve the relationship for predicting the mean annual peak flood. However, if the physiographic characteristics other than area as well as climatological characteristics of all the catchments are considered, it may further refine the developed regional flood formula.

(e) The design floods obtained from the conventional Dicken's formula for the 2 test catchments correspond to very high return periods.

(f) Form of the developed regional flood formula is quite simple and the field engineers may use this formula for estimation of design floods of desired return periods for small catchments of the subzone-3(d) within reasonable accuracy.

(g) Such studies may also be carried out for other hydrometeorologically homogeneous regions of India and develop the regional flood formulae may be developed for various regions of the country.

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APPENDIX - I

Some commonly used empirical formulae

No. Author	Formula in metric unit	Values of constants C in Different Regions		Limitations
1. Dicken	$Q=C\ A^{3/4}$ Q in cume A in Sq.Km.	North-Indian plains	6.0	Generally applicable for moderate size basins in North and Central India
		North-Indian hilly Regions	11-14	
		Central India	14-28	
		Coastal Andhra and Orissa	22-28	
2. Ryves	$Q=C\ A^{2/3}$ Q in cumec A in Sq.km.	Area within 80 Km from the east coast	6.8	Derived from a study of rivers in south India
		Area within 80-2400 km from the coast	8.3	
		Limited area near the hills	10.2	
		Actual observed values are	Upto 40	
3. Graig	$Q=7.75\ NB \times \ln(4.97\frac{L^2}{B})$ B=average width of strip in km. L=length of strip in km. or $Q=10cvi \times \ln(4.97\frac{L^2}{B})$ C=co-efficient of discharge V=Velocity in m/sec i=rainfall in cms	Value of N	0.12 - 0.18	Area should be divided into a number of triangular strips before application, gives too low values in practice
4. Lillie	$Q=0.058\ VR\lambda(QL)$			Formula gives

	$\lambda = 1.1 + \log 0.621L$ Q in m^3/sec $R = 2 + \frac{P}{38.1}$ P=annual rainfall in cm Q=angle substended by a strip at site L=length of arm in km. V=Velocity of flow in m/sec		too high values
5.Inglis	$Q = \frac{124\ A}{\sqrt{A+10.4}}$ Q in m^3/s A in SQ Km		Derived on the basis of rivers of Maharashtra
6. Ali Nawaz Jung	Q=C(0.386x [0.925-(1/14)log A] A)	Value of C 49 to 60 max.value=86	Lower values for south India and Upper values for North India
7. Rhind	$Q = 0.095 \frac{CSR\ a}{L} x (0.386A)^{p}$ Q in cumec S=average slope in m/km for 5 km above the site Ra=greatest average rainfall in cms p =index L =greatest length of the catchment in km. C =a co-efficient which varies as $\frac{Ra}{L}$		Derived on the basis of data of some Indian rivers. Formula is not of much practical utility
8.Dredge and Burge	$Q = 19.5\ WL^{1/3}$ or $Q = 19.5 \frac{A}{L^{2/3}}$		Based on Indian records but not useful.

	Q in cumec W= average width of basin in km L= Length of basin in Km. A= Area in sq.km.		
9.Hyderabad formula for Tunga-bhadra	$Q= 49.6(0.386 * A)^{(0.92-1/14 \log 0.386 A)}$ Q in m^3/s A in Sq Km		Local applicability
10.Madras formula for Tunga-bhadra	$Q=56.7 (0.386 \times A)^{(0.89-\frac{1}{15} \log 0.386 A)}$		Local applicability
11.Bransby Willian	$Q=80 A^{0.52}$		For Western Indian catchments $A \geq 25$ Sq.km.
12.Greager's formula	$Q=C(0.386 A)^{0.894(0.386A)^{-0.048}}$ Q in m^3/s A in Sq.km.	value of C 40-130 Lower values for ordinary floods and higher values for intense and acute flood	For North Indian catchment and South Indian catchments.
13.Military Engineering Services	$Q= 17 A^{3/4}$ For A < 25 $Q= 37 A^{1/2}$ For 25>A<31000 Q in m^3/s A in sq.km.		

14. G.C.Khanna	$Q=42\ A^{9/4}$ Q in $m^{3/5}$. A in sq.km.		Applicable for hilly areas high value of flood for medium size catchment not applicable for catchments exceed-ing 1600 sq.km.
15. Boston Society	$Q=C_F RA$ R is the average run-off for the catchment per day from a worst storm (cm), A is the catchment Area sq km Q is in cumec	Values of constant c ($C=C_F R$) 0.2 - 50 depending up-on the average runoff and overage rai-fall during the monsoon month.	Wide applicabi-lity if some actual hydrograph and rainfall data are available. Used in Punjab considering seven different values of co-efficient C corresponding to each zones in which punjab is divided depending upon rainfall during monsoon months.

PDF, DF and statistical parameters for GEV distribution when $K < 0$

A. Reduced variate of GEV distribution

PDF/DF/Statistics	Relationship
P.D.F. (g(y))	$\frac{-y^{1/k-1}}{K} e^{-y^{1/k}}$
D.F. (G(y)	$e^{-y^{1/K}}$
Mean ($\bar{y}$)	$\Gamma(1+K)$
Median (y_{med})	$(\ln 2)^K$
Mode (y_{mod})	$(1-K)^K$
Variance (σ_y^2)	$\Gamma(1+2K) - (\Gamma(1+K))^2$
Coeff. of variation (CV_y)	$[\frac{\Gamma(1+2K)}{(\Gamma(1+K))^2} - 1]^{1/2}$
Third moment (M_3)	$\Gamma(1+3K) - 3\,\Gamma(1+2K)\,\Gamma(1+K) + 2(\Gamma(1+K))^3$
Skewness (g_y)	M_3/σ_y^3
Range of parameter(K) and reduced variate	$K < 0; \quad 0 \leq y \leq \infty$

B. Variate of GEV distribution

PDF/Df/Statistics	Relationship
P.D.F. (f(z))	$\frac{1}{\alpha}(1- \frac{z-u}{\alpha} K)^{1/K\ -1}\ e^{-[1-K(z-u)/\alpha]^{1/K}}$
D.F. (F(z)	$e^{-[1-K(z-u)/\alpha]^{1/K}}$
Mean ($\bar{z}$)	$u + \alpha/K - \alpha/K\ \bar{y}$
Median (z_{med})	$u + \alpha/K - \alpha/K\ (\ln 2)^K$
Mode (z_{mod})	$u + \alpha/K - \alpha/K\ (1-K)^K$

Variance (σ_z^2)	$(\alpha/K)^2 \sigma_y^2$
Coeff. of variation (CV_z)	$[\sigma_z^2 / \bar{z}^2)]^{1/2}$
Skewness (g_z)	g_y
Lower bound (z_{lb})	$u + \alpha/K$

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