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FLOOD ESTIMATION IN INDIA USING REGIONAL FREQUENCY ANALYSIS

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ABSTRACT

The use of regional flood frequency approach provides one of the most effective ways for the estimation of design floods at ungauged sites. Many distributions such as Gumbel EV-I, Log normal, Log Pearson type-3 etc, are some of the most frequently used distributions for flood frequency analysis. Recently, a very versatile five parameters distribution known as 'Wakeby Distribution has been introduced for modelling of flood flows, which overcomes many deficiencies associated with the traditional distributions. In this paper, some of the flood frequency studies conducted for different regions in India are briefly reviewed. Procedure and results of regional flood frequency analysis using Wakeby distribution for some typical regions of India have been described and discussed. Regression relationships in the form of $Q = A\ (CA)^B$ have been developed between the James - Stein corrected mean flood, and catchment area. Though the computations for Wakeby distribution are quite involved, with the use of computer programmes quite encouraging results have been obtained.

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1.0 INTRODUCTION

The problem of floods has received considerable attention in India in recent times, as the damage caused by it to crops, properties and cattle is on an increase, besides, the loss of human lives. The use of empirical formulae, which were developed based on insufficient data and individual judgement, had sometimes resulted in under-estimation of design flood for cross drainage works. Rather than resorting of empirical formulae, it has been recognised that the use of design flood estimate based on regional frequency analysis would be more appropriate for such cases. When only a short record or no record is available at a site the use of regional approach enables improvement of site specific estimates for design floods or to make inferences for estimation of design floods at ungauged sites. In regional flood frequency analysis, the hydrologic data from several locations within a region, which is hydrologically homogeneous in terms of the characteristics being studied, are combined. Some such methods which have been comonly used are: USGS index flood approach (Dalrymple, 1960), parameter regionalisation method (USWRC, 1977), regression equation approach (Benson, 1962), and the region curve method recommended in U.K. flood studies report (NERC, 1975). The hydrometeorological homogeneity of the regions is delineated by similar climate (particularly seasonality and intensity of heavy rainfall and flood producing weather patterns) topography, drainage networks and soils.

Apart from ease of application the regional flood estimation technique ensures a consistent design approach to flood estimation within each region. The U.S. Geological Survey (USGS) method of regionalizing flood estimates is reported by Dalrymple (1960). This method involves the preparation of two graphs: (i) a curve based on Gumbel EV-I distribution showing the variation with return period of the ratio between the T-year flood and the mean annual flood obtained from graphical fitting of Gumbel EV-I distribution. and (ii) a plot relating the mean annual peak flood of all the sites to the size of the drainage area of the corresponding sites.

The USGS Method has been applied in many parts of the world including India for regional flood frequency analysis. In this approach, the catchment area is adoptd as the sole independent variable for developing relationship for the mean annual flood. Gupta (1980) applied USGS Method for estimation of peak floods for subzone 3(d) Mahanadi basin. The available/estimated 23 years annual peak flood series for each of 18 railway bridge sites with catchment areas ranging from 17 to 1150 km^2, of this zone recorded during 1958-1980 were used. The relationship for mean annual flood $\bar{Q}$ was as follows:

$$\bar{Q} = 3.366\ A^{0.774} \quad (r = 0.886) \qquad \ldots(1)$$

where r = correlation coefficient.

Perumal and Seth (1985) suggested a regional analysis approach in which the annual peak flood data of each gauging site is standardised with reference to the site specific mean annual flood, and flood frequency analysis (using power transformation method) is carried out assuming that standardized series of different gauging sites are the realizations from the single population. This study using same data base as Gupta (1980) indicated that power transformation method could be considered useful for regional frequency analysis. Venkataraman and Gupta (1986) used USGS approach for deriving relationship between 50 year return period flood Q_{50} and catchment area A for small and medium catchments in sub-Himalayan region using data from 11 sites with catchment areas ranging from 6 to 2072 km^2. The following relationship was obtained:

$$Q_{50} = 15.84\ A^{0.75} \qquad \ldots(2)$$

Venkataraman and others (1986) presented a study for subzone 3(f) Lower Godavari basin, using 26 years data of 14 small and medium railway bridge catchments with catchment

areas ranging from 15 to 824 km^2. The authors examined choice between (i) general extreme value (GEV) and Gumbel EV1 distributions, (ii) regional pooling of data vis-a-vis averaging of ratios obtained at individual sites, and (iii) using parameters like catchment area $A(km^2)$, length of main stream L (km), statistical slope S, 50 year 24 hour point rainfall R_{24}(cm) and 2 year one hour point rainfall R_1(cm) for developing regression relationships with mean annual flood $\bar{Q}$ taken as $Q_{2.33}$ for important hydraulic structures. Keeping in view risk considerations regional flood frequency ratio based on Gumbel approach was found appropriate; and for less important structures where economic considerations decide the choice, use of GEV growth curve was suggested. Typical relationship for mean annual flood were obtained as follows:-

$$\bar{Q} = 1.23\,A^{0.74}\;R_1^{-0.98} \qquad \ldots(3)$$

$$\bar{Q} = 7.10\,A^{0.755} \qquad \ldots(4)$$

Thirumalai and Sinha (1986) carried out regional flood frequency analysis using data for 14 bridge catchments (30 to 730 km^2 in size) of Krishna basin varying in length from 6 to 26 years. Mean annual flood $\bar{Q}$ was related with catchment area A and 2 year 24 hour point rainfall R_{24}(2 yr) (cm) as follows:

$$\bar{Q} = 3.35\,A^{0.682} \qquad \ldots(5)$$

$$\bar{Q} = 1.009\,A^{0.664}\;R_{24}^{0.64} \qquad ..(6)$$

Another approach, which has been commonly used involves development of relationships between T-year recurrence interval flood (Q_T) and physiographic characteristics. The work of Benson (1962) on the estimation of floods corresponding to nine specific return periods in north-eastern states of

America and the work of estimation of floods by Rodda (1969) for 4 specific return periods in England, Wales and Scotland, are typical examples of this approach. Huq and others(1986) evolved the frequency flood formulae relating 50 year flood peak Q_{50} with the catchment area, A, statistical or equivalent slope, S_{st} or S_{eq} (m/km) and 24-hour 50 year storm rainfall, R_{24}(cm). The rainfall and runoff data of 219 small and medium gauged catchments located in different parts of the country (India) were used for developing the regional relationships for four different cases depending upon the catchment slope and average loss rate within the catchment. James et al (1987) carried out regional frequency analysis using data from nine stations in the Chaliyar river basin of western ghats region. The relationship between mean flood Q and area A were obtained as

$$Q = 3.53\ (A)^{0.37} \qquad \ldots(7)$$

It is thus seen that methodlogies adopted for regional frequency analysis differ from author to author. There has not been any attempt to carry out such analysis for different regions for evolving relationships and testing the same on independent data.

An application of the Probability Weighted Moment(PWM) technique of parameter estimation to regional flood frequency analysis was proposed by Wallis (1982). The method proposes to combine regional and site specific information by simple averaging and scaling. Moments of the regional distribution are obtained by simple averaging of the respective probability weighted moments at each site. The regional quantile estimate is then obtained by scaling at site estimate by a regional estimate of the mean. This methodology appears to work well for situations where records are extremely short, and streamflow observations are highly skewed and highly kurototic. The regional frequency analysis study was carried out for

Mahanadi basin (subzone 3d) using the Wakeby distribution approach by Singh and Seth (1985). In this method, the regional parameters of Wakeby distributions are estimated by the probability weighted moments technique and the catchment area is related with the James-Stein corrected mean. The regional parameters of Wakeby distribution and James-Stein corrected means are used to estimate floods of different return periods. The results obtained from the analysis are summarized in Table 1.

Table 1: Flood estimation and fitting efficiencies

	Test Catchment No.1			Test Catchment No.2			Test Catchment No.3		
	Flood Estimates (m^3/sec)		*APE (%)	Flood Estimates (m^3/sec)		*APE (%)	Flood Estimates (m^3/sec)		*APE (%)
	*Case 1	*Case 2		*Case 1	*Case 2		*Case 1	*Case 2	
2yrs-flood	56	57	2	624	559	10	190	145	24
5-yrs flood	88	101	15	1315	981	25	271	255	6
10-yrs flood	116	136	17	1626	1319	19	336	343	2
20-yrs flood	149	173	16	1802	1674	7	40.6	436	7
50-yrs flood	202	224	11	1915	2173	13	507	566	12
efficiency η (%)	98	90	-	98	82	-	99	99.1	-

*** Case-1 Using actual parameters, Case 2- using regional parameters and APE - Absolute percentage error.**

In the present study, typical regions of India, namely Lower Godavari basin(subzone 3f), Brahmputra basin and sub Himalayan Region basin, have been considered for regional flood frequency analysis. Some gauged catchments for each

of the regions are considered as test catchments for judging the performance of the regional relationships, on the basis of computed error function and efficiency using appropriate plotting position formula

2.0 METHODOLOGY

Wakeby Distribution

A random variable X is said to be Wakeby Distributed, if

$$x = m + a\,[1-(1-F)^{b}]-C[1-(1-F)^{-d}] \qquad \ldots(8)$$

where $F = F(x) = P\ (X\ \ x)$, and

a,b,c,d and m are the parameters for Wakeby distribution.

Estimation Of The Parameters Of Wakeby Distribution

The parameters of Wakeby distribution are estimated based on the concept of probability weighted moment which is defined as:

$$M_{j,k} = \frac{1}{N(j)} \sum_{i=1}^{N(j)} X_{i,j}\ (F)\ (1-F_{i,j}\ )^{k} \qquad \ldots(9)$$

where $j = 1,2,\ldots NS$

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

NS = Nos. of gauging sites

$M_{j,k}$ = k th order probability weighted moment for jth gauging site.

$N(j)$ = No. of annual maximum peak flows at jth gauging site.

$X_{i,j}$ = ith item in the sample of ranked annual maximum peak flows in ascending order at jth gauging site, and

$F_{i,j}$ = the probability of non-excedence for the ith item in the ranked sample of annual maximum peak flows in ascending order at the jth gauging site and it is evaluated using the plotting position formula (Landwehr and others (1979b))

$$F_{i,j} = \frac{(i-0.35)}{N(J)} \qquad ...(10)$$

The probability weighted moments as expressed by Eq.9 can be normalized after dividing them by zeroth order probability weighted moment, which is simply the arithmatic mean of the annual maximum peak flow values.

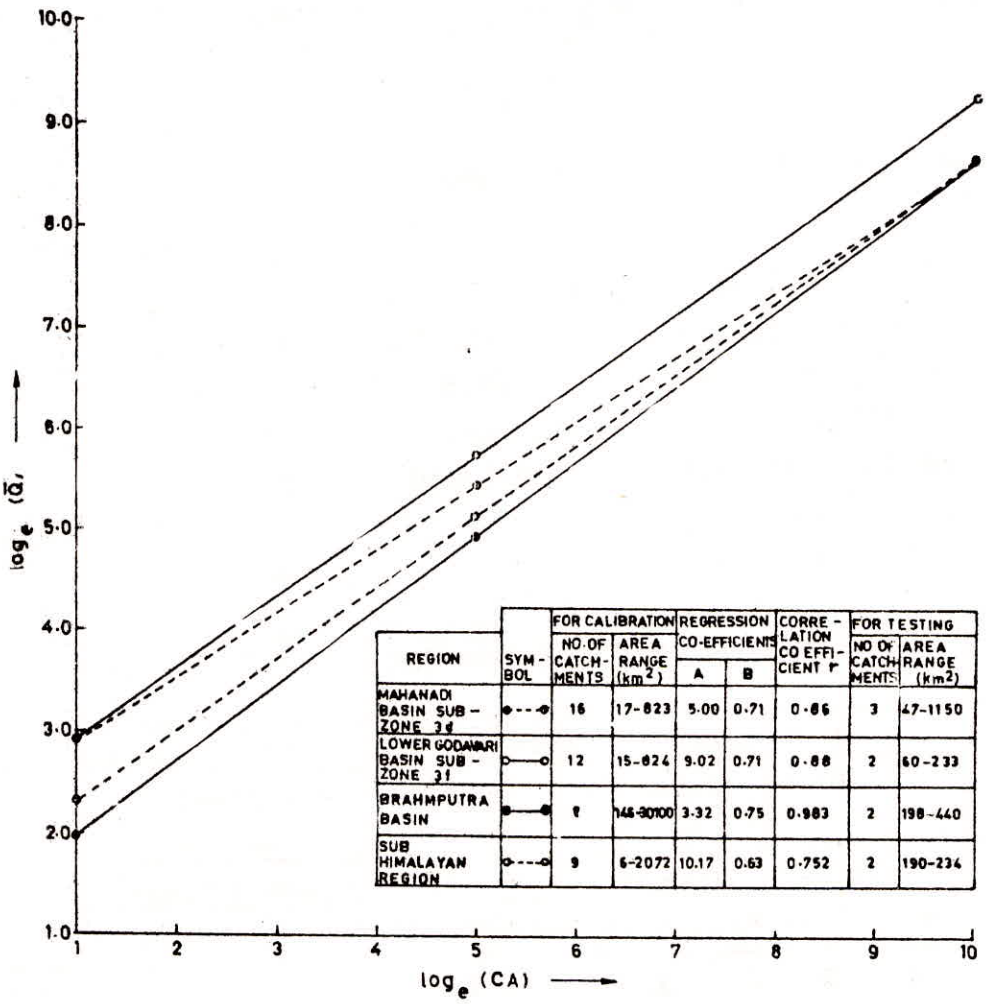
The regional parameters of the Wakeby distribution are estimated using the regional values of probability weighted moments based on a special algorithm suggested by Landwehr and others (1979c)

Estimation Of James-Stein Corrected Means And Recurrence Interval Floods

James-Stein corrected means are estimated from the methodology suggested by James-Stein and quoted by Singh and Seth (1986). The James Stein corrected means, thus obtained, along with the estimated parameters of the Wakeby distribution for a specific region are used for computing the T-year recurrence interval floods at a gauging site located in that region:

Relationship Between James-Stein Corrected Means And Catchment Areas

Simple linear regression is performed, taking the logarithm of the catchment areas of various gauged catchments as independent variable and the logarithm of their James-Stein Corrected Means as dependent variable, in order to devolop the regional relationship between James Stein Corrected means, Q and catchment area, CA for a specific region. The form of the equation developed is given as:



REGION	SYMBOL	FOR CALIBRATION NO. OF CATCHMENTS	FOR CALIBRATION AREA RANGE (km²)	REGRESSION CO-EFFICIENTS A	REGRESSION CO-EFFICIENTS B	CORRELATION CO EFFICIENT r	FOR TESTING NO OF CATCHMENTS	FOR TESTING AREA RANGE (km2)
MAHANADI BASIN SUB-ZONE 3d	●---○	16	17-823	5.00	0.71	0.86	3	47-1150
LOWER GODAVARI BASIN SUB-ZONE 3f	○—○	12	15-824	9.02	0.71	0.88	2	60-233
BRAHMPUTRA BASIN	●—●	[illegible]	146-30100	3.32	0.75	0.983	2	198-440
SUB HIMALAYAN REGION	○---○	9	6-2072	10.17	0.63	0.752	2	190-234

Fig.1 Relationship between James-Stein Corrected mean flood and catchment area.

$$Q = A(CA)^B \qquad \ldots(11)$$

Equation (11) is linear in log domain, and A and B are coefficients to be obtained from linear regression.

Computation Of Fitting Efficiency And Absolute Percentage Error Function

The efficiency η of the regional Wakeby parameter in fitting the data of observed annual maximum flow series for a gauging site and absolute percentage error function APE computed using the expressions given by Singh and Seth (1986).

3.0 ANALYSIS AND DISCUSSIONS OF THE RESULTS

Regional flood frequency analysis has been carried out for three typical Indian basins using the approach based on Wakeby distribution as described in Section on 'Methodology' Figure 1 illustrates the relationship in log-domain for those three regions and also for Mahanadi Basin subzone 3d which was analysed by Singh and Seth (1985). The results are also summarized in Table 2 .

Table 2: Flood estimates and fitting efficiencies

	Test Catchment No.1			Test Catchment No.2		
	Flood estimates (m^3/sec)		*APE	Flood estimate (m^3/sec)		*APE
	* Case 1	* Case 2	(%)	* Case 1	* Case 2	(%)
Basin-Lower Godavari Basin (Subzone 3f)						
2-yrs flood	282.2	283.7	0.5	214.6	204.5	4.7
5-yrs flood	464.0	436.6	6.3	335.2	313.2	6.6
10-yrs flood	556.6	540.5	2.8	397.5	389.6	1.9
20-yrs flood	622.7	651.3	4.6	443.5	469.[illegible]	5.9
50-yrs flood	682.0	807.2	18.0	486.4	581.8	20.0

efficiency (η) %	97	90	-	96	91	-
Basin-Brahmputra Basin						
2-yrs flood	237.4	253.5	6.7	181.7	195.9	7.8
5-yrs flood	368.4	381.7	3.6	289.3	294.9	1.9
10-yrs flood	465.9	470.2	1.0	370.8	363.3	2.0
20-yrs flood	562.2	552.4	1.7	454.10	426.9	5.9
50-yrs flood	688.9	652.2	5.3	567.3	503.9	11.1
Efficiency (η) %	96	96	-	99	98	-
Basin-Sub Himalayan Region						
2-yrs flood	605.5	555.6	8	254.0	241.4	5
5-yrs flood	810.9	970.4	20	403.5	421.7	5
10-yrs flood	1028.6	1282.2	25	507.9	557.2	10
20-yrs flood	1329.9	1592.9	20	605.4	692.2	14
50-yrs flood	1913.7	2001.7	5	724.4	869.8	20
Efficiency (η) %	96	86	-	94	77	-

*Case 1- using actual parameters, Case 2-using regional parameters, and APE- Absolute percentage error

The comparison of flood estimates for different recurrence intervals and fitting efficiencies have been made for some test catchments whose data was not used in calibration, using actual and regional Wakeby parameters. The fitting efficiencies of regional parameters are quite comparable with that for the actual parameters for the respective catchments.

The reduction of efficiency for test catchments in Sub-Himalayan region is due to considerable difference in average normalized probability weighted moments and actual normalized probability weighted moments obtained from the peak flood series of the respective catchments , suspected to be due to data inaccuracies. The values of absolute percentage errors as given in table 2 lie in the range of 0.5 to 25% while computing the different recurrence interval floods (2,5,10, 20 or 50 years) using actual and regional parameters. Figure 2 illustrates the regional frequency relationships for different regions on log-log scale having growth factor $Q_T/\bar{Q}$ on Y-axis and recurrence interval (T) in years on X-axis. These frequency

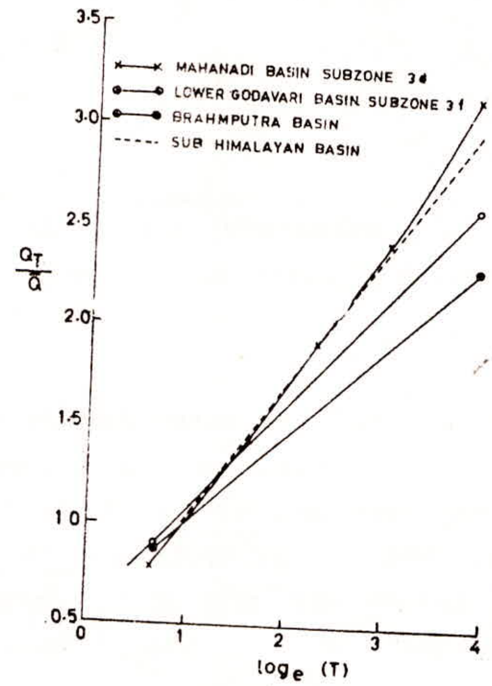


Fig.2 Regional frequency relationships

relationships together with the relationship between the James-Stein corrected mean flood and catchment area for the respective regions form the regional relationships, which may be used to compute the different recurrence interval floods at the ungauged sites situated in the respective regions. However, one has to be very careful in using these relationships for estimating the floods in the extrapolation range (beyond 50 years return period).

CONCLUSIONS

The regional flood frequency analysis is based on Wakeby distribution approach for different regions in India gives encouraging results. Even for the test catchments the flood of different recurrences intervals are estimated with the error less than 25% using regional parameters; which is of reasonable accuracy for practical applications. Therefore, it would be desirable that such studies are repeated using data of other regions in the country.

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